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A framework for a carbon-based urban vegetation typology - A thematic review

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A R T I C L E I N F O

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A B S T R A C T

Generally, the carbon neutrality targets of cities underline the role of vegetation especially natural biotopes and ecosystems. City-wide carbon pool assessments have so far focussed on land cover and land use types, with the role of urban trees receiving particularly significant attention. However, the carbon sequestration and storage (CSS) capacity of various vegetation types in urban areas as well as their potential to enhance urban carbon sinks remains largely unexamined. Planning and managing urban green infrastructure (GI) requires a climate-wise strategy of CSS that provides a scalable link between habitats and individual plant species. Therefore, this study focusses on the CSS capacity of urban vegetation through a thematic review and identifies the key elements influencing CSS in cold-climate cities. The study further highlights that the basis for atmospheric carbon sequestration lies in the favourable growth and stomatal functioning of an individual plant. The CSS of individual plants forms the basis for urban GI and the ecosystem services they provide. Moreover, the growth of urban vegetation is affected by diverse urban growing conditions, which are under continuous change as vegetation is managed, used and modified by residents. Although soils are a major storage for carbon, the role of vegetation in transforming carbon from the atmosphere into soil organic carbon is fundamental. In this study, with; the understanding of the key drivers influencing CSS, we define a framework for a; carbon-based vegetation typology and discuss the links between growing conditions and maintenance practices with regard to the CSS capacity of diverse vegetation types. This framework provides a conceptual basis for further interdisciplinary research into the CSS of urban vegetation, for example, for CSS capacity modelling and life cycle assessment of urban vegetation. It also supports climate-wise planning, design and maintenance by formulating practical and science-based recommendations for multi-professional actors engaged in GI.

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1. Introduction

1.1. Background

Many cities worldwide are committed to the goal of carbon neutrality, which means achieving a state in which the city's CO_2 emissions and the various carbon sequestration mechanisms, or carbon sinks, are equal. To achieve this goal, it is essential to comprehensively assess and monitor organic carbon pools in urban areas. Carbon sequestration and storage (CSS) for vegetation and soils is one of the most efficient natural mechanisms for removing carbon from the atmosphere (Griscom et al., 2017). Recent research on the urban green infrastructure (GI), including both natural and man-made habitats on all scales (European Commission, 2013), has focussed on specific perspectives, such as urban trees and habitats (Dorendorf et al., 2015), trees and soils (Richter et al., 2020), green spaces (Lindén et al., 2020) and horticultural soils (Dobson et al., 2021). Some studies focussing on urban GI on a large scale suggest that the urban biomass holds twice the carbon fluxes of rural areas (Hardiman et al., 2017). Other studies suggest that urban green areas offset the CO_2 emissions from 2.6% to 16.9%, depending on the seasonal variation (Vaccari et al., 2013). However, despite the potential impact and growing body of research on this topic, there is still limited knowledge on the carbon cycle of urban GI and how to maximise the CSS potential of various urban vegetation types in practice.

One important knowledge gap concerns the assessment of CSS. The current methods are potentially inaccurate because of the limited datasets or the wide spatial resolution available, which does not consider the heterogeneity of urban environments (Dorendorf et al., 2015; Hardiman et al., 2017). Moreover, the current assessment methods are often based on research focussing on the carbon pools of forests and soils in forestry and agriculture (Don et al., 2011; Guo and Gifford, 2002; Li et al., 2012). Thus, the role of urban vegetation has often been overlooked in national carbon assessments (Dorendorf et al., 2015). Furthermore, there is a knowledge gap concerning the methods of life cycle assessment (LCA) of urban GI, which is a key methodology for tackling climate change in the built environment (Kuittinen et al., 2021; Strohbach et al., 2012).

To understand the CSS of urban vegetation, it is essential to recognise the specific growing conditions on the plant scale in urban environments. In general, continuous developments and changes in urban areas differ from those in non-urbanised areas, hence affecting both above- and underground carbon pools (Cambou et al., 2018; Davies et al., 2011). Moreover, the growing conditions for urban vegetation are diverse, and several factors, such as the soil's condition, urban water cycle and various maintenance practices and disturbances, impact the growing conditions and development of urban vegetation.

It is also worth highlighting that the lack of knowledge regarding the carbon cycle of urban vegetation extends to the management practices. In this context, the growth of urban vegetation, and thus carbon sequestration, depends on growing conditions that can be

Table 1
Earlier studies on city-wide urban carbon pools and the classifications used therein.

Publication	Scope/area	Carbon assessment method		Classification/typology
		Soil	Vegetation	
Richter et al. (2020)	Berlin	Sampling	Tree biomass equations	Land use types Trees
Dvornikov et al. (2021)	Murmansk and Rostov-on-Don, Russia	Data from previous soil surveys	–	Land cover classes: sealed soils, green lawns, trees and shrubs, bare soils and water bodies
Lindén et al. (2020)	Parks in Helsinki	Sampling	Tree surveys	Soil samples based on maintenance classes (A1, A2 or A3) and vegetation types (lawns, shrubbery and herbaceous perennials)
Edmondson et al. (2012)	Leicester, UK	Sampling	Vegetation inventory, tree biomass equations	Land cover types: residential lands (green space, artificial surface) and non-residential lands (green space, artificial surface and buildings) Impervious surfaces Vegetation types: trees, shrubs, tall shrubs and herbaceous vegetation
Cambou et al. (2018)	New York and Paris	Sampling	–	Open soil land use types: Paris: parks, woodlands and gardens New York: urban fallows, urban woodlands, salt marshes and parks Sealed soils
Davies et al. (2011)	Leicester, UK	–	Vegetation surveys	Vegetation types (land cover): herbaceous plants, shrubs, tall shrubs, trees and domestic gardens Land ownership categories: mixed, public and private
Dorendorf et al. (2015)	Hamburg	Sampling	Tree biomass equations	10 biotope types from land cover data: agriculture, densely built-up, scattered built-up, industry and administration built-up, dry forest, wet forest, grassland, leisure area, ruderal, transportation and wetland
Canedoli et al. (2020)	Milan	Sampling	–	Urban land uses (park/non-park) and land cover (woodland/grassland)
HSY (2021)	Helsinki region (public green areas and forests	Yasso soil carbon model	Estimated biomass per maintenance class	Local and national forest data for forest land use types and the national green space maintenance classification for other green spaces

affected by urban and landscape design, construction and maintenance. For instance, urban vegetation often grows in limited growing media and suffers from the effects of impermeable surfaces, such as the limited gas exchange between the soil and the air, as well as extreme moisture conditions, such as standing water or drought. Furthermore, the growing conditions are affected by ongoing earthworks and construction next to vegetated areas, as well as by compaction, the littering of soil and the damage of roots, shoots and trunks. Hence, urban and landscape design, construction and maintenance aim to provide long-lasting vegetation with reasonable investments under varying conditions, which also has an impact on the CSS potential (Kotze et al., 2021).

Besides carbon sequestration, urban vegetation and GI in general provide several other ecosystem services. Because of these co-benefits, GI is regarded as a potential and cost-effective climate solution in urban areas (European Commission, 2013). Several methods and models have been developed to assess the overall provision and value of the different benefits of urban GI, and several vegetation-related classifications have emerged for the purposes of these assessments (Bartesaghi Koc et al., 2017; Lehmann et al., 2014). However, these assessments do not often focus on the CSS capacity.

Given the current climate crisis, it is important to unlock the full potential of ecosystem services to sequester and store carbon. To support this goal, practice-oriented research is required to maximise the CSS of urban vegetation. In addition, comprehensive and established methods are required to conduct reliable and efficient estimations of CSS to support climate-wise planning and design solutions and maintenance practices.

1.2. Previous research

Several recent studies adopting different approaches have estimated urban carbon pools (Table 1). Land use types, such as park or non-park areas, and land cover classifications, mostly based on soil sampling data and tree biomass equations, were used to obtain city-wide and regional estimates. Studies focussing on the assessment of the carbon stocks of different land use types have also been performed, for example, by Edmondson et al. (2012) in Leicester, UK, and by Cambou et al. (2018), who compared the soil carbon stocks of urban land use types in Paris and New York.

A large body of research has focussed solely on urban soil or urban vegetation. Many studies have also focussed on trees, on the basis of either tree cover data (Nowak and Crane, 2002) or biomass equations developed for different tree species groups (Hou et al., 2020; Jenkins et al., 2003; Richter et al., 2020). For example, using land cover data, Dvornikov et al. (2021) examined the effect of urbanisation on the soil carbon stocks in two Russian cities and projected the results over initial pre-urban soil maps.

Among all studies, the most comprehensive city-wide ones have involved both soil and tree carbon stocks (Dorendorf et al., 2015; Edmondson et al., 2012). Richter et al. (2020) estimated the total carbon storage of the city of Berlin. They estimated the organic carbon pool in soils using samples across different land use types and vegetation based on aboveground tree biomass. Lindén et al. (2020) quantified carbon stocks in urban parks in Helsinki in terms of management practices, vegetation type and age. Many other cities have also performed their own studies to reach their target of carbon neutrality, such as the study by Helsinki Region Environmental Services (HSY, 2021).

Generally, many of the earlier studies on urban carbon pools have focussed on land cover types at a general level and for trees. However, no clear correlations between land cover and urban carbon pools have been found. Reviews of urban soil carbon pools have even demonstrated conflicting results regarding the impact of urbanisation on soil carbon levels (Chien and Krumins, 2022; Vasenev and Kuzyakov, 2018), which is partly due to different methods of research. Vasenev and Kuzyakov (2018) found greater carbon levels in deeper soil layers in urban areas and stress the importance of urban subsoil and sealed soils. Chien and Krumins (2022), in turn, did not address sealed soils in their research, which is in line with findings of Lu et al. (2020), at least in cool climates.

Recent studies on urban plant–soil interactions indicate that urban soil ecosystem services, including carbon storage, are related to the plant functional type and human impact (Chien and Krumins, 2022; Kotze et al., 2021). Although similar results were obtained in natural ecosystems (Fornara and Tilman, 2008), in urban areas, anthropogenic drivers can override natural development. Thus, we believe that, for the purposes of achieving more reliable studies and models of urban carbon flow, urban vegetation types and their CSS capacity should be better understood. This includes the definition of urban growing conditions and the various anthropogenic factors, such as maintenance, that should be considered to differentiate between urban vegetation and non-urban environments.

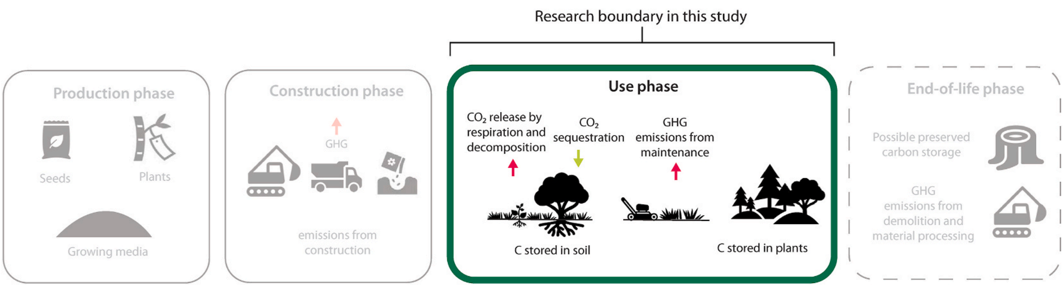

Fig. 1. Life cycle stages of urban green (based on ISO EN-15643-2) and research boundary of greenhouse gas (GHG) impacts. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Aim and method

The aim of this study is to define a framework for an urban vegetation typology that is based on plant-scale elements to function as carbon sinks in cold climates. In this study, the term ‘cold climate’ refers to a humid continental climate, in which distinct warm and cold seasons can be observed affecting the annual cycle of vegetation phenology.

The purpose of this study is twofold: (1) to identify the key elements influencing the CSS of urban vegetation and (2) to develop a framework for a carbon-based vegetation typology as a basis for further research and practical implications. The specific research question is how urban vegetation and its CSScapacity can be classified to support climate-wise planning, design and maintenance practices in cold climates.

Generally, the analysis of the CSS capacity focuses on factors impacting growth over the lifetime of urban vegetation. Other life cycle impacts, such as the carbon footprint of construction or plant production, as well as the end-of-life phase, were excluded from the framework, as examining these factors requires a different approach and method (Fig. 1) (Kuittinen et al., 2021).

This study was performed as a thematic review and analysis by a multi-professional team with both scientific and practical experience in landscape design and construction. A climate-wise vegetation framework was built in two iterative phases. The first phase involved reviewing the biological basis of plant-scale carbon flow and storage (presented in Sections 3.1 and 3.2) and formulating the typology of urban vegetation that is relevant to the processes of CSS. The second phase involved the analysis of how typical urban factors modify growth (presented in Sections 3.3 and 3.4). Finally, these two review phases were used to develop the framework, and recommendations for the design and maintenance of climate-wise urban vegetation.

3. A thematic review

3.1. Carbon sequestration of urban vegetation

In general, the carbon exchange process between an ecosystem and the atmosphere consists of CO_2 fixation during photosynthesis and CO_2 loss through plant respiration and the microbial decomposition of soil organic matter. The intake of CO_2 depends on the plant’s leaf area index (LAI) and stomatal functioning, which respond to several environmental factors, such as the soil water status, light, temperature and atmospheric humidity. On the plant scale (Fig. 2), the flow occurs from the source organs, such as mature leaves and storage structures, to the sink organs, such as the roots, young leaves, flowers and fruits (Knoblauch and Peters, 2017; Schulze et al., 2019a).

Besides the plant’s phenotype and prevalent growing conditions, the carbon intake of plants is regulated by phenology, which

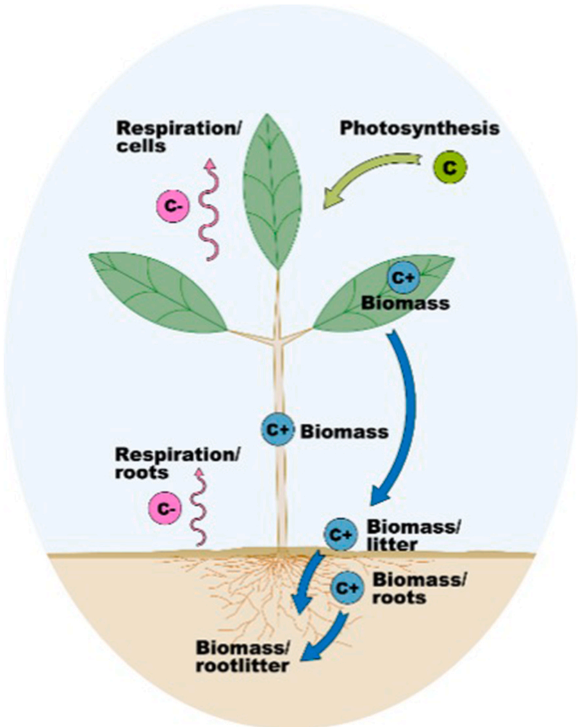

Fig. 2. The main components of carbon flow and storage. The flow consists of continuous carbon sequestration and respiration, whereas the longevity of the storage elements varies.

refers to the timing of the different developmental cycles, such as leaf emergence and senescence (Gu et al., 2003). In this context, species-specific responses to phenology are considered an important factor in the different species' coexistence and carbon uptake, as phenology determines the duration of the growing season for each individual plant, species or functional group, and differences in phenology reduce competition (Cleland et al., 2007; Gu et al., 2003).

Plants use assimilated carbohydrates mainly for vital functions, growth and reproduction. Some of the assimilates are stored as non-structural carbon for later use. In natural environments, competition with other species leads to different plant life forms and plant functional groups, which can be classified with different reproduction strategies and methods for storing carbon and nitrogen in plant tissues (Monsi, 1960). Urban plants can be either of natural origin or based on horticultural production. The cultivated plant material used in landscape construction is, however, the result of selective breeding from the natural selection and can, thus, be assumed to follow the same fundamental principles regarding the allocation of carbon.

Within urban vegetation, the carbon cycle and storage undergo constant change throughout the growing season or different periods of vegetation. Plants play two roles in the carbon cycle. They absorb carbon from the atmosphere and then eventually release it from dead tissues after senescence. Fallen leaves and other dead plant parts provide an important component for the soil habitat, and the soil's microbes break down organic matter into the elements needed by plants to grow (Bardgett and Wardle, 2010). However, in the urban context, this cycle is often disturbed. This occurs, for example, when trees are planted in a limited growing space with tree grilles protecting the roots, which at the same time prevent the leaves from entering the soil. Litter can also be found in different forms. For

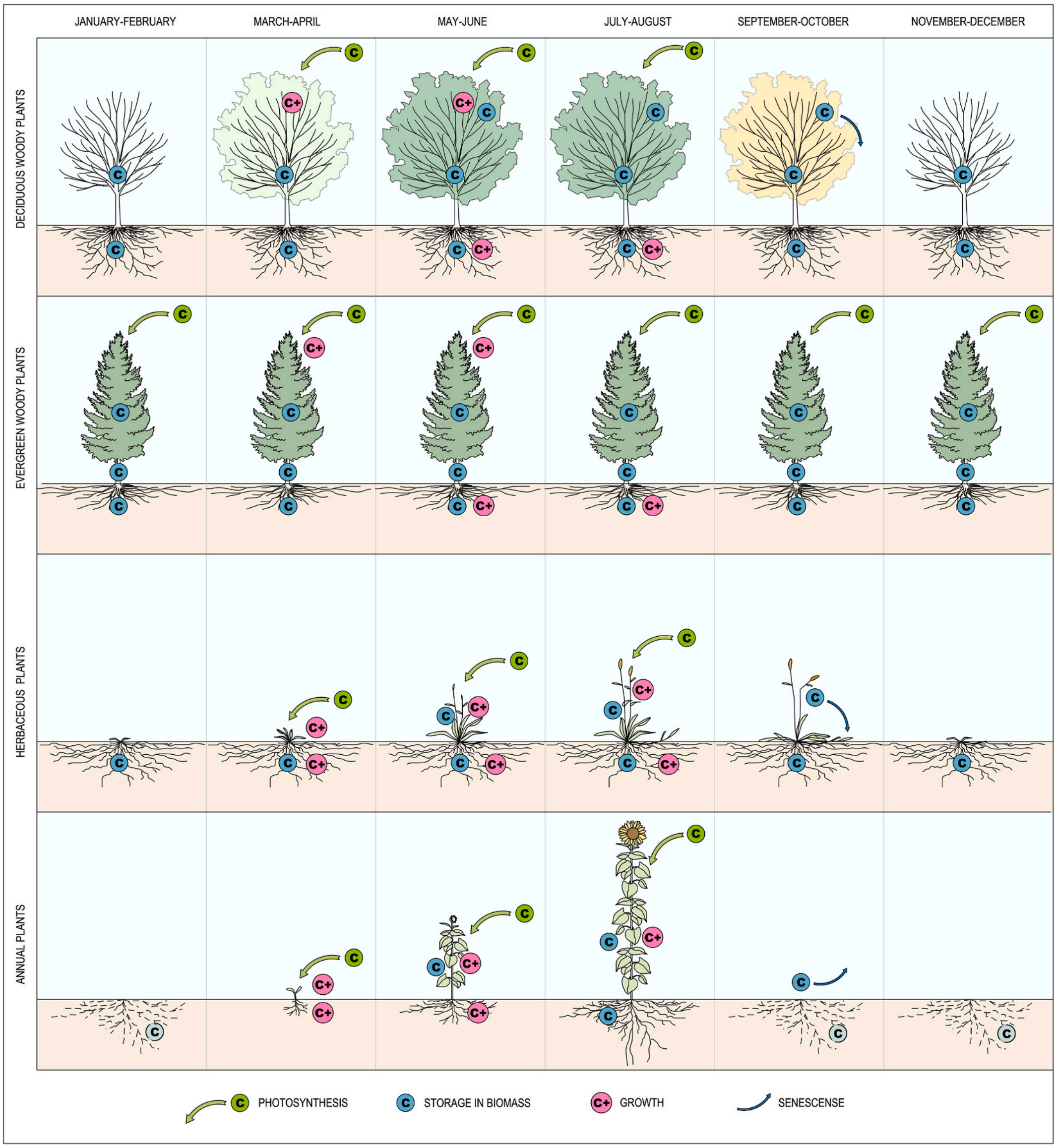

Fig. 3. Seasonal variations of urban vegetation presented as the main elements and processes of carbon sequestration and storage.

example, labile leaf or grass litter decays faster under cool, boreal conditions than recalcitrant litter, such as needles (Lu et al., 2020). This affects the microbial activity of the soil, since labile and recalcitrant litter affects the fungal and bacterial composition of the soil in different ways (Bardgett and Wardle, 2010).

Carbon is stored in plant tissues both above and below the ground, and the soil itself has a substantial capacity to store carbon through decaying litter, root exudates and leaching (Kuzyakov and Domanski, 2000), also in urban areas (Edmondson et al., 2014b; Setälä et al., 2016). In the UK, Davies et al., 2011 have estimated that 97,3% of the carbon in urban above-ground vegetation is stored in trees and only 0,7% and 2% in other woody vegetation and herbaceous vegetation respectively.

Carbon allocation, which includes the root-to-shoot ratio and how the biomass is divided between roots, branches and the trunk, is not only genetically fixed, but also dependent on the growing conditions and competition (Schulze et al., 2019a). The timing of root and shoot growth also depends on the vegetation type and varies at the species level (Radville et al., 2016; Steinaker and Wilson, 2008).

3.2. *Plant functional groups based on carbon allocation*

The vegetation classification developed by Monsi in the 1960s is based on the allocation and cycle of resources within different plant types and is, thus, considered a useful baseline for the urban vegetation typology serving the needs of carbon sequestration. The two main categories in Monsi's system, the tree system and the herb system, are applicable in the carbon-based classification of urban GI in cold climates. However, not all sub-categories are relevant for this study. Therefore, we combined the group of "permanent herbs" (Monsi 1960) with that of perennial herbs on the basis of their similar size and uses in landscape construction. We also considered annual herbs as a separate group given their different carbon allocation and maintenance practices compared to perennial herbs. Thus, urban plants are introduced here under three main topics: woody vegetation, herbaceous perennials and annual plants (Fig. 3).

3.2.1. *Woody plants*

Trees are an integral part of urban landscapes defining spaces and providing multiple ecosystem services. Trees also represent a relatively long-lasting storage site for carbon in urban green areas (Lindén et al., 2020; Rowntree and Nowak, 1991; Strohbach et al., 2012). Woody plants, including trees and shrubs, store assimilates, such as carbon, in their trunks, branches and root systems and require space to grow without excessive disturbance.

Shrubs are also commonly used in urban landscape planning and construction, although they are rarely mentioned in research focussing on carbon sequestration in urban areas. Since no commonly used definition exists for the vegetation type, different classifications have been used in research focussing on shrubs in urban areas (e.g. Davies et al., 2011; FAO Food, 2014; Lindén et al., 2020).

The root biomass of trees has often been estimated to be around 25% of the aboveground biomass (Bardgett and Wardle, 2010; Nowak and Crane, 2002). It has also been observed that over one-third of the net primary production of Scots pine (*Pinus sylvestris* L.) is allocated to roots in boreal forests (Ding et al., 2020). Underground biomass has also been interpreted to considerably vary (Johnson and Gerhold, 2003), which is why some researchers exclude it from their biomass calculations (Strohbach et al., 2012).

Time is a significant factor in sequestration on several levels, but its impact is not similar among different plant traits or parts. First, deciduous plants cannot perform assimilation during the winter, and they lose carbohydrates when their leaves fall. However, since evergreens assimilate CO_2 generally at a lower level than deciduous plants, the material balance between these two types throughout a year (Schulze et al., 2019b) or over time (Rowntree and Nowak, 1991) is quite similar. Second, plant parts above and below the ground do not necessarily grow simultaneously. For example, in boreal forests, the roots grow mainly in mid-summer and autumn, after most of the aboveground growth has already occurred (Abramoff and Finzi, 2015; Ding et al., 2020). Therefore, it is worth highlighting that the allocation of carbon within woody plants varies during the growing season.

According to the findings of Setälä et al. (2016), the soil carbon pool varies between different vegetation types and parks of different ages. Woody vegetation seems to boost carbon accumulation in the soil, and the level of accumulation reaches its maximum value in soils under evergreen trees, with the effect increasing with time. According to Lu et al. (2020), the amount of carbon under evergreen trees is associated with the more recalcitrant needle litter, lower soil CO_2 flux and higher root production in comparison to deciduous trees and lawns. Ectomycorrhizal and ericoid mycorrhizal fungi, which are common companions for woody plants, also seem to enhance the sequestration of carbon in the soil more than arbuscular mycorrhizal fungi do (Averill et al., 2014). However, research on street trees has shown that after the establishment of new growing media, which are commonly rich with easily decomposable soil organic matter, the photosynthesis process requires time to exceed the soil respiration rate on site (Havu et al., 2021; Riikonen et al., 2017).

3.2.2. *Herbaceous perennials*

Herbaceous perennial plants appear in urban environments in designed green areas, natural-like meadows and ruderal non-maintained vegetation or wetlands. In general, the reproduction strategy of herbaceous perennials is to store carbon and nitrogen in their tissues to ensure the growth and survival of individual plants (Monsi, 1960; Schulze et al., 2019a). In the growing season, carbon is mainly stored during the vegetative growth phase. However, in the autumn, the plant withers and some of the carbon and nitrogen are stored in plant parts mostly underground, such as the roots and rhizomes. With this reservoir, perennials can withstand the cold season, overcome other disturbances and start growing early in the spring (Schulze et al., 2019a).

Although urban herbaceous perennial plantings have not been largely studied in the context of carbon, some references can be found in research on natural vegetation (e.g. (Steinaker and Wilson, 2008) and lawns (Decina et al., 2016; Kotze et al., 2021; Pouyat et al., 2009; Raciti et al., 2011; Setälä et al., 2016; Wu, 1985). Lawns are considered a typical herbaceous perennial element in the urban environment. For example, Steinaker and Wilson (2008) found close synchrony between the growth of roots and the growth of shoots in native grasslands, but they found that leaves in forests start to grow significantly earlier than the roots. This likely occurs because the atmosphere becomes warmer faster than the soil, and herbaceous plants also take time to translocate nutrients from underground storage sites to support the growth process. This phenomenon seems to occur also under similar urban vegetation and growing conditions. According to Steinaker and Wilson (2008), the process of underground plant production is significantly important, as they claimed that this process may represent up to 80%–90% of the total leaf and root production in both grasslands and forests in temperate and semi-arid climates. Although most of the lawn grass species used in cold climates have relatively shallow roots (Wu, 1985), there is evidence of soil organic carbon (SOC) accumulation much deeper than the rhizosphere (Raciti et al., 2011). The amount of carbon sequestered in lawn soils seems to reach its maximum value 30–50 years after a construction project or other major disturbances (Pouyat et al., 2009).

3.2.3. Annuals

Annuals have a short life cycle, but all of their aboveground tissues are active in terms of photosynthesis. Annuals also have relatively small roots, and they reproduce through a high yield of seeds (Schulze et al., 2019b). After the growing season, the whole plant, both above and below the ground, dies and starts to decompose. In addition to seeds and the decomposing plant parts, carbon is also allocated below-ground during the growing season by root turnover, exudates and secretions (Kuzyakov and Domanski, 2000). This extra carbon input to the soil can be 50% or more of the total carbon input below-ground as Sauerbeck and Johnen (1977) observed with cereal crops.

One advantage of the reproductive strategy of annuals is that when they are growing freely, they can spread rapidly on patches of bare soil (Monsi, 1960). In the urban setting, however, planted annuals and biennials mostly occur in annual flower beds, (annual) meadows and vegetable patches or ruderal areas. Under these conditions, plants do not usually disperse or reproduce by seeds, because the vegetation is removed before the seeds fall off, the seeds are harvested or the seeds do not overwinter in cold climates. In contrast, annuals found in ruderal areas can seed and spread freely. Although there is limited research on the ability of urban annual plants to sequester carbon, research on annual cereals reveals similar patterns as in perennial pastures, when the same growth period is considered (Kuzyakov and Domanski, 2000).

Biennials are not a typical plant group used in urban landscaping in cold climates; they occur in some meadow seed mixtures. However, because of their scarce use and functional similarity to annual plants, we consider biennials here together with annual plants.

3.3. Urban growing conditions

Generally, in urban areas, the bio-physical conditions are versatile and differ in many cases from those of natural environments. On the one hand, temperature, light, precipitation, sub-soil characteristics and the duration of the growing season depend on the location and reflect features of the local climate. On the other hand, phenomena such as urban heat islands (UHIs), impervious surfaces, modified growing media, construction projects, maintenance practices and human everyday life change the circumstances for plant growth. This change can be either enhancing, with decreased competition between plant individuals or species, increased lighting and improved growing media, or deteriorating, as a result of drought or wetness, compared to natural soils, or decreased humidity (McHale et al., 2009; Van Den Berge et al., 2021). The growing conditions may also vary from natural-like circumstances with an uninterrupted connection to the surrounding soil and water systems to detached and limited structures, such as planters or roof gardens.

3.3.1. Urban climate

Climate is one of the key factors affecting plant growth through, for example, temperature and precipitation. Urbanisation modifies the local climatic conditions, including the UHI effect, which results in an increase in the temperature in densely built areas compared to less built areas and rural surroundings (Oke, 1973). Higher temperatures have been observed to extend the growing season and, thus, enhance photosynthesis (Wohlfahrt et al., 2019). However, the UHI phenomenon may simultaneously enhance respiration (Davidson and Janssens, 2006) and result in decreased CO_2 uptake through changes in the soil water status and heat stress (Hu et al., 2010).

Generally, the impact of UHI on plant phenology strongly depends on the local and micro-climate, which are modified by the topographic features (Cleland et al., 2007), urban design, amount of impervious cover and vegetation type within the zone of influence (Upmanis and Chen, 1999; Zipper et al., 2016). The climate near the ground, which is usually most relevant to plant life, is especially prone to vast daily changes in temperature and is also affected by the soil conditions, mainly the moisture content (Stoutjesdijk and Barkman, 2015). Thus, the trade-offs and co-benefits among temperature, water balance and CO_2 sequestration in urban areas depend on several factors and are related to the local circumstances, vegetation and management practices (Li and Wang, 2021).

In general, the amount of daylight varies in two ways in urban areas. On the one hand, shading decreases carbon sequestration in street canyons, especially at city centres (Guo et al., 2020). On the other hand, the amount of light available may even increase when the plants are of an even size and grow in strictly specified patterns, as in tree rows, where plants do not cast shade on each other (Van Den Berge et al., 2021). However, although the impact of artificial light on urban vegetation at night remains controversial, especially in cold regions, it can lead to significant differences in the plant biomass and modify the species composition (Bennie et al., 2018; Zheng et al., 2021).

In the future, the accumulated temperature is expected to increase considerably, and the possibility of heavy rain is expected to increase in Northern Europe, especially in winter (EEA, 2022a, 2022b). Although warmer winters mean decreased snow cover and ground frost (EEA, 2022b), vegetation is not necessarily affected in an even manner. The temperature may also further increase in grasslands more than in forests, because trees decrease the temperature more than grass does. This is likely to have implications for the growth of fine roots in grass areas and for the competition of growing space underground and, thus, may eventually modify even the species composition (Steinaker and Wilson, 2008).

3.3.2. Soil and growing media

Urban soils represent a wide range of different materials, which are commonly more affected by human interventions than conventional patterns of soil formation. These soils are also referred to as anthrosols or technosols, and they contain anything from urban forest lands to agricultural soils, landscaping soils and materials, soils in traffic and industrial areas or waste materials (FAO Food, 2014).

In general, the properties of the soil greatly affect the growth and wellbeing of plants. Although the soil temperature in urban areas follows local climate regimes, in addition to the effect of UHI, for some features, such as the soil structure and fertility, pH and moisture are more dependent on the local conditions and are also modified by landscaping. Plant roots can sense difficult conditions in the soil and send inhibitory messages to the shoot, thus hindering growth when the resources are limited. Although many of these responses are related to the plants' ability to extract water from the soil, soil compaction, especially in soils with excessively large pores or soils that are too loose, can hinder plant growth regardless of the soil water status (Passioura, 2002). Such compaction affects, for example, the root growth of lawns as a result of poor soil aeration (Wu, 1985). Roots can also detect whether the growing space is small and, hence, adapt the growth of the shoot to match these conditions (Passioura, 2002). Ding et al. (2020) highlighted a positive correlation between tree root growth and soil temperature.

Urbanisation increases soil sealing. Impermeable surfaces prevent water and sunlight from reaching the soil and prevent the exchange of gases between the soil and the air. As a result of frost protection, the construction of buildings, pavements and infrastructures in cold climates involves the exchange of earth masses and use of coarse-grained infills with no organic matter. In general, the amount of roots growing under sealed soils is very small (Lu et al., 2020), unless a specific structural soil is used. Furthermore, in densely built areas, plants are commonly planted on separate pockets of engineered soils, on podium structures, on rooftops or in planters, resulting in the loss of soil connection and, hence, disturbances in the movement of water and soil fauna. Even when the growing media are connected to the sub-soil, construction projects and earthworks often disturb the natural succession of the soil. Soil communities mainly develop in concert with the overlying vegetation, and the interaction between the plant and the soil depends on the plant species (Bardgett and Wardle, 2010). In urban environments, this process is modified, and the successional phases of vegetation and soil do not necessarily match, as there may be an end-phase tree species planted in a soil with 'pioneer qualities' or qualities from another plant community. However, plant residues, root exudates and other organic matter accessing the soil alter the development of the soil microbial community (Bardgett and Wardle, 2010) and, hence, modify the circumstances. Setälä et al. (2016) found that the properties of park lawn soils in cold climates reach a new equilibrium generally in 50 years after disruption but that pH reaches a new lower level faster, especially in soils under evergreen trees. According to Raciti et al. (2011), soil carbon in lawn soils seems to recover in 20 years.

3.3.3. Hydrology

Urban development modifies natural hydrological processes, and urban hydrology is closely related to the increase of imperviousness and soil functions (Haase, 2009; Kokkonen et al., 2018). Drainage systems can facilitate dramatic changes in the magnitude, pathways and timing of runoff (McGrane, 2016). Urbanisation also contributes to altered soil water cycling, including the heterogeneity of urban soils, altered horizons and compaction resulting from construction activities (O'Riordan et al., 2021). All of these factors affect the availability of water for urban vegetation.

Both the lack of soil moisture and excessive soil moisture have been found to limit the growth of trees in urban areas (Iakovoglou et al., 2001). Under dry conditions, the growth of tree leaves limits biomass production and CO_2 uptake (Li and Wang, 2021; Passioura, 2002), but dry conditions may increase root growth in the long term and, thus, increase underground biomass production, as found in studies on semi-arid climates (Steinaker and Wilson, 2008). However, there seems to be a lack of similar studies in the urban context and in cold climates. In general, species with the capacity to grow well under fluctuating saturated and dry conditions are likely to perform best in urban environments (Livesley et al., 2016). In addition, wet conditions seem to increase the organic carbon values in urban soils. For instance, Dorendorf et al. (2015) found that plots with wet conditions have exceptionally high storage values.

Although watering plants artificially may improve their growth, the hidden carbon costs of irrigation are likely to overweigh the benefits (Tresch et al., 2019). The need for irrigation varies considerably across regions with different climates and different vegetation types (Nouri et al., 2013). Plant selection should always be based on the local climate conditions to avoid the need for irrigation, but within the built areas the local climate may differ substantially from the natural areas. Furthermore, also in cold humid climates the warm dry periods in the summer are likely to increase in the future (Ruosteenoja and Jylhä, 2022). For plants adapted to humid growing conditions extreme drought periods are difficult, which can increase the importance of irrigation for plant growth in urban areas.

3.4. Anthropogenic drivers

3.4.1. Management

According to Jansson and Lindgren (2012), green space management embodies the activities conducted by a management organisation to maintain and develop existing urban green space for users. Such management includes operational maintenance practices, such as lawn mowing and the application of fertilisers, pesticides and herbicides; the use of irrigation systems; pruning of trees;

removing weeds and plant litter and mulching. The frequency and intensity of these activities vary greatly among different type of green spaces. The aim of these practices is to provide favourable growing conditions for vegetation and to take care of the plant health so that certain aesthetic and functional qualities are reached. Since the favourable growth of plants likely increases carbon sequestration through the production of biomass, there is a great potential to enhance carbon pools through management. However, increasing the carbon stocks of vegetation or soils is usually not the priority, or even the goal, of urban green space maintenance practices. Furthermore, the maintenance and use of machines themselves result in carbon emissions.

So far, there has been no clear evidence regarding the effect of different maintenance practices on the carbon pools (both below and above the ground) of different urban vegetation types (Canedoli et al., 2020; Lindén et al., 2020). W. Hundertmark et al. (2021) found that decreased maintenance may reduce biogenic carbon emissions, at least under certain climatic and soil conditions. However, the possible results of decreased maintenance, such as the shorter lifespan of vegetation and less organic matter input, require further investigation. The authors also found that mulching significantly increases soil respiration and, thus, the release of carbon from urban green spaces. Similarly, Decina et al. (2016) found that soil respiration increases in constructed urban green spaces compared to nearby rural areas. Generally, mulching and other maintenance practices, such as using peat or compost for soil amendment, may benefit the growth and increase the input of organic matter in the soil (Edmondson et al., 2012, 2014b; Lindén et al., 2020). Urban lawns are an example of a vegetation type that would not exist without maintenance (Milesi et al., 2005), although their relevance to carbon sequestration is controversial. The results obtained by Milesi et al. (2005) and Pouyat et al. (2009) indicate that a well-maintained lawn can function as a carbon sequestering system. W.J. Hundertmark et al. (2021) also claimed that lawns are always net carbon negative if they are traditionally maintained.

In the same context, Kotze et al. (2021) claimed that the carbon pools of urban GIs and their vegetation are the result of vegetation–soil interactions, which can be affected by maintenance practices. Some studies have also highlighted the need to focus on the management of SOC (Edmondson et al., 2012). Generally, the prediction of soil carbon responses to different maintenance practices is difficult to interpret, with many studies showing varying results. Many variables, such as the timing and frequency of maintenance activities, differences in plant taxa, climate and habitat type, make it difficult to interpret which factors are important (Edmondson et al., 2014a; Kotze et al., 2021; Lindén et al., 2020; Setälä et al., 2016). The same maintenance practices that increase plant productivity, such as irrigation or fertilisation, may simultaneously increase decomposition and, thus, decrease soil carbon (Raciti et al., 2011). In addition, the removal of aboveground litter may disconnect the carbon input of the soil in the carbon cycle. Lorenz and Lal (2015) proposed that SOC-enhancing maintenance practices include, for instance, the revegetation of bare urban soils, reduced soil disturbance and returning of grass litter on urban lawns. Moreover, maintenance should focus on optimising the net primary production and especially increasing the input of organic matter in the soil (Canedoli et al., 2020; Lorenz and Lal, 2015).

Notably, the maintenance practices themselves result in emissions, which can lead to a significant annual carbon footprint, especially in high-quality management areas and in climates where intensive irrigation is used (McPherson et al., 2015). The release of CO_2 from maintenance activities depends on the use of vehicles and equipment and the irrigation practices. Canedoli et al. (2020) presumed that maintenance-related emissions vary greatly between the different vegetation types and climate regions. Urban lawns that require intensive maintenance with machines and are also commonly irrigated have high carbon costs (Kong et al., 2014; Selhorst and Lal, 2013), although the accumulation of carbon in the soil can be increased through management practices that avoid the removal of grass litter (Lorenz and Lal, 2015). According to McPherson et al. (2015), reducing the aboveground pruning of urban trees can both increase the aboveground biomass and reduce emissions.

3.4.2. Spontaneous disturbances

Besides planned management, urban vegetation experiences various types of disturbances and stress factors due to the use of green spaces, trampling and vandalism. These disturbances, including soil compaction (Francini et al., 2021), dog litter, pollution and trampling of plants and soil, may have both negative and positive effects on the growing conditions. Urban vegetation can also be prone to pests and plant diseases. Some studies on urban carbon pools have highlighted that if the history of a study area and the possible disturbances are unknown, this might explain some contradictory or otherwise unexpected results in carbon stocks (Canedoli et al., 2020).

4. Results: a carbon-based framework for urban vegetation typology

In the previous chapters, we identified the key elements influencing the CSS of urban vegetation. On the basis of our findings, we propose a carbon-based framework for urban vegetation typology. This framework highlights the impacting factors of urban vegetation in terms of CSS and discusses the relevance of the findings and their practical implications. Although the framework does not address the quantities of carbon sequestered by each vegetation type, it aims to contribute to the knowledge on how to maximise the CSS of urban GIs.

4.1. Two main carbon storages

In general, CO_2 accumulates through photosynthesis at two storage sites: plant parts and soil. Woody vegetation types can store carbon in both aboveground and underground plant parts for decades. Although herbaceous vegetation types do not have permanent aboveground carbon storage sites, the root systems can be extensive and persist for several years. Annual plants store carbon in the seeds, whereas all other plant parts decay at the end of the growing season. Through littering and decomposition, both aboveground and underground plant parts of all vegetation types create a constant carbon input that may accumulate in the soil. Thus, we assume that the soil carbon stocks in urban green areas are actually largely driven by the carbon cycle, which in turn is driven by vegetation type and management.

4.2. Vegetation typology

Besides general vegetation types, we identified several sub-categories that represent the most common vegetation types in urban environments. Given the remarkable difference in the potential aboveground carbon storage and the expected lifetime of different species, woody plants are divided into trees and shrubs. In urban green spaces, shrubs are also a common vegetation type that is often applied as a single-layer vegetation type, very different from natural ecosystems. Furthermore, trees are classified into evergreen and deciduous sub-categories, as the recalcitrant litter created by evergreen plants seems to create higher soil carbon stocks in the urban context.

Herbaceous perennials occur in various combinations and types in the urban context, although some of them are far more common than others. Since the areal quantity and maintenance of lawns in urban areas differ drastically from other herbaceous perennials, lawns are considered as their own sub-category in the framework. Meadows, on the other hand, represent a grassland vegetation type that differs from lawns in terms of maintenance practices, and they are thus considered as their own group in the framework. Perennial plantings represent a sub-category that refers to various types of urban herbaceous vegetation, ranging from very intensively maintained ornamental plantings to natural and dynamic built ecosystems. The CSS capacity of these vegetation types is defined by the species composition, growing conditions and maintenance practices. Furthermore, wetlands, or constantly water-covered habitats, are defined as a sub-category because of their drastically different CSS qualities compared to other vegetation types and also because of their specific species composition. Similar to other sub-categories, wetlands also cover various habitat types, from natural shores to artificial ponds.

Vegetated roofs and walls are not represented as separate sub-categories, as the plant type, growing conditions and maintenance factors identified in the framework define the CSS potential of vegetation types with very limited growing conditions (Shafique et al., 2020). Similarly, vines can be considered to be part of either herbaceous perennial or woody shrub types, depending on the species. Spontaneous urban vegetation types, such as ruderates, are considered as meadows with no planned maintenance, although ruderates

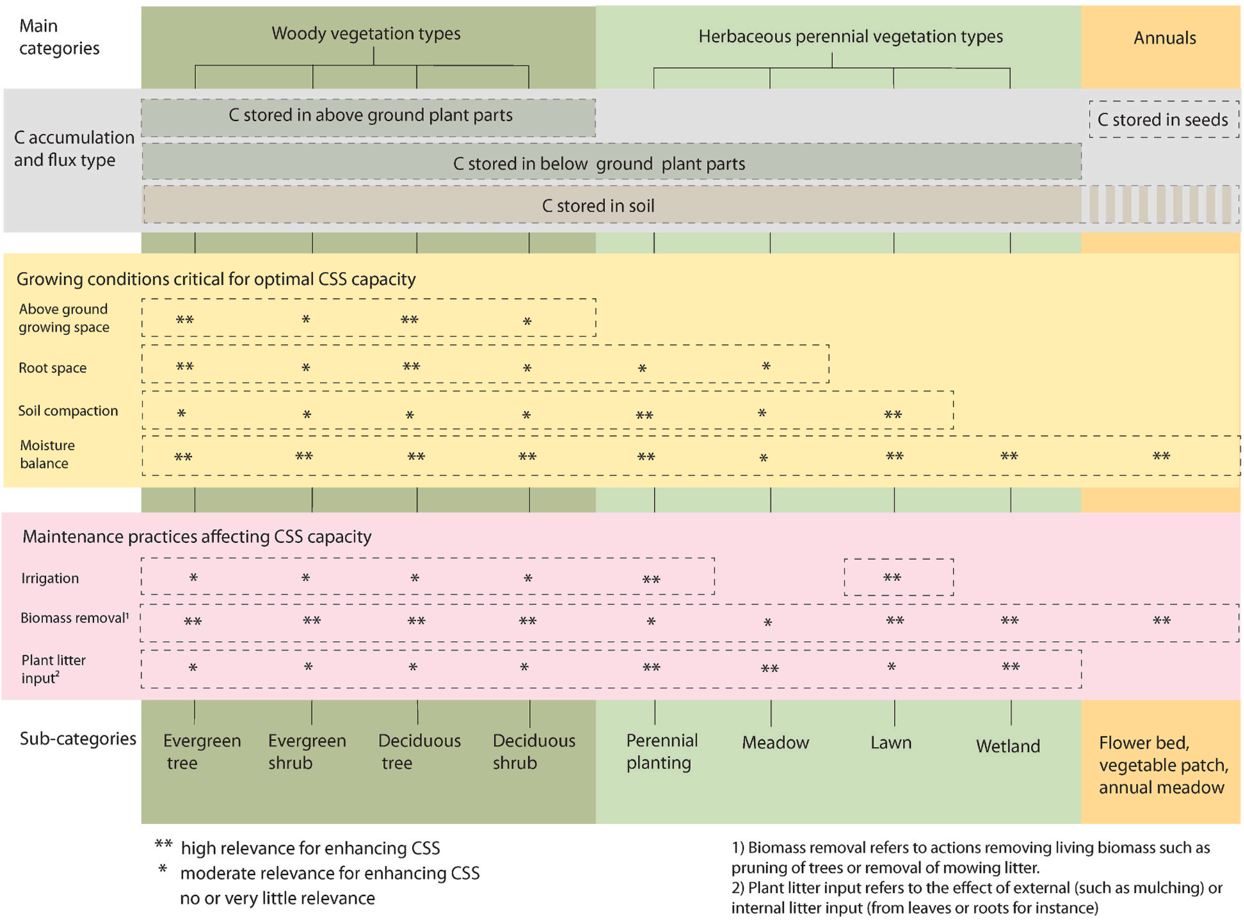

Fig. 4. Framework for a carbon-based vegetation typology in urban areas.

can also include woody plants.

Although the ability of annual plants to sequester carbon in urban environments is relatively weak and varies between species, this plant group is distinct from the perspective of maintenance. One key difference to other groups is that the soil is usually bare outside the growing season, and it is often disturbed by cultivation, which is known to release carbon in agricultural fields (Shafique et al., 2020). Carbon storage in the soil also depends on whether the plant parts below-ground are removed at the end of the growing season or left in the ground (Bolinder et al., 1997). Seasonal, ornamental plants are often pre-cultivated and thus planted and removed with a root ball. Many domesticated annual plants are also not very hardy, because selective breeding favours other traits, such as crop production (Passioura, 2002).

4.3. Criteria for optimal growing conditions and maintenance

Our analyses showed that favourable growing conditions and optimal maintenance are two key factors through which the CSS capacity of urban vegetation can be impacted by landscape design and management. Good growth is a prerequisite for carbon sequestration similarly as appropriate soil is for carbon storage. Although the proposed framework focusses on vegetation, it also recognises the importance of the soil storage of carbon. Therefore, in this study, we identified four critical criteria for optimal CSS in urban environments with cold climates. The importance of these criteria varies between the different vegetation categories, which is illustrated in the framework (Fig. 4).

In this context, the first factor is the aboveground growing space, which is especially important for trees and other woody plants that store carbon in aboveground plant parts. This growing space is often limited in densely built urban areas or in areas with traffic restrictions. The second factor is the root space, which is often restricted for urban vegetation. Generally, the size of the roots affects the size of aboveground plant and is thus considered a factor that defines the sequestration capacity of the plant. The third factor is soil compaction, which limits the root growth. Plants with shallow roots, as in lawns, are increasingly prone to the effects of compaction. The fourth and final factor is the moisture balance, which is crucial for plant survival and growth. Both excess water and the lack of water may complicate the plant growth process, depending on the species.

Maintenance may support favourable growth in several ways, and some urban vegetation types even rely on maintenance for their survival. According to our analyses, irrigation and plant litter input are the most important maintenance practices for supporting the CSScapacity. Instead of technical irrigation systems, nature-based stormwater solutions can be used to store and convey rainwater for vegetation in built environments, as water availability is a crucial factor in adequate growth (McGrane, 2016; van Roon, 2012). Designers should also consider whether irrigation is in fact a standard solution, and they should consider only the amount of water to be supplied in order to maintain the health of urban vegetation (Nouri et al., 2013).

Fertilisation is obviously used to improve the vegetation growth, and thus biomass production, but in recent studies in the urban context its impact on carbon accumulation is not mentioned. Greenhouse gas emissions of industrially produced fertilisers, herbicides and pesticides is apparently higher than the benefits for carbon accumulation (Zhang et al., 2022), but more life-cycle studies are required to further investigate this aspect.

Plant litter input is critical for the accumulation of organic matter in the soil, and this process can be supported by maintenance. However, excess litter input can increase the rate of decomposition and respiration. Hence, mulching is not necessarily considered an effective way for CSS optimisation. For woody plants, pruning removes the biomass, thus reducing the carbon stock, and is often necessary because of the limited growing space or safety. Thus, it is important to strike a balance between the sufficient and the necessary amount of maintenance.

5. Discussion

5.1. Implications for planning and research

The framework proposed in this study can be applied as a starting point for further studies on the CSS potential of urban vegetation at different scales and for different purposes. The CSS potential of different vegetation groups in urban environments is affected by several factors. By identifying carbon-smart vegetation typologies, urban planners, designers and researchers can inform climate-wise urban planning, landscape design, construction and maintenance. The framework can support the optimisation of the growing conditions and maintenance practices for each vegetation group. The framework can also serve as a basis for the development of national or local guidelines or as a starting point for building climate-wise socio-ecological models for increasing interaction between people and urban nature.

Our study highlights that planning and designing urban GIs have a significant, yet rather complex impact on urban organic carbon pools. This complexity results from the various land cover types in urban patterns and the large influence of various anthropogenic factors. Moreover, such complexity is even further compounded by the conflicting research results (i.e. Canedoli et al., 2020). However, we believe that by understanding the basic processes of carbon flux and storage of different vegetation types and by the optimisation of maintenance, the capacity of urban vegetation to function as a CSS site can be systematically enhanced.

The carbon-based framework of urban vegetation can serve as a basis for the further development of the assessment and modelling tools of CSS, which are required to meet the climate targets of urban regions. To consider the different vegetation types present in urban areas in CSS modelling, it is important to generalise the vegetation types. For example, although many ecosystem models are simply based on plant functional types, they cannot consider the variability of urban vegetation (Schürmann et al., 2016). Thus, more specific sets of urban parameters are required to present the different vegetation types and species in cities (Havu et al., 2021).

Furthermore, to appropriately model the CSS, information on the specific local climate and management practices should be implemented in the models. This can allow more comprehensive assessments of the climate impacts of urban planning, with a better understanding of urban GIs. It can also allow comparing alternative scenarios and planning solutions and more effectively steer the climate impacts of planning.

Life cycle assessment (LCA) is a specific application for a carbon-oriented vegetation typology. It is a method used to estimate the environmental impacts and benefits that may arise during the life cycle of a building, product, service or infrastructure. However, there are currently no specific methods or standards for calculating the environmental impacts of plants and soils in landscape design and construction (Kuittinen et al., 2021). After defining the goal and purpose of the assessment, an important part of the LCA is the inventory analysis, which is the accounting of all materials and energy flows that are arising during the life cycle of the “product”. In the case of an urban park, for instance, this would mean to account for every material and plant type, but also for maintenance processes, energy use and logistics. Therefore, vegetation typologies provide a framework to assess differences during nursery production, construction, use and end-of-life phase and thus create a starting point for developing datasets for LCA studies of urban GI.

Our study highlights the role of vegetation as the main element in the accumulation of carbon in soils. Almost all city-wide studies have concluded that soil and tree carbon stocks are the ones that are considered important (e.g. Richter et al., 2020). However, the role of other vegetation types, and in particular their capacity to increase SOC pools, has been neglected. The soil’s quality and conditions have a major impact on the growing conditions, and soil construction also impacts the carbon balance (Kotze et al., 2021). Notably, the current green space topsoil holds significant SOC storage (Edmondson et al., 2014b). While earthworks and landscape construction have a significant carbon footprint, preserving the current vegetation and soils should be a priority in landscape planning and design. In new construction projects, it is important to provide enough space for new urban vegetation in parks, street areas and residential yards.

According to our review, climate-wise GI planning and design should consider both vegetation types and soils. Research has shown that no correlation exists between carbon stored in trees and mineral topsoil (Canedoli et al., 2020; Dorendorf et al., 2015). Therefore, areas with the largest tree cover or biomass are not necessarily the areas with the largest soil carbon storage. Although the soil carbon stock exhibits certain correlations to the land cover and vegetation type, a large amount of variation exists in this regard (e.g. Canedoli et al., 2020). Further studies are needed to understand the plant-soil system and the main variabilities in the urban context.

Planting design has a significant impact on CSS. To maximise the CSS, it is important to optimise the growing conditions in order to ensure favourable growth. Moreover, plant type plays an important role in determining the carbon sequestration potential, and it also highlights the need for maintenance together with species selection. More research is needed on the specific vegetation types suitable for urban environments that can enhance the accumulation of stable SOC. In this context, new concepts have emerged in the field of planting design. For example, micro-forests represent a multi-layered vegetation type with a high LAI, and dynamic planting design forms a habitat that minimises the period of bare soil. Furthermore, wetlands, which exhibit a high CSS capacity (van Roon, 2012), can be applied more extensively. In addition to carbon sequestration, these vegetation types can provide other ecosystem services.

Generally, carbon-smart maintenance of urban vegetation can be supported in two ways. First, the maintenance dependency should be reduced to minimise the emissions of the maintenance work itself. Second, the aim of the overall maintenance should be to maximise the carbon sequestration of vegetation, which requires a re-evaluation of the aesthetics of urban green spaces. One of the key questions regarding maintenance is to support the cycle of organic matter. This requires alternatives for typical plant litter removal and careful consideration of how and where to handle plant litter within green spaces.

Carbon-based urban vegetation typology can also be applied for implementing the principles of carbon farming in urban areas. The approach of carbon farming combines different technologies (Becker et al., 2013), techniques (Fenner and Freeman, 2020) and pragmatic solutions (Samruthi et al., 2020) as part of regenerative farming to maintain and possibly increase organic carbon into farming systems (Jiang et al., 2014). It favours the use of organic fertilisers, manure and compost to support the microbiological activity in the soil, thus impacting carbon flux both in plant and soil. These regenerative approaches deserve more attention also in the context of urban vegetation.

5.2. Study limitations

This study is based on a thematic review of the current knowledge on a relatively wide and unestablished research topic and thus includes several uncertainties and further research needs. First, there is a conceptual challenge in CSS research when applied to urban environments. Several partly overlapping concepts for urban greenery are used, which are not always specifically defined. City-scale urban greening can be defined as urban green spaces, green structures or green area networks as a spatial element, or GI or urban ecosystem as a functional entity of soil and vegetation. It is not always clear if, for example, private green spaces or informal green spaces are included in the studies. Thus, it is difficult to compare the results of different studies as their scope varies.

Second, the factors influencing CSS vary greatly, and even research results are sometimes contradictory. The life cycle of urban vegetation includes several phases, but many previous studies have not considered the whole carbon cycle of urban greening: for example maintenance is often excluded. This means that the carbon stocks of urban greening may seem more positive than they really are, or it may result in neglecting the potential to enhance urban CSS. As a result, the actual differences between natural and urban ecosystems as carbon sinks remain relatively unclear.

Third, time dimension plays a very fundamental role in the CSS capacity of urban vegetation and soils, but it has not been included in our framework. In this study, we considered vegetation as a system that is undergoing a constant change (Tahvonen, 2019) and thus does not often have a specific definable lifetime. Built environments, however, usually have a construction phase and possibly a demolition phase, which have a potentially high impact on the actual CSS of urban vegetation. Moreover, only a few previous studies have considered the effect of time on carbon accumulation in urban environments. For instance, the soil carbon levels have been found to stabilise roughly in 50 years after a construction disturbance (Lindén et al., 2020; Setälä et al., 2016). Livesley et al. (2015) also demonstrated a significant increase in the soil carbon concentration in tree canopy areas with increasing green space age. However, the impact of time on the overall CSS capacity depends on several variables, such as the management of green spaces and for example vegetation litter. Thus, it remains difficult to draw clear conclusions on the impact of time in this regard.

Fourth, the CSS potential of urban vegetation depends on the climate. Besides the temperature, local variations in rainfall and drought periods may affect the growing conditions and the CSS ability of urban vegetation as well as maintenance-related emissions. For example, the need for watering can vary a lot depending on the climate. Although our study focusses on the context of cold climates, some of the referenced studies have been performed in warmer climates, since studies made purely focussing on cold climates are rare. In these cases, we considered the results to be applicable in cold climates. The principles of the framework are probably mostly applicable to various climate conditions.

6. Conclusion

In this study, we investigated the CSS capacity of urban vegetation and used a thematic review to identify the key elements influencing the CSS in cold climates. The results obtained highlight the fact that the CSS potential of vegetation is highly dependent on the favourable growth of individual plants, which is affected by urban growing conditions and maintenance practices. Besides urban trees, we emphasised the role of other vegetation types. Although the actual carbon stock of the aboveground biomass of herbaceous plants is relatively low, they impact the overall CSS capacity of urban green spaces remarkably through plant–soil interactions. On the basis of the thematic review, we defined a framework for a carbon-based vegetation typology and discussed the link between the growing conditions and maintenance practices and their effects on the CSS capacity of diverse urban vegetation types. The results obtained in this study can be applied on a larger scale, as individual plants form the basis of urban habitats and the ecosystem services they provide. Furthermore, our framework supports climate-wise planning, design and maintenance practices for multi-professional actors engaged with urban green spaces. The framework can also be used to develop practical guidelines and inform strategies for enhancing urban carbon sinks. Moreover, the framework forms a basis for further research needs, such as for modelling the CSS capacity and assessing the life cycle of urban vegetation. Hence, closer examination is required to calculate and compare the impacts of different vegetation groups during their whole life cycle and to quantify the magnitude of the impact of different maintenance practices. Further research is also required to understand the impact of diverse multi-layered plantings on the CSS potential.

Author contributions statement

Ariluoma Mari - Conceptualization; Data curation; Analysis; Methodology; Validation; writing original draft.**Paula-Kaisa Leppänen** - Conceptualization; Data curation; Analysis; Methodology; Validation; Writing original draft.**Outi Tahvonen** - Conceptualization; writing original draft; Methodology; Validation.**Ranja Hautamäki** - Supervision; Funding acquisition; writing original draft; Methodology; Validation.**Anna Rymin** - Conceptualization; Validation; Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work **reported** in this paper.

Data availability

No data was used for the research described in the article.

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