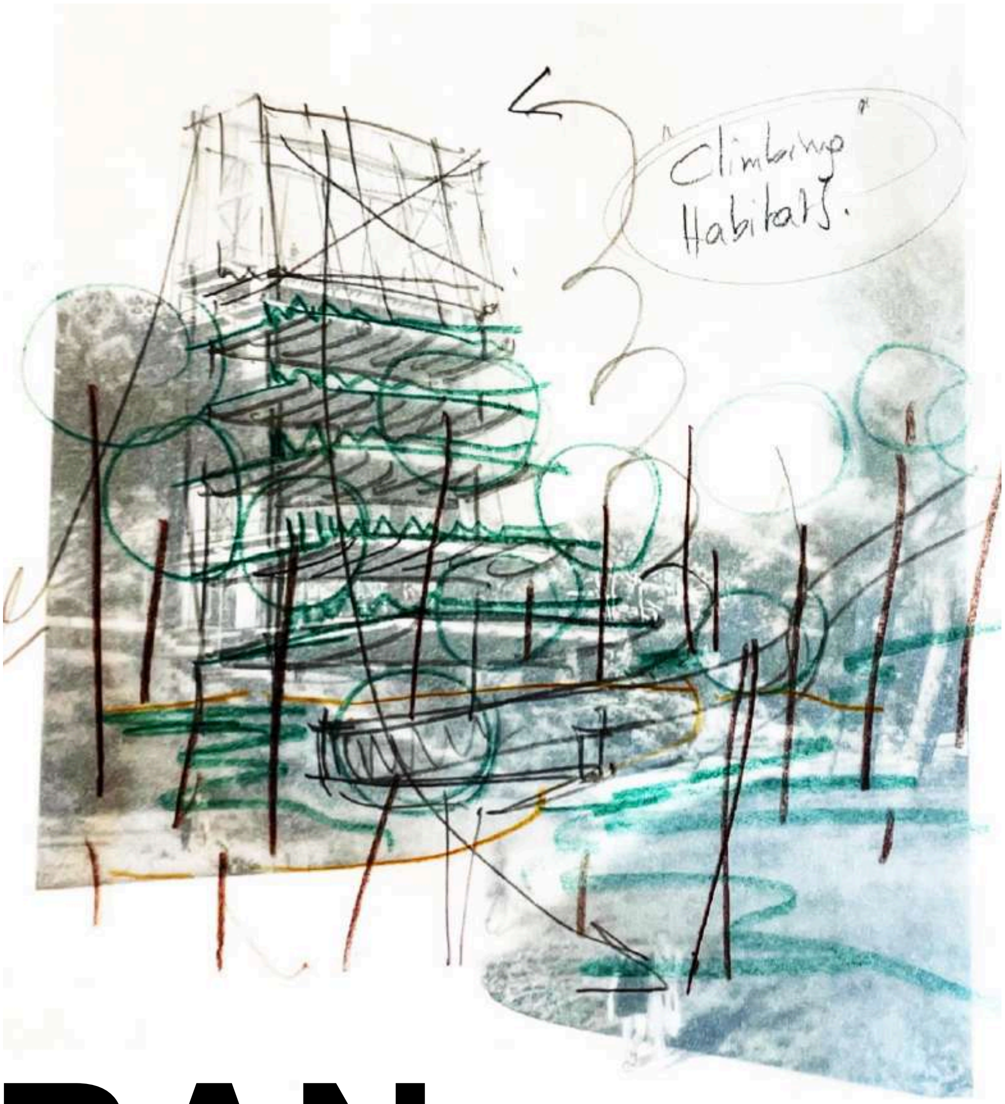
VERTICAL URBAN ECOLOGY



Explorative Study on Nature-Based Solutions within the Swedish Built Environment

Case study: Tensta, Stockholm, Sweden

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Independent project • 30 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences
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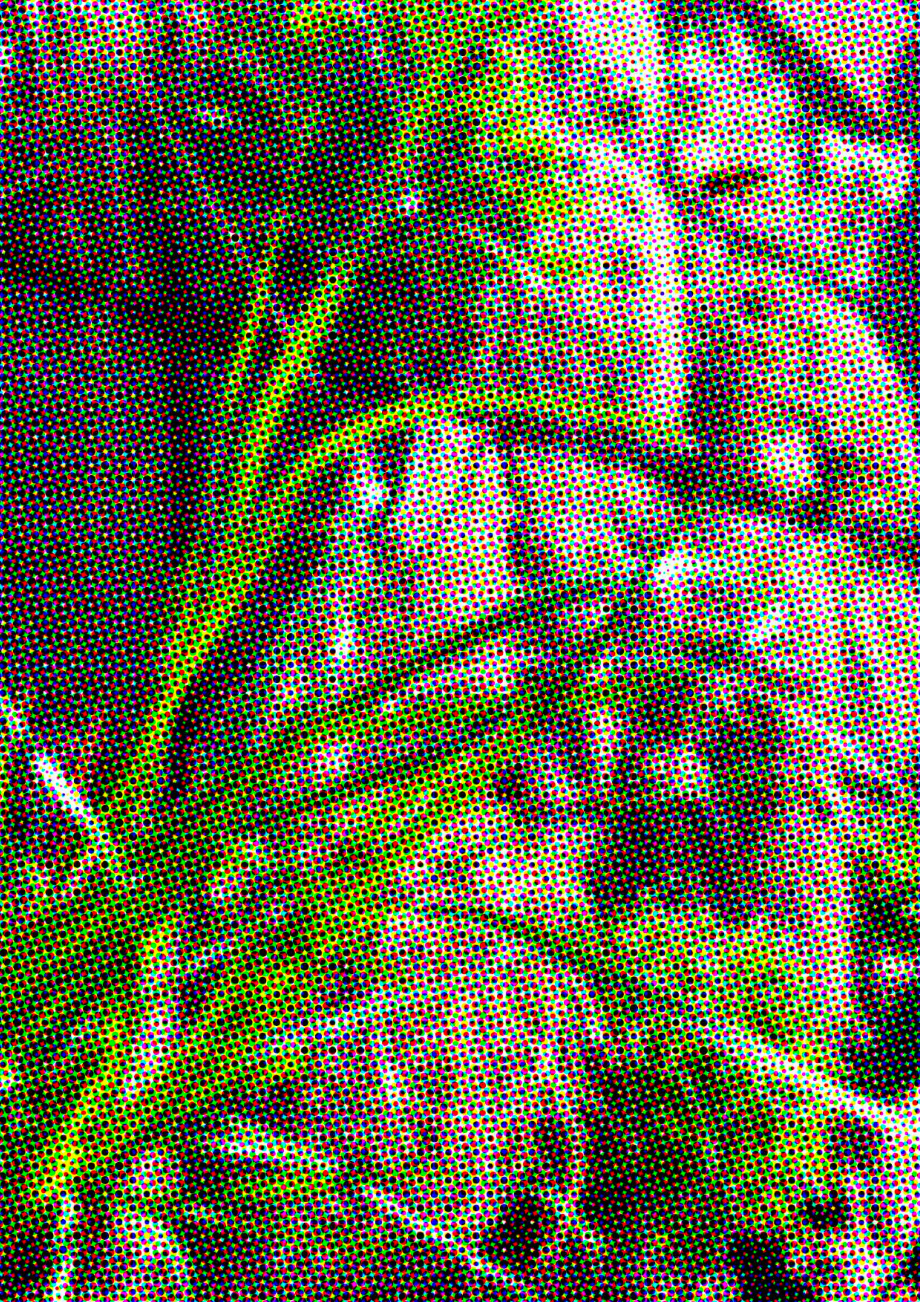

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Explorative Study on Nature-Based Solutions within the Swedish Built Environment

Case study: Tensta, Stockholm, Sweden

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ABSTRACT

A central theme within the Landscape Architecture for Sustainable Urban Development (LASU) master program has been the growing environmental pressures faced by cities across the globe. Processes of rapid urbanization, densification, and climate change are transforming our direct environments into sites where ecological and climatological challenges converge with increasing intensity.

Within both academic discourse and design practice, cities have emerged as critical laboratories for experimenting with sustainability strategies, climate adaptation measures, biodiversity protection, and the development of green economies. But despite the growing recognition of the spatial and temporal potential of the urban biosphere, many urban planning and design strategies continue to conceptualize urban ecology primarily through ideologies which see the natural landscape, and the built environment as two separate worlds.

Nature Based Solutions (NBS) are typically planned across the cities ground plane, while the vertical dimension of the built environment remains comparatively underutilized. Yet, contemporary cities are inherently three-dimensional environments in which buildings, infrastructure, and subterranean systems create complex spatial layers that could be valuable hosts for many Nature Based Solutions (NBS).

With this work, I would therefore like to introduce the concept of "Vertical Urban Ecology" (VUE), which I defined as:

> *"The three-dimensional ecological rethinking of the urban landscape, where volume, height, and both horizontal and vertical surface planning replace two-dimensional thinking."*

VUE explores the stacked relationships and potential between the city's ground level, canopy cover, and built (architectural) form. Through this perspective, the city can be understood as a layered ecological system in which architectural elements such as façades, roofs, terraces, and other infrastructural surfaces could be re-designed and activated in support of urban ecological, economical and social functioning.

Over the past four months, I reviewed the most documented benefits of building-integrated NBS, while critically examining their potential and practical implementation within everyday planning processes and urban environments in Sweden. This research ultimately evolved into the development of concrete measurement, design, and implementation scenarios in regards to NBS applied to a million housing program neighbourhood in Stockholm.

The thesis finally culminated in four distinct pilot projects and a full scale living wall mock-up, which are meant to inspire planners, designers, developers, residents, and policymakers, while simultaneously addressing the legal, technical, economic, and social constraints that might impact their realizability.

Ultimately, this thesis seeks to reposition the built environment as an active ecological agent, contributing to new spatial imaginaries for more resilient, biodiverse, and climate-adaptive cities.

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ABBREVIATIONS

BAF — Biotope Area Factor (Berlin)

BRF — Bostadsrättsförening (condominium association)

CE — Canopy Equivalent (value)

GF — Green Facade

GIS — Geographic Information Systems

GnPR — Green Plot Ratio (Singapore)

GR — Green Roof

GSF — Green Space Factor (Malmö/Stockholm)

LWS — Living Wall Systems

MHP — Million Housing Program

NBS — Nature Based Solutions

NIR — Near-Infrared (aerial imagery)

NUP — National Urban Park (Stockholm)

OSR — Opening-to-Solid Ratio

PBA — Planning and Building Act

PM — Particulate Matter

RUFS — Regional Development Plan (2050–60)

TCC — Tree Canopy Coverage

TOD — Transit Oriented Design

UGI — Urban Green Infrastructure

UHI — Urban Heat Island

VCM — Vertical Capacity Model

VGS — Vertical Green Structures

VUE — Vertical Urban Ecology

WWR — Window-to-Wall Ratio

> **“ Vertical Urban Ecology =**
>
> **The three-dimensional ecological rethinking of the urban landscape, where volume, height, and both horizontal and vertical surface planning replace two-dimensional thinking. ”**

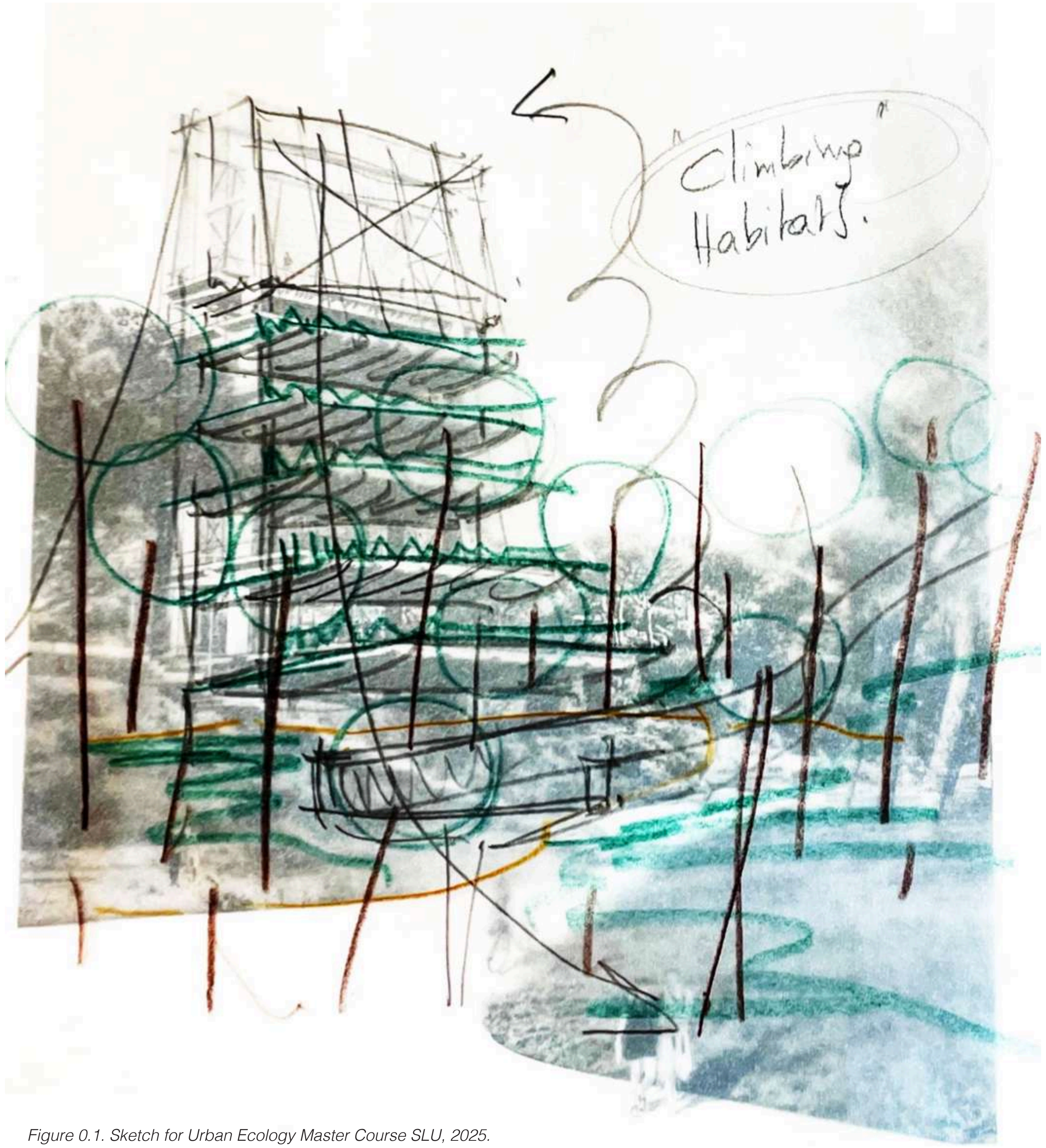


Figure 0.1. Sketch for Urban Ecology Master Course SLU, 2025.

INTRODUCTION

1. Background*

Climate change, biodiversity loss, urban densification, and growing demands on housing and infrastructure place increasing pressure on urban environments worldwide. Within planning practice, academic research, and environmental policy, Nature-Based Solutions (NBS) have emerged as a framework for addressing these challenges through interventions that integrate ecological processes into the urban landscape. Particularly within Europe, the concept has gained prominence through policy initiatives such as the European Green Deal, the EU Biodiversity Strategy for 2030, and the EU Climate Adaptation Strategy.

Despite the growing prominence of the NBS concept within planning and policy, the implementation of Nature-Based Solutions in cities remains largely concentrated on the ground plane. Public environments such as streetscapes, parks, playgrounds, urban forests, and blue-green corridors increasingly serve as hosts for ecological interventions and climate adaptation measures. While these approaches are essential, they are often implemented within a planning tradition that continues to treat the built environment and the landscape as separate spatial domains.

This tendency becomes increasingly problematic in dense urban environments where competition for land is intensifying. As cities continue to densify, opportunities for expanding conventional green space become more limited, while large portions of the urban environment remain ecologically underutilised. Contemporary cities are fundamentally three-dimensional systems in which façades, roofs, terraces, and other architectural surfaces collectively represent a vast but largely overlooked spatial resource.

This observation forms the basis for the concept of Vertical Urban Ecology (VUE), which I introduced in this thesis as a way of rethinking the relationship between architecture, landscape, and ecology.
I accordingly defined VUE as:

> *“The three-dimensional ecological rethinking of the urban landscape, where volume, height, and both horizontal and vertical surface planning replace two-dimensional thinking.”*

Rather than treating buildings and landscapes as separate domains, VUE explores how ecological functions may become integrated within the existing built environment itself. Through this perspective, buildings are no longer understood solely as consumers of ecological resources, but also as potential hosts for biodiversity, climate adaptation, water management, environmental education, and other ecosystem services.

2. Problem Formulation*

Despite growing awareness of the possible benefits of building-integrated NBS, their implementation within existing urban environments remains limited. In countries such as Sweden, planning frameworks, governance structures, ownership conditions, and economic considerations continue to favour more conventional approaches to urban development and green-space provision. This notion is particularly relevant in the Stockholm region, which combines ambitious environmental and climate-adaptation goals with continued urban growth and densification. As demands for housing, infrastructure, and urban development increasingly compete with open space, opportunities for expanding conventional green infrastructure become more constrained. This raises important questions regarding how ecological functions can be integrated more effectively within the existing built environment rather than relying solely on additional ground-level space.

At the same time, large parts of Stockholm’s post-war housing stock, particularly within the so-called Million Housing Programme (MHP) neighbourhoods, are approaching major renovation cycles. Mostly constructed in the 60’s and 70’s of the last century as part of a national effort to address housing shortages, these large-scale suburban districts represent some of Sweden’s most extensive concentrations of multifamily housing. Many MHP neighbourhoods have become central to contemporary debates surrounding segregation, socio-economic inequality, housing affordability, and urban regeneration. Simultaneously, Stockholm’s continued growth and densification is increasing development pressures on these areas, creating tensions between physical renewal, social sustainability, and housing justice.

As these districts undergo transformation, a unique opportunity emerges to integrate ecological improvements into existing urban structures while simultaneously rethinking the relationship between environmental quality, resident well-being, and neighbourhood regeneration. This raises important questions regarding how ecological, social, and spatial objectives can be pursued together without reinforcing existing inequalities.

3. Aim and Purpose*

The aim of this thesis is to explore how building-integrated NBS can contribute to more resilient, biodiverse, climate-adaptive, and socially sustainable urban environments in Sweden through the lens of VUE.

Using Stockholm’s MHP neighbourhoods, and Tensta in particular, as a case study, the thesis investigates the ecological potential of the existing built environment and examines how planning frameworks, governance structures, and implementation mechanisms may support or constrain its activation.

Rather than seeking to validate a predetermined solution, the thesis adopts an exploratory approach.
It investigates opportunities, limitations, and possible implementation pathways while examining how ecological functions may be integrated into existing urban structures and contribute to ongoing discussions surrounding sustainable urbanisation.

4. Research Questions*

The thesis is guided by the following overarching question:

*To what degree can the Swedish built environment contribute more actively to urban ecological functioning through the integration of Nature-Based Solutions?

This question is explored through four supporting questions:

*Why are building-integrated Nature-Based Solutions relevant within the Swedish and Nordic planning context?

*Why do Stockholm's Million Housing Program neighbourhoods represent strategic opportunities for ecological retrofitting?

*How can the ecological potential of façades, roofs, and other building-envelope surfaces be identified and evaluated?

*What opportunities, limitations, and governance challenges emerge when translating Vertical Urban Ecology into implementable design proposals?

5. Methodology and Data Selection*

This thesis is structured as a mixed qualitative research, combining literature review, policy analysis, spatial analysis, design exploration, and physical prototyping. The methodological structure gradually moves from broad theoretical discussions on NBS towards the detailed investigation of a specific urban context in Stockholm resulting in the development of concrete spatial implementation scenarios, and finally ending in recommendations for addressing structural challenges in Sweden's built environment.

5.1 Literature Review

The first phase of the research consisted of an exploratory literature review aimed at understanding the ecological, climatic, social, and economic implications of building-integrated NBS. Particular attention was given to green roofs, green façades, living wall systems, and emerging discussions surrounding urban ecology and ecological urbanism.

Literature was identified through systematic searches conducted in Web of Science, Scopus, and Google Scholar between January and April 2026. Search strategies combined keywords related to urban ecology, architecture, biodiversity, Nature-Based Solutions, and building-integrated vegetation. Additional sources were identified through citation tracking and reference-list screening.

In the literature review I primarily focused on peer-reviewed journal articles published during the last fifteen years, although some seminal publications and foundational theoretical works were also included when considered relevant. My main intention was to identify the most documented benefits associated with building-integrated NBS. This theoretical synthesis further established the scientific foundation of the thesis and provides the conceptual and empirical basis for the later spatial investigations, and design explorations.

The literature review therefore functions not only as a contextual background, but also as the primary framework for analytical parameters, through which the later pilot projects, and mock-up were interpreted and developed.

Four principal search strings were deployed in the online database search process:

Search String 1: Vertical Urban Ecology

("urban ecology" OR "urban ecosystem*" OR "urban biodivers*")
AND
(vertical* OR "three-dimensional" OR "building envelope" OR facade* OR façade*)
AND
("green infrastructure" OR "nature-based solution*" OR "ecological infrastructure")

Search String 2: Architecture-Landscape Integration

(architecture OR "landscape architecture" OR "urban design")
AND
(integrat* OR hybrid* OR cross-disciplinary)
AND
(ecolog* OR biodivers* OR "urban nature")

Search String 3: Vegetation-Integrated Architecture

("green facade*" OR "green façade*" OR "living wall*" OR "vertical greenery system*")
AND
(building* OR architecture OR "built environment")
AND
(biodivers* OR habitat* OR ecolog*)

Search String 4: Vertical Green Infrastructure and Climate Adaptation

("green infrastructure" OR "blue-green infrastructure" OR "nature-based solution*")
AND
(vertical* OR facade* OR roof*)
AND
("climate adaptation" OR microclimate* OR "urban heat island")

5.2 Policy and Planning Analysis

The second phase of the research focused on urban policy and planning frameworks within a Nordic context. Given that much of the international literature on building-integrated NBS originates from regions with different climatic conditions, urban densities, and governance structures, this phase critically examined the relevance and potential value of VUE within Sweden and the wider Nordic region.

Accordingly, both regional and municipal planning documents were reviewed to investigate how NBS are currently positioned within Stockholm's planning framework and to what extent existing policies support, encourage, or constrain their implementation within the built environment. Particular attention was given to Stockholm's Regional Development Plan (RUFS), municipal environmental strategies, green infrastructure policies, and climate-adaptation frameworks.

5.3 Case Study Selection

In the third research phase I investigated the ecological, social, and spatial conditions that make Stockholm's MHP neighbourhoods relevant contexts for ecological retrofitting. Particular emphasis was placed on understanding the history and current challenges of these areas, along with a brief analysis of the municpal policies in regards to green-space provision. Additionally also the current status of renovation practice in the Swedish rental housing stock was examined.

After reviewing several MHP housing areas in Stockholm, Tensta was selected as a case study because it combines several characteristics that make it particularly suitable for investigating the potential of VUE. As one of the most densely built MHP districts in Sweden, it contains extensive building-envelope surfaces and large-scale residential typologies that offer significant opportunities for building-integrated NBS.

Beyond its physical characteristics, Tensta occupies a strategic position within the Stockholm region. Located adjacent to the Järvafältet green wedge and embedded within broader regional ecological networks, the neighbourhood offers opportunities to explore how building-integrated greening might complement existing landscape-scale ecological structures. Simultaneously, Tensta remains central to ongoing discussions surrounding urban regeneration, socio-economic inequality, territorial stigma, and future densification.

Therefore the area provides a particularly relevant context for investigating whether ecological retrofitting can contribute not only to biodiversity enhancement and climate adaptation, but also to broader ambitions regarding environmental quality, and social sustainability within a district undergoing significant physical and social transformation.

-

At the neighbourhood scale of Tensta, aerial imagery, and digital three-dimensional modelling were used to quantify existing land-cover and to investigate the spatial capacity of buildings to host NBS. This process resulted in the development of a Vertical Capacity Model (VCM), an exploratory analytical framework used to compare horizontal and vertical greening opportunities.

Additionally, multiple site visits were conducted between February and May 2026 in order to document spatial conditions, building typologies, public spaces, existing vegetation, renovation activities, and everyday interactions between the built environment and urban nature. These site observations also informed the selection of pilot-project locations and helped to visually identify practical opportunities and constraints that were not visible through remote analysis.

5.4 Research-by-Design, Pilot Projects and Prototyping

The final phase of the research employed a research-by-design methodology. A series of pilot projects were developed to explore how theoretical insights, policy frameworks, and spatial analyses could be translated into concrete implementation scenarios.

Rather than functioning as definitive design solutions, the pilots were conceived as exploratory implementation scenarios through which different dimensions of VUE could be tested. Together they investigate a range of ecological, spatial, social, technical, and governance-related questions which are summarized in case-specific analytical frameworks which can be linked back to the parameters from the first chapter.

Each pilot is further based on existing case-studies which are formulated under "learning from others". Additionally, two informal expert interviews were conducted with actors relevant to the specific cases. The interviews were primarily used to gain insight into practical implementation challenges, maintenance requirements, governance structures, economic considerations, and stakeholder perspectives and helped to bridge the gap between theoretical potential and practical feasibility.

To complement the design proposals, a full-scale living wall mock-up was constructed in which questions of construction, materiality, maintenance, biodiversity support, and possible bottom-up governance approaches were more closely explored.

6. Contribution to planning and design for sustainable urbanisation*

In essence, this thesis explores the extent to which the Swedish urban built environment may be reconsidered as a host for ecological processes and how this perspective might complement existing approaches to urban greening, climate adaptation, and neighbourhood regeneration.

Within the context of sustainable urbanisation, the thesis will therefore hopefully contribute to ongoing discussions concerning how cities can accommodate continued growth and densification while simultaneously enhancing biodiversity, environmental quality, climate resilience, and human well-being.

Ultimately, the thesis should be understood as an exploratory investigation rather than a prescriptive framework. Its intention is not to prove the validity of an ideological "green" vision, but to open a discussion regarding the ecological potential embedded within the built environment.

More specifically, it proposes Vertical Urban Ecology as a lens through which planners, designers, residents, building owners, and policymakers may identify new opportunities for ecological retrofitting within their everyday urban surroundings.

CHAPTER 1:

A Summary on Nature-Based Solutions (NBS)

This chapter explores how building-integrated Nature-Based Solutions can contribute to biodiversity, climate adaptation, and human well-being, while establishing the theoretical foundation for Vertical Urban Ecology.

1.1 Introduction to Nature-Based Solutions in Urban Planning and Environmental Policies

The concept of Nature-Based Solutions (NBS) has grown to become a central topic in global urban policy and science communities in the last decade. The term was first mentioned in a 2008 World Bank report regarding biodiversity and climate change, where after the International Union for Conservation of Nature (IUCN) formally introduced the concept at the COP 15 in Copenhagen, proposing it as a solution for climate change mitigation (COP 15 | UNFCCC n.d.).

As an umbrella concept, NBS are intended to encompass a wide range of sustainability interventions that employ natural processes and ecosystems, integrating existing approaches such as ecosystem services and green-blue infrastructure, while also incorporating assessments of the social and economic benefits of resource-efficient and systemic solutions (See Figure 1.1). Generally they are aimed at providing a broad set of services such as carbon storage, water flow regulation, reduction of air pollution and mitigating urban heat, but they are also aimed at promoting mental health, physical activity, social capital, and other cultural values (Cohen-Shacham et al. 2016; Scott et al. 2016).

At a project scale, NBS in cities include a range of interventions that work with natural processes, such as tree canopies, blue-green corridors, and various water-sensitive design features (See Figure 1.2) (Warner et al. 2025). In addition, green roofs, green walls, and planted balconies have proven to be effective alternatives to ground-based green spaces in contexts where urban space is limited. These approaches were also highlighted in the EU Biodiversity Strategy for 2030 (Lehmann 2021).

In the realm of urban planning and landscape architecture, NBS promote a perspective to move beyond the debate of land-sparing approaches of protection and preservation (Scott et al. 2016). Cities, with their diverse and often contested interests combined with limited space, can therefore act as laboratories for establishing multifunctional land-use and testing new governance structures within the domains of urban planning and design (Andersson et al. 2014).

Although the concept of NBS has been widely adopted by major research and innovation projects (Kabisch et al. 2016; Faivre et al. 2017; Lupp et al. 2020), they often remain outside the everyday work routines of many stakeholders. As a result, they are often not well integrated into planning and governance practices where knowledge is separated into "silos" between departments, disciplines, sectors, and jurisdictions (Clar et al. 2013; Pasquini & Cowling 2015; Timboe & Pharr 2021).

At the same time, while the concept is frequently presented as a multifunctional solution capable of simultaneously addressing climate change, biodiversity loss, and social well-being, several scholars have questioned whether such promises can always be realised in practice.

Hillier (2025), for example, warns that planning concepts such as NBS may become ideological fantasies when their anticipated benefits are accepted uncritically and detached from the political, economic, and institutional realities of implementation. This suggests that the success of NBS should not be assumed a priori, but instead evaluated in relation to the specific social, spatial, and governance contexts in which they are applied.

The European Commission defines NBS as: "solutions that are inspired and supported by nature, which are cost-effective, provide environmental, social and economic benefits and help to build general resilience. These solutions bring more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." (European Commission 2015:24).

Figure 1.1. NBS umbrella concept, adapted from Cohen-Shacham et al. (2019).

Figure 1.2. Gottsunda dagvattenpark Sweden, an example of a NBS as water purification infrastructure, site visit with studio water environments SLU, September 2025.

In a recent study across three Southern European cities, Kauark-Fontes et al. (2023) examined the integration of NBS into urban policy and planning processes. The study highlights both the pathways that support the implementation and co-design of NBS, while also identifying gaps in integration that continue to hinder their wider adoption.

In their results, they concluded that all three cities incorporated NBS within their metropolitan and regional plans, but overall a clear definition of the concept is missing. Most municipal documents tended to refer to, and describe NBS, as urban forests, green space, urban greening, and urban nature; while cross-cutting policies such as resilience, climate change, or sustainability plans, presented the integration of the NBS.

Other findings revealed that several gaps still hinder the depth of NBS integration into urban policy. Environmental departments most commonly lead the development of NBS policies, while other departments (health, economic, education, and communication) tended to play more supporting roles.

The limited involvement of municipal education and communication departments proved particularly problematic, as it reduced opportunities to raise public awareness and communicate the benefits of these solutions.

Given the inherently multidisciplinary and place-based nature of NBS, their effective implementation requires cross-scale collaborative governance between public and private actors, as well as strong participation from local communities to enable transformative change and long-term management (Randrup et al. 2020; Dorst et al. 2022). Also a closer integration with economic realities is considered desirable (Teotónio et al. 2021).

Ongoing methodological advances advocate Living Labs, adaptive governance, and life cycle assessments to scale NBS in retrofit programs, ensuring that biodiversity co-benefits, climate adaptation, and social well-being are monitored, valued, and equitably distributed (Warner et al. 2025).

In conclusion, NBS are becoming increasingly important within Global and European climate and environmental policy. However, their successful implementation requires more than ecological ambition alone. The literature suggests that the long-term value of these solutions depends on their ability to translate environmental goals into socially equitable, economically feasible, and context-sensitive interventions.

Consequently, future research and practice should focus not only on expanding NBS, but also on critically examining the governance structures and societal assumptions through which they are realised.

1.2 Building-Integrated Nature-Based Solutions: A System Overview

The following overview introduces the most common building-integrated NBS typologies currently found in research and practice. Understanding their characteristics, opportunities, and limitations is essential for evaluating how different greening systems may contribute to Vertical Urban Ecology (VUE) and how they might be applied within the Swedish built environment.

As described by Perini et al. (2011), building-integrated NBS can generally be categorised into three main groups: green roofs (GRs), green façades (GFs), and living wall systems (LWSs). While these systems differ considerably in terms of technical complexity, maintenance requirements, ecological performance, and cost, they all share the ambition of integrating vegetation into the built environment and expanding the ecological functioning of buildings:

*1. Intensive Green Roofs**

Intensive GR's are generally referred to as roof gardens, designed with a considerable substrate depth (>15-20 cm), a wide variety of plants, high water retention capacity, and a heavy weight (180-500 kg/m2). Due to their increased soil depth, the plant selection can be more diverse, including small trees, shrubs, and bushes. Therefore, they usually also require a high level of maintenance. Their greater weight usually requires special structural attention as most existing roofs are not designed to hold such high surface loads. Additional reinforcement, drainage and irrigation must generally be utilized, increasing the technical complexity and associated costs. One of the main advantages of an intensive roofing system is their creation of a close-to-natural environment with high ecological and recreational values (Cascone 2019).

*2. Extensive Green Roofs**

Extensive GR's can be characterized by a shallower depth of substrate layer (<15cm) and therefore also a lower weight in comparison to intensive types. Extensive roofs can utilize only limited species of plants, such as grasses, mosses, and succulents, which is why this type of GR is often referred to as a "sedumroof". The main advantages of extensive roofing systems are their relatively low capital cost, maintenance and irrigation requirements, compared to intensive roofs. They are usually lightweight and directly applicable to new or existing buildings without additional structural support. Furthermore, these systems can be installed on steeper slopes and their construction process is technically simple and appropriate for large-size difficult to access rooftops. Both the energy performance, ecological value, and storm water management potentials of extensive green roofs are relatively low (ibid.).

*3. Green Façades**

GF's make use of climbing plants planted in full soil or in planters at the base of building, which either grow and attach themselves directly to the building surface, or are indirectly supported by cables or trellis.

In the case of direct greening, climbers make use of adhesive rootlets or pads to anchor themselves directly to the facade surface. Species like Hedra helix or Hydrangea petiolaris produce aerial roots that grow out from the stem and secrete a glue-like substance, bonding to surfaces, forming thousands of micro-anchors across the wall; these climbers are most suited for rough-textured façades. Climbers like Parthenocissus tricuspidata send out tendrils that end in small pads which stick to surfaces via adhesion and pressure; these can also attach smoother surfaces.

Direct climbers are among the cheapest systems to obtain fast façade greening, but have to be planted with thought as they damage façades. Dense vegetation creates a humid micro-climate which can speed up material deterioration processes such as surface scaling or micro-cracking. Also panel joints, window frames, and sealants are generally vulnerable to these sorts of climbers, as they tend to crawl in the cracks, possibly creating structural damage over time (Perini et al. 2011).

In the case of indirect greening, vegetation is usually supported by cables or mesh. Twining climbers like Wisteria sinensis and Lonicera wrap their stems around these supports and grow in spirals around them. Climbers like Clematis use tendrils that grab onto supports, while sprawling climbers like roses just lean and sprawl over surfaces and need tying to go vertical. Multiple structural materials such as steel, wood, plastic or aluminium can be used as support, influencing the aesthetic, functional, and sustainable properties of the system due to different weight, profile thickness, durability and cost.

*4. Living Wall Systems**

LWS are generally constructed from modular panels, which contain a growing medium like soil, foam, felt, perlite or mineral wool. Depending on the substrate composition and irrigation system, different sorts of vegetation can be applied. The plant type for these systems is usually evergreens. The most common living wall systems are either based on plastic (HDPE) planter boxes filled with a soil-mixture, foam substrate with steel netting as support, or felt layers working as substrate, supported by a water repellent baseboard.

From a functional and economical point of view, LWS demand a more complex design and maintenance strategy, and are generally more expensive. However, the technology is still relatively new and research in the last few years has shown these systems hold serious ecological, technical (water buffering, filtration,etc.) and creative (aesthetic) potential (ibid.).

1.3 Building-Integrated Nature-Based Solutions: Key Benefits

In order to better understand the potential of building-integrated NBS, this section draws upon the systematic literature review conducted by Kandel and Frantzeskaki (2024). In their review, 222 scientific studies examining building-integrated NBS were analysed in order to identify the most consistently documented benefits associated with these systems.

These categories serve a dual purpose within this thesis. First, they provide an overview of the principal ecological, social, and technical arguments supporting the use of these solutions. Second, they form the analytical framework that is later used to evaluate the pilot projects and implementation scenarios developed in Chapter 06.

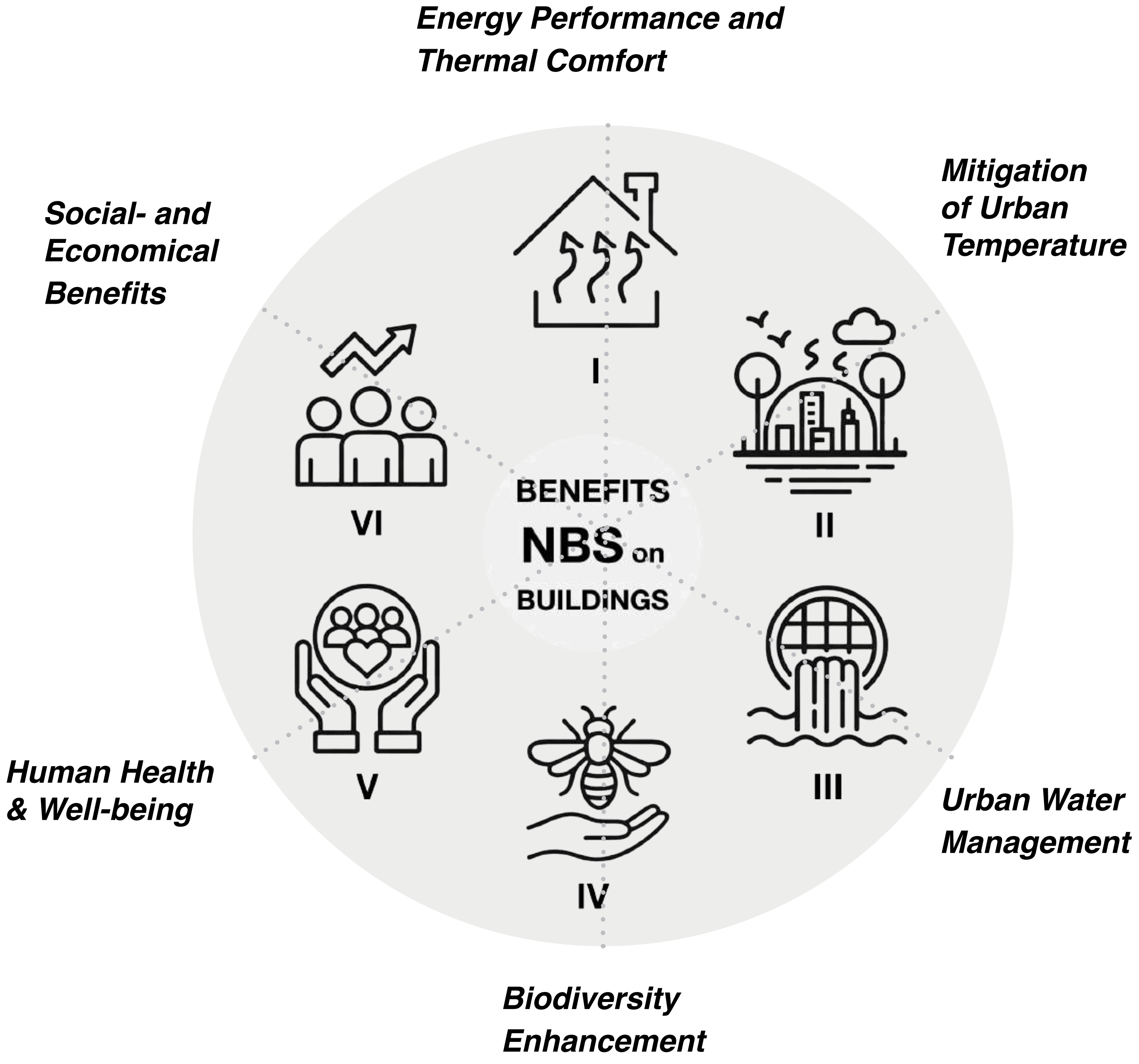


Figure 1.3. Analytical framework highlighting the six main benefits in regards to NBS on buildings.

I.

Energy Performance and Thermal Comfort

An abundance of studies have proven that NBS on buildings have a positive impact on the inertial potential of structures, both reducing external and internal surface temperatures during the summer months, as well as in isolating the building envelope during colder seasons. This generally has a positive impact on the thermal comfort within buildings, but also reduces energy consumption for space cooling and heating.

The thermal performance metric which is most commonly used to measure the impact of NBS in regard to thermal performance, is the building exterior surface temperature. Here it is important to mention that this metric can be misleading, because differences in orientation, building construction and materials lead to varied heat transmission coefficients (Kontoleon & Eumorfopoulou 2010).

By implementing GR's and VGS on buildings, the external surface temperatures tend to decrease in all climates and for all different structures that were studied in the review (Kandel & Frantzeskaki 2024). In comparison with the surface of a concrete roof, a GR can lower the outdoor surface temperature by 35°C in a temperate climate (He et al. 2017). The temperature of the indoor surface could be reduced up to 20°C compared to the internal surface of a conventional roof (Hao et al. 2022).

A Venetian field measurement campaign, studied and determined that the impact a living wall can have over the back wall is depended on multiple variables, being (1) the protection effect from the external solar radiation, (2) the wall orientation, (3) the kind of wall over which it is installed (i.e. insulated wall vs a massive wall). (4) plant parameters, such as evapotranspiration rate, Leaf Area Index (LAI), solar absorption coefficient and emissivity of the vegetation, etc.

In their conclusion, best cooling results were obtained with massive south-facing walls where the reduction of the cooling energy reached values of about 66% for Northern Italian latitudes. Much lower benefits were found on well insulated building envelopes. In these cases the reduction was only around 2% in the case of externally insulated walls and around 5% in the case of internally insulated walls (Mazzali et al. 2012).

During wintertime, Stella and Personne (2021) measured in a temperate climate that semi-extensive GR's could hold higher temperatures than a bare roof and an extensive green roof. Thicker soil-packages on GR's have therefore been proven to help with isolating the roof slab. However, the behavior of NBS on buildings, and especially of VGS, during the cold season are much less documented and need additional research.

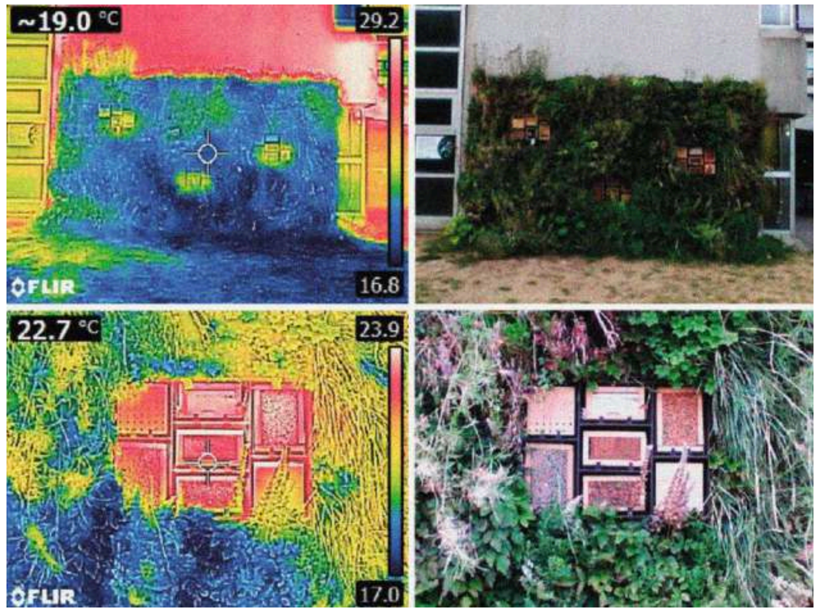


Figure 1.4 Thermographic image of a living wall mock-up (Krause et al. 2023:48)

II.

Mitigation of Urban Temperature

In urban areas, natural vegetation is often replaced with a complex, three-dimensional impervious cityscape that absorbs large amounts of solar radiation during the day, accordingly this energy is slowly released at night, keeping urban areas warmer than the surrounding rural areas. This leads to so-called Urban Heat Islands (UHI's) (Oke 1982).

The implementation of NBS on buildings can decrease the temperature of the exterior air, meaning that they can help balance urban micro-climates.

To mitigate urban heat, widespread implementation of Urban Green Infrastructure (UGI) is required, which one can define as a network of planned and unplanned green spaces, spanning both public and private realms. UGI can include greenery found in urban parks, private gardens, golf courses, tree lanes, remnant native vegetation, biofilters, rain gardens, and within NBS on buildings such as GR's and VGS (Lovell & Taylor 2013).

Norton et al. (2015) conclude that UGI research is currently not very well integrated within urban planning, and provides us with a decision framework to implement UGI more effectively (See Figure 1.5). They describe that the character of the urban landscape with already existing UGI and built structures plays an important role as the width, height, geometry, and orientation of street canyons influence urban micro-climates.

Further they recommend to primarily add green roofs to larger, low buildings, or in areas with limited ground level green open space, as modelling suggests that they mainly provide cooling on a neighbourhood-scale when covering larger surfaces (Gill et al. 2007), and since their influence on cooling at street level is rather minimal (Ng et al. 2012). Additionally, GR's have proven to reduce surface temperatures best when covered in taller vegetation (Lundholm et al. 2010) and when regularly irrigated (Liu & Bass 2005).

GF's, defined as climbing plants grown up a wall directly or supported by a structure set away from the wall, either planted directly in the ground or in planter boxes (Hunter et al. 2014) are presented as a realistic option for widespread UGI implementation because of their low installation and maintenance cost (Ottelé et al. 2011).
They primarily prevent heat gain to building walls but can also provide cooling effects through the process of evapotranspiration (Köhler 2008).

In narrow urban canyons, where there is adequate light, green façades can be employed to both save space and to allow better ventilation and long wave cooling at night. (Rayner et al. 2010).
To gain the most effect, growing vegetation on dark coloured walls of older uninsulated buildings is to be prioritized over light coloured or reflective walls of newer developments in terms of efficiency (Kontoleon & Eumorfopoulou 2010).

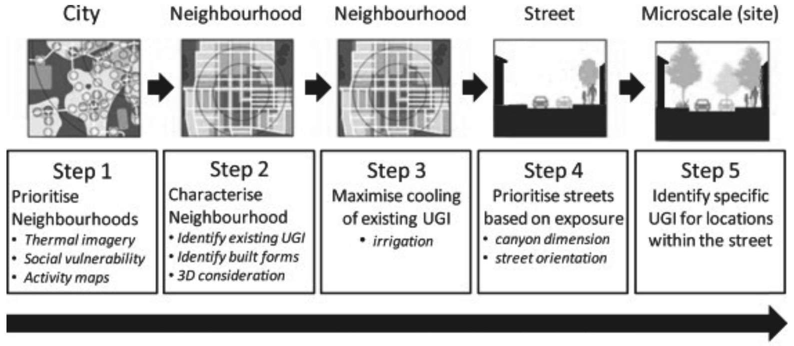


Figure 1.5. Prioritisation framework for optimising UGI cooling benefits (Norton et al. 2015:129)

III. Urban Water Management

The expansion of impervious surfaces in urban environments tends to lead to increasing flood risks, deteriorating water quality in receiving water bodies, erosion of urban streams, and pressure on aging drainage infrastructure (Nizamani & Torgersen 2025). The economic impacts of urban flooding with annual damages estimated to exceed tens of billions of dollars globally, highlight the urgent need for innovative and sustainable solutions (Agonafir et al. 2023). Field studies have proven that both GR's and VGS can play their role in reducing, buffering, and filtering urban runoff.

Hydrological Key Performance Indicators (KPI's) are reported in most studies, including metrics such as runoff reduction, retention volume, peak flow attenuation, and time-to-peak delay. They all reflect the system's ability to intercept, store, and gradually release rainfall. (Nizamani & Torgersen 2025).

Perales-Momparler et al. (2017) observed a seven times greater reduction of runoff from buildings with a GR compared to a conventional roof in a temperate climate. The greatest retention rates for GR's are generally observed for light rainfall events (96% on average), this percentage drops to 27% with heavy rainfall events (Abualfaraj et al. 2018). The presence of vegetation on GR's has also proven helpful in removing pollutants and improving the water quality by reducing the total amount of suspended solids, organic pollutants, and balancing nitrogen and phosphorus concentrations (Liu et al. 2021).

Implementation of VGS, specifically for stormwater management tends to be less common, as their hydrological efficacy is less of a universal constant and rather dependent on local climatic conditions, system typology, functional traits of vegetation, and substrate composition (Nizamani & Torgersen 2025).

However, the amount of vertical surface area, especially in urban settings, will always exceed available roof area, meaning that there is literally more area for storm water management on walls than on roofs; which suggests that serious consideration of green walls for water management makes good sense (Kew et al. 2014).

The hydrological principle of VGS in water management, is primarily based on how vertical vegetation and the substrate it is rooted in, intercept precipitation, thereby reducing the kinetic energy of raindrops and delaying runoff. The water which is retained in the substrate is subsequently released through the process of evapotranspiration, which completes the hydrological cycle (Pirouz et al. 2020). Beyond volume reduction, VGS also have shown to improve water quality by filtering sediments, absorbing pollutants, and supporting microbial communities that break down contaminants (Pucher et al. 2022).

Green façades grown on trellis systems, as studied in the UK, excel in rainfall interception and evapotranspiration, effectively delaying and reducing runoff volume with generally lower maintenance and cost requirements (Tiwary et al. 2018). However, living Walls with integrated substrate layers on the facade, tend to offer more possibilities regarding retention volume and water treatment (Nizamani & Torgersen 2025).

Living walls can for instance function as vertical bioreactors by closing water loops and delivering year-round benefits, especially when irrigation and precipitation water is collected in closed cisterns and recycled (See Figure 1.6).

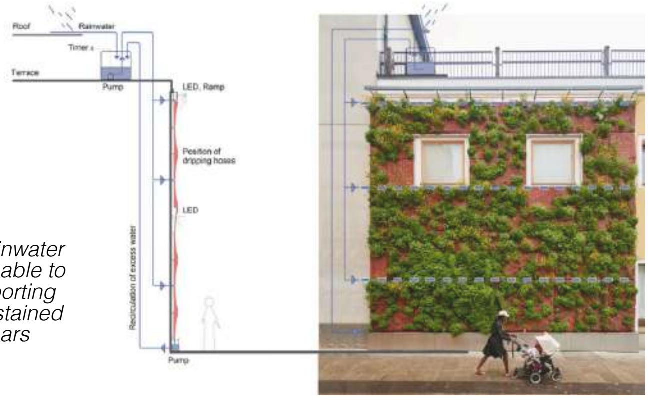


Figure 1.6. Pável Carpenter's Alley Uppsala, Sweden. This living wall demonstrates how an engineered rainwater capture and drip irrigation system is able to overcome rainfall dependency, supporting full vegetation establishment and sustained hydrological function over several years (Butong 2020).

IV. Biodiversity Enhancement

When studying the influence of urbanization on biodiversity, impacts such as habitat loss and fragmentation, changes to resource availability, alteration of local climates, modification of natural disturbance regimes, introduction of exotic species, and increased levels of artificial light and noise pollution often become part of the discussion (Grimm et al. 2008). Most of these phenomena tend to lead to a reduced number of species, genetic diversity, and biotic homogenization (McKinney 2006). As biodiversity underlies many of the ecosystem services improving human well-being, its decay evidently also has negative consequences for humans themselves (Reid et al. 2005).

The possible role of NBS on buildings within biodiversity enhancement also has been proven in multiple studies, where both GR's and VGS have shown improvement of both fauna and flora species in urban areas, mainly due to the presence of vegetation and habitat aids on the building envelope.

In a systematic search of scientific literature on the qualitative and quantitative evidence of ecological gains through GR's and VGS, Tiago et al. (2024) analyzed a total of 75 publications from 2006 to 2024, focusing on the advantages for arthropods, bats, and birds. From their bibliographic research, they identified a significant increase in publications in 2022, which might indicate a growing interest in these structures for biodiversity. They identified the benefits most mentioned by authors for the three taxonomic groups were habitat creation, species diversity, and connectivity.

Biodiversity & Green Roofs*

Using GR's as supportive habitats for insects has gained significant attention in policy strategies, such as the EU biodiversity strategy (Knapp et al. 2019) as their decline leads to profound and irreversible impacts at all levels of ecosystem organization. GR's can serve as steppingstones for a variety of insect species and help strengthen the ecological network throughout cities by connecting it with existing natural areas (Leather 2018).

Insect diversity on GR's seems to depend mainly on the substrate quality & diversity, and the structural complexity of the vegetation (Lepp 2008). Also, the presence of flowering plants has proven to be important (Jacobs et al. 2023). Both substrate and vegetation depend on the type of GR, usually classified as extensive or intensive roofs, but sometimes also named after their functionality. Other factors like the height of a building, distance to ground-level green areas, percentage of green area in the surrounding and the roof age also play their role, but findings are often inconsistent, likely due to the high variability among roof typologies (Drukker et al. 2026).

Apart from insects, there has been a growing interest in arthropod diversity research (Wang et al. 2022), as they form important indicators for ecological performance. The richness and diversity of arthropods tends to increase with higher vegetation cover, roof size and age, connectivity with other habitats, vegetation complexity, and greater substrate depth (Schindler et al. 2019).

Figure 1.7. A green roof on top of the Ohboy Hotel, Malmo Sweden, study trip urban ecology course SLU, May 2025.

Biodiversity & Vertical Green Structures*

Although the literature regarding VGS and biodiversity is more limited, I noticed an increased amount of recent studies examining the influence of green façades on the richness of mammals, birds, and invertebrates. Green façades (GF's) are considered the highest-ranking among different types of green wall systems in terms of benefits and drawbacks, although they are surpassed by hydroponic or cassette systems in terms of biodiversity (Perini & Rosasco 2013).

In a recent study from Poland, it was found that the implementation of GF's significantly enhances species' biodiversity compared to non-vegetated walls. Especially for insects and synanthropic birds, GF's can be qualitative habitats providing nesting, shelter, and foraging opportunities (See Figure 1.8). The study analysed on a total of 20 objects (including walls, hedges and building façades) that the diversity of invertebrates was greater on surfaces with climbing vegetation, then on those without.

Additionally, a strong correlation between the age of creeping plants and the number of bird nests seemed to exist. The highest number of nests was observed on more mature climbers (usually older than 10 years), additionally, nesting was not limited solely to the higher parts of the facades, as the lowest nest of a Blackbird was located at only 1m above ground level (Ołoś 2024).

Birds such as House Sparrows (Passer domesticus) , Blackbirds (Turdus merula) , Eurasian collared dove (Streptopelia decaoct) , and Common wood pigeon (Columba palumbus) were observed nesting, while redstarts and great tits were observed foraging for small invertebrates.

Boston ivy (parthenocissus tricuspidate), common ivy (hedera helix) and virginia creeper (parthenocissus quinquefolia) were most common climbers on the observed sites. As Boston ivy generally formed the densest and vertical thickets vine-network, it was consequently most preferred for nesting. Moreover, the fruits of this climber provided food for all local thrush species in winter (ibid.).

Another German field study, highlights the importance of plant composition, structural richness, and other factors, such as micro-climate in relation to improving the interplay between VGS and biodiversity. Many species typically require heterogeneous micro-structures, consisting of mineral and organic cavities, as well as sandy and loamy areas for brood laying. Although scientific studies, practical examples, and recommendations for promoting structural richness on horizontal surfaces exist, they are rarely applied to green façades (Krause et al. 2023).

Figure 1.8. A multitude of birds' nests within the bare branches of the climbing vegetation in the Linneanum orangery, Uppsala Sweden, February 2026.

V. Human Health & Well-being

Most of the human health benefits related to NBS in cities, can be linked to (1) access and interaction with nature, (2) temperature and pollution control, (3) noise reduction, and (4) how Urban Green Infrastructure (UGI) influences our psychological well-being. Since NBS on buildings tend to be physically less accessible, I will mainly focus on heat mitigation, air quality control, noise reduction and biophilic design principles, since gains related to physical movement are not as applicable here.

Heat Mitigation*

Generally, health impacts related to high urban temperatures are well documented in medical literature, e.g., (Shattuck & Hilferty 1933; Gover 1938; Basu 2009). The human body reacts to elevated temperatures by increasing blood supply to the skin in order to dissipate excess heat, and by producing sweat to cool the skin. This leads to an increased cardiac demand for oxygen which can result in cardiovascular collapse.

Also hyperventilation, pulmonary stress, heat strokes and dehydration, are common health risks related with urban heat. Specifically vulnerable population groups, such as children, elderly, or people with pre-existing conditions are susceptible to becoming victims of these heat related health risks (Crandall & González-Alonso 2010). Since I already discussed the possible advantages of NBS on buildings, in relation to thermal comfort and urban heat mitigation in the first two paragraphs, I will not further elaborate on them here.

Airquality Quality Control*

A second major contributor to human health issues in cities is air pollution, which includes particulate matter (PM), volatile organic compounds, ozone, carbon monoxide, sulphur oxide and nitrogen oxide (Piracha & Chaudhary 2022).

The main sources are traffic, heating, cooking, industrial processes and power generation. Transport related air pollution is however the biggest culprit in developed countries (Awais Piracha & Marotullio 2003) causing 3.5 million premature deaths in 2017, induced by respiratory infections, diabetes, cardiovascular disease, lung infection, obstruction and cancer (Climate & Clean Air Coalition 2019). More recent studies even indicate links between air pollution and poor mental health (Bhui et al. 2023).

Studies on air pollution dispersion show that vegetation barriers can significantly improve air quality near busy roads, with effectiveness depending on factors such as leaf size and texture, vegetation height, density, and planting design. Research by Barwise & Kumar (2020) and Abhijith et al. (2017) found that tall, dense vegetation and species with rough leaves, such as the London plane tree, can reduce particulate pollution by over 50% in some environments.

In regards to NBS on buildings, VGS have been proposed as a possible solution to reduce PM, without altering the air exchange between the street canyon and the air above it (Litschke & Kuttler 2008). However there remains uncertainty regarding the effectiveness of vegetation removing ambient PM pollution, since results strongly depend on many spatio-temporal factors (Paull et al. 2020).

A more valid process of air purification is linked to VGS & intensive GR's and their ability to capture CO2, however, it is still unclear whether they can also remove ozone and nitrogen dioxide (Barmparesos et al. 2018).

Noise Reduction*

The hard surfaces of our cities reflect and enhance the sound of ground- and air traffic, industries, building sites, schools, public events,etc., but also environmental sounds such as wind or heavy rainfall. A third source of urban health issues can therefore be traced back to noise pollution, as it can disrupt sleep and work productivity, limit cognitive abilities, contribute to mental illness and can even be linked to cardiovascular disease (den Boer & Schroten 2007).

GR's have been proven to be effective in absorbing structure-borne sound, especially from the rain (Yuliani et al. 2021); while VGS can be used to absorb air-borne sounds that would otherwise be reflected between buildings. This effect is due to mechanical vibrations of plant elements induced by sound waves, leading to dissipation by converting sound energy to heat (Embleton 1963; Martens & Michelsen 1981; Tang et al. 1986).

A modelling study conducted by Patel and Boning (2016) predicted that green walls could reduce emergent and traffic noise by up to 10 dB, while Klingberg et al. (2017) found that traffic noise reduction is proportional to the depth of vegetation through which the sound passed.

*Psychological Well-being**

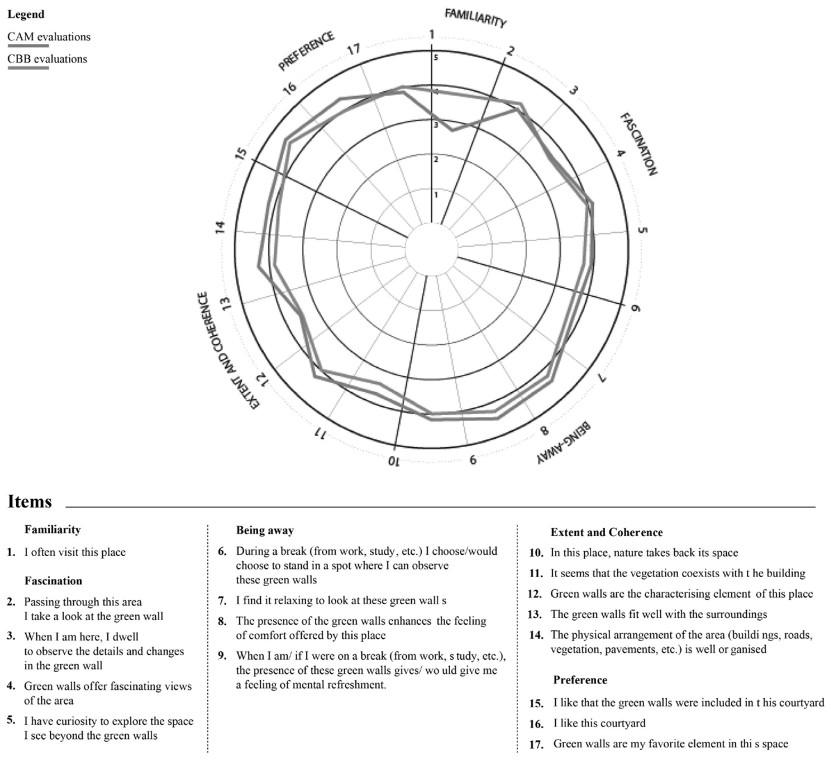
In the last ten years, the interest in greening building envelopes in support of psychological well-being and cultural services has been growing (Bustami et al. 2023; Ling et al. 2020; Ode Sang et al. 2022). Since NBS on buildings can hardly be compared to more traditional interventions of UGI such as parks (Dover 2015), it remains however difficult to assess the intangible benefits on people's perception.

In an Italian-Portugueze study, Molari et al. (2024) investigate the restorative capacity of a green facade located in Turin, meant to improve the physical and cognitive health of students and workers, and a living wall in Lisbon related to the topic of sustainable museums within the framework of Lisbon European Green Capital 2020.

They discuss that one main group of researchers tends to focus on quantitative assessment by monitoring stress related parameters such as blood pressure, heart rate, and salivary alpha-amylase; while another group has been investigating the perceived well-being more qualitatively, through the use of questionnaires discussing liveability, perceived mental relief, sense of place etc.

In their analysis, they made use of the Perceived Restorativeness Scale (PRS) tool (See Figure 1.9), which allows them to define in a hybrid quali-quantitative way the sense of relief and restoration perceived by a person in response to a specific environment (Berto et al. 2018). Based on their results and the occurrence of high values for restorative factors such as 'familiarity', 'fascination', 'being-away',etc., they concluded that especially VGS pose a promising addition to other UGI, to effectively re-introduce vegetation and the feeling of nature in cities.

According to Collins et al.(2017), public awareness regarding the impact of urban green infrastructure on the quality of life and general biodiversity in cities ranges from 54% to 75%. Therefore, there is significant potential for raising awareness in regards to biophilic design and lifestyles, simultaneously generating large amounts of social capital (Mumaw & Bekessy 2017).



Items

Familiarity

1. I often visit this place

Fascination

2. Passing through this area I take a look at the green wall

3. When I am here, I dwell to observe the details and changes in the green wall

4. Green walls offer fascinating views of the area

5. I have curiosity to explore the space I see beyond the green walls

Being away

6. During a break (from work, study, etc.) I choose/would choose to stand in a spot where I can observe these green walls

7. I find it relaxing to look at these green walls

8. The presence of the green walls enhances the feeling of comfort offered by this place

9. When I am/ if I were on a break (from work, study, etc.), the presence of these green walls gives/ would give me a feeling of mental refreshment.

Extent and Coherence

10. In this place, nature takes back its space

11. It seems that the vegetation coexists with the building

12. Green walls are the characterising element of this place

13. The green walls fit well with the surroundings

14. The physical arrangement of the area (buildings, roads, vegetation, pavements, etc.) is well organised

Preference

15. I like that the green walls were included in this courtyard

16. I like this courtyard

17. Green walls are my favorite element in this space

Figure 1.9. Example of the Perceived Restorativeness Scale (Molari et al. 2024: 10).

VI. *Social- and Economical Benefits*

In general, studies have proven that by introducing every-day experiences with nature in the urban realm, we provide a parallel opportunity to re-enchant city-dwellers with plants, animals and their neighbouring communities. Re-naturing efforts may provide a common purpose which helps building a sense of community and belonging (Hartig et al. 2014; Rasidi et al. 2018; Shanahan et al. 2019).

*Wildlife Gardening**

The provision of habitat for native species on private or collective land, also known as wildlife, habitat, or ecological gardening; includes planting indigenous flora, nurturing indigenous regrowth, removing weeds, adding habitat aids, etc. (Goddard et al. 2010; Lindemann-Matthies & Marty 2013). Since complementary public and private conservation actions will be important to sustain native biodiversity in cities (Mumaw & Bekessy 2017), urban residents and their private or collective gardens and terraces can play an important supportive role in improving the landscape matrix, while simultaneously improving community social interaction.

In an Australian study, initiatives like the 'Knox gardening for wildlife program' have been proven useful in engaging a diverse group of residents in helping their council and community conserve indigenous biota. Successful features of this specific program included on-site garden assessment; an indigenous plant nursery hub; visible involvement of council and community; and a locality-based framework that encourages learning by doing (Mumaw & Bekessy 2017).

*Social, Economic and Environmental Justice Considerations**

A frequently cited benefit of urban greening initiatives is their capacity to improve neighbourhood attractiveness and perceived quality of life, while numerous studies have demonstrated that investments in urban green infrastructure can also lead to increased property values (Wolch et al. 2014; Baró et al. 2021).

These outcomes should not automatically be interpreted as socially or economically beneficial. Critical studies have increasingly highlighted how environmental improvements may contribute to processes of green gentrification, whereby ecological upgrades become associated with rising rents, increasing housing costs, and the displacement of existing residents (Anguelovski et al. 2019).

In such cases, the environmental benefits may disproportionately benefit newcomers and private investors, rather than the communities for whom the interventions were originally intended.

Consequently, NBS should not be evaluated solely through environmental performance indicators or economic returns. Questions concerning accessibility, affordability, participation, and long-term housing security are equally important.

From this perspective, NBS should be understood not as socially neutral interventions but as spatial investments with potential distributive consequences. Their implementation therefore requires careful consideration of environmental justice principles and, where appropriate, complementary measures that safeguard affordable housing and protect existing residents from displacement pressures.

This is particularly important in the context of Sweden's MHP neighbourhoods, where public and affordable housing play a significant role, and ecological upgrading should contribute to improved living conditions for existing residents rather than becoming a mechanism through which vulnerable groups are indirectly displaced.

Rather than viewing increased property values as an objective or economical benefit in itself, this thesis considers the primary value of building-integrated NBS to lie in their potential to improve environmental quality, support resident well-being, strengthen local stewardship, and enhance everyday experiences of urban nature without compromising social inclusion.

Direct economical gains for residents from NBS on buildings are for the moment primarily to be traced back to the reduction of energy consumption (Lundholm et al. 2014; He et al. 2016; Fleck et al. 2022).

Some other studies mention how food production could generate income (Nagle et al. 2017), while Pérez-Urrestarazu et al. (2017) highlight high returns on investment for extensive green roofs but mention the payback time can be long.

Kandel & Frantzeskaki (2024) notice that the socio-economic benefits of NBS on buildings need more interdisciplinary research and need to be more systematically assessed. This to ensure financial feasibility and social equity in both planning, construction and maintenance processes.

1.4 Building-Integrated Nature-Based Solutions: How to Approach 3D Green Valuation ?

1.4.1 Conventional Green Space Metrics

Urban ecological performance is commonly evaluated through two-dimensional indicators such as Land Cover and Tree Canopy Coverage (TCC). These metrics have become widely adopted within planning practice because they provide relatively simple ways of assessing the quantity and distribution of urban greenery. Tree Canopy Coverage in particular has gained increasing attention through initiatives such as the 3-30-300 rule introduced by Konijnendijk (2021), which suggests that neighbourhoods should aim for approximately 30% canopy coverage in order to support climate adaptation, public health, and environmental quality.

Most scientific backing for the 30% figure comes from UHI studies. Research in cities across the globe have shown that cooling effects are negligible when canopy cover is below 15-20%. Once a neighbourhood hits 30-40% TCC, the cooling effect "accelerates." At this density, the individual "cool islands" created by trees merges (Ziter et al. 2019).

Also public health researchers have been looking for the minimum amount of nature required to lower stress and disease. One influential study by Astell-Burt et al. (2022), found that residents in neighbourhoods with 30% or more tree canopy had 31% lower odds of developing psychological distress compared to those in areas with less than 10% canopy. Other literature suggests that reaching a 30% canopy level correlates with meaningful reductions in cardiovascular risk factors, and obesity signals in many contexts, but the strength and universality of these associations depend on local factors such as equity of access, maintenance, species composition, and the spatial arrangement of canopy within neighbourhoods (Santamouris & Osmond 2020).

While 30% is the rule, many experts argue that for extreme heat mitigation in the face of climate change, we actually need 40%. The rule uses 30% because it is a "universal baseline", a floor rather than a ceiling (Ziter et al. 2019).

1.4.2 The Challenge of Valuing Building-Integrated Nature-Based Solutions

Urban Green Infrastructure (UGI) is typically understood as a network of natural and semi-natural areas that provide ecosystem services such as climate regulation, air purification, water management, and biodiversity support. Most of these services rely on inherently three-dimensional processes, including heat exchange, radiation balance, evapotranspiration, turbulent diffusion, sound absorption, and ecological connectivity (Norton et al. 2015).

Yet despite this three-dimensional functioning, urban ecological performance is still predominantly assessed through horizontal indicators. This raises an important question: how should building-integrated Nature-Based Solutions be evaluated when they operate across the volume of the city rather than solely at ground level?

Several cities and planning authorities have attempted to address this challenge through the development of more comprehensive ecological valuation systems:

1.4.3 Examplary Approaches to Three-Dimensional Green Valuation

1. Singapore: Green Plot Ratio (GnPR)

First, there is the approach based on vegetation's cooling capacity. Research such as studies by Wong et al. (2010) propose the use of the Leaf Area Index (LAI), which is defined as the single-sided leaf area per unit ground area. It is a dimensionless number that ranges from about 1-2 for grassland, 3 for small bushes, and 6 for trees. This index provides a valuation framework for greenery based on its structure and cooling capacity. The concept has moreover been formalised in Singapore's' Landscaping for Urban Spaces and High-Rises' (LUSH) programme (Zheng et al. 2024). From 2018, all new developments in key areas of Singapore must meet a minimum Green Plot Ratio (GnPR), defined as the ratio of the total single-sided leaf area of the planted landscape to the plot or site area (URA 2017).

2. Berlin: Biotope Area Factor (BAF)

Already in the early 90s,Germany developed a 'Biotop Flächenfaktor' or Biotope Area Factor (BAF). The BAF can be defined as the ratio of "ecologically effective areas" against a site's total land area, and therefore serves as a quantitative benchmark for safeguarding essential ecosystem functions such as micro-climate regulation, air hygiene, soil preservation, and habitat availability. The BAF employs a nuanced weighting system that assigns values to surfaces, based on their ecological significance. At the bottom of this scale are sealed areas, which receive a 0.0 weighting because they offer no water infiltration, air cooling, or habitat value; At the top of the hierarchy is vegetation connected to soil, which receives a full 1.0 weighting (Becker Giseke Mohren Richard Landscape Architects 1990).

3. Malmö & Stockholm's: Green Space Factor (GSF)

A third approach can be traced back to Malmö. Here a so-called Green Space Factor (GSF) was introduced in 2001 in connection with the Bo01, the international housing exhibition fair (Interlace Hub 2023). Following Malmö's success, Stockholm Stad developed its own version (Grönytefaktor för kvartersmark). The GSF used by Stockholm's and the German BAF are conceptually similar, but the weighting logic is quite different. The German system is very much surface based with each surface receiving a coefficient between 0-1, while the Stockholm system has a more layered approach where surface factors are added up with bonus points for biodiversity, social values, etc. The designer enters the area (or number of elements such as trees), multiplies it by the assigned factor, and sums all weighted areas to obtain the eco-effective area. (Stockholms stad 2015)

For this work, these examples are important because they reveal both the possibilities and limitations of current valuation methods. They suggest that future planning tools may need to move beyond conventional surface-based approaches and increasingly recognise façades, roofs, balconies, and other building-envelope surfaces as potential ecological infrastructure. This observation ultimately forms the methodological foundation for the Vertical Capacity Model (VCM) developed later in this thesis and the analytical framework used to evaluate the pilot projects.

Literature Review Discussion & Implications for VUE

When drawing a closure to this literature review on NBS, I conclude that NBS have become an increasingly important concept within contemporary urban planning, climate policy and environmental governance. However, despite their conceptual prominence, the practical implementation of NBS within everyday planning processes remains limited due to Institutional fragmentation, disciplinary silos, ownership structures, and difficulties in quantifying environmental benefits.

The review further suggests that many existing planning frameworks remain strongly oriented towards the city's ground plane. While considerable attention has been given to parks, urban forests, and green-blue infrastructure, the ecological potential of the built environment itself remains comparatively under explored. At the same time, the discussion of Tree Canopy Coverage, Green Plot Ratios, Biotope Area Factors, and Green Space Factors demonstrates a growing recognition that urban ecological performance cannot be understood solely through two-dimensional measures of land cover.

One of the central insights emerging from the literature is that the built environment potentially represents a substantial yet largely underutilised ecological resource. This observation forms the conceptual basis for what is described in this thesis as Vertical Urban Ecology (VUE): an approach that recognises buildings and infrastructure not merely as architectural objects, but as potential habitats, climate regulators, and active components within broader urban ecosystems.

As discussed by critical scholarship, planning concepts such as NBS risk becoming ideological fantasies when their anticipated benefits are accepted uncritically and when they are detached from the realities of implementation. The challenge therefore is not simply to demonstrate that building-integrated NBS can generate benefits, but to understand under which social, economic, and institutional conditions these benefits can be realised in practice. For this reason, the following chapters investigate how VUE might be implemented within a specific planning context.

CHAPTER 2:

Planning and Regulatory Analysis - Focus Stockholm, SE

This chapter investigates whether the arguments for Vertical Urban Ecology remain relevant within a Nordic context and how existing planning frameworks shape its implementation in Stockholm.

2.1 The Value of Vertical Urban Ecology in a Nordic Context

From a global perspective, it could be argued that the implementation of Vertical Urban Ecology (VUE) in Nordic urban landscapes, mostly dominated by small and medium-sized cities with a relatively sparse built environment and well accessible green areas (Randrup & Persson 2009), may have relatively limited impact on the big environmental challenges we're facing today.

From a statistical point of view, this might be a valid comment, however, the value of studying VUE in the North does not lie simply in its local environmental impact, but also in its potential to serve as a research and development platform for broader global applications. Many projects throughout Sweden, Norway, Finland, and Denmark provide successful examples of how cities can ensure exposure to, accessibility of, and engagement with green outdoor environments. Nordic cities are also frequently highlighted as global leaders in creating conditions that support equality, well-being, and quality of life, and they often rank highly in international networks and initiatives promoting healthy cities and age-friendly cities (WHO, n.d.-a; WHO, n.d.-b).

That being said, also in Nordic capital cities high levels of social and spatial segregation have been reported, together with recent large scale urban densification and renovation agenda's leading to generally less urban green space and social gentrification (Randrup et al. 2020; Andersson et al. 2011; Næss et al. 2007; Tunström & Wang 2019). Additionally, Kandel & Frantzeskaki (2024) concluded in their literature review, that the behaviour of NBS on buildings, and especially of VGS, during cold seasons is currently under documented.

All these trends bring challenges and rationale for developing experimental forms of NBS in Nordic cities.

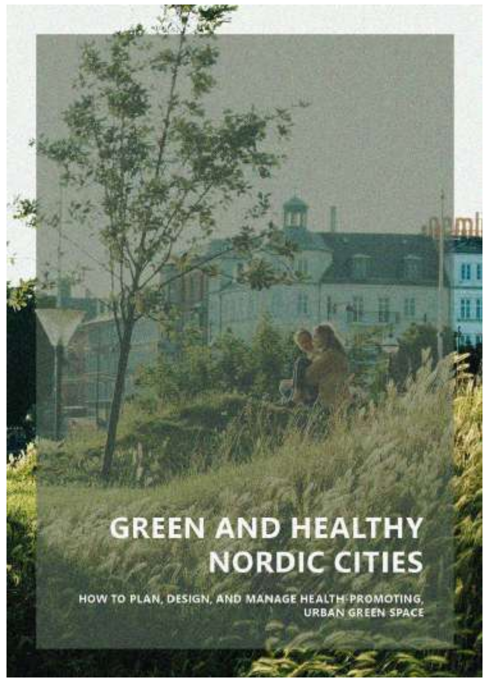


Figure 2.1. Cover of the Nordgreen Handbook (Nordregio et al. 2024).

Figure 2.2. Map of the participating Nordgreen countries & municipalities, adapted from (Nordregio et al. 2024:14).

Nordic research initiatives such as the Nordgreen project (2020-2023), demonstrate the presence of a stable institutional, technological, and planning environment in which new forms of nature-based infrastructure can be tested, monitored, and evaluated over time.
In 2024, the Nordgreen project published a handbook (See Figure 2.1) for delivering health promoting urban green space. This book presents the background on the evidence linking green spaces and health, practical tools for planning, designing, and managing green spaces, along with various methods, models, examples and guidelines for delivering health- promoting green space (Nordregio et al. 2024).

Although the Nordgreen study primarily addresses a human perspective to green space provision, which represents only one component of the broader concept of VUE, its insights remain highly relevant for informing decision-making processes related to the implementation of NBS in cities. In particular, the project's data sources, research methods, and understanding of the Nordic planning system.

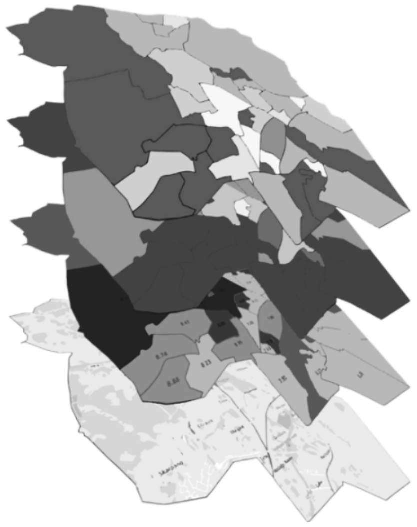


Figure 2.3. Stacking multiple green space indicators in order to find areas that need particular attention when developing health-promoting muncipalities, adapted from (Nordregio et al. 2024:46).

Nordgreen acknowledges that decisions regarding green space provision in northern municipalities are often driven by public expectations or political priorities. This can result in inefficient and ineffective planning practices. Therefore, planners require more multidisciplinary knowledge and analytical tools to map, monitor, and assess green spaces in relation to a wider range of parameters. The study further highlights that combining different green space indicators with social, economic, and health-related parameters could help planners more effectively justify targeted interventions and planning measures. (Nordregio et al. 2024)

Although green space indicators are generally familiar to planners, there remains a broader need for increased knowledge regarding both the evaluation and implementation of indicators originating from disciplines outside their own field (ibid.). Stacking map layers of different indicators (green space, local health data, actual and perceived access to green space, and perceived levels of well-being) (See Figure 2.3) has proven effective in finding potential challenges in the physical environment. However, the available GIS data often lacks detail about the quality of green spaces, and national health statistics are often too coarse. Therefore, Nordgreen emphasizes the need for planners to conduct local fieldwork and qualitative assessments, and to supplement existing surveys with local questions to obtain finer, district-level insights. (ibid.).

Another essential topic from the handbook, revolves around Nordic planning legislations (See Figure 2.4). Nordgreen emphasised that in Nordic contexts, municipalities can often make decisions without extensive interference from regional or national levels, leading to a variety of organisational structures. However, there are usually three recurring levels to be differentiated: (1) the policy level of vision development and goal setting, (2) the tactical level of institutional development and functioning, and (3) the operational level of implementation. These levels are usually translated into comprehensive plans (political long-term ambitions and large-scale priorities for the entire municipality), detailed plans (tactical level), and short-term operational plans (maintenance related) (Randrup & Jansson 2020; Singh et al. 2021).

Programmatic alignment occurs when both the horizontal components (the connections across departments at the same organisational level) and vertical components (the linkages between organisational levels) collaborate on a specific issue (See Figure 2.4) (Nordregio et al. 2024).

This multi-level coordination is particularly relevant for the implementation of NBS in northern cities, where climate adaptation, biodiversity goals, public health, and long-term maintenance responsibilities must be integrated across multiple planning sectors and governance scales.

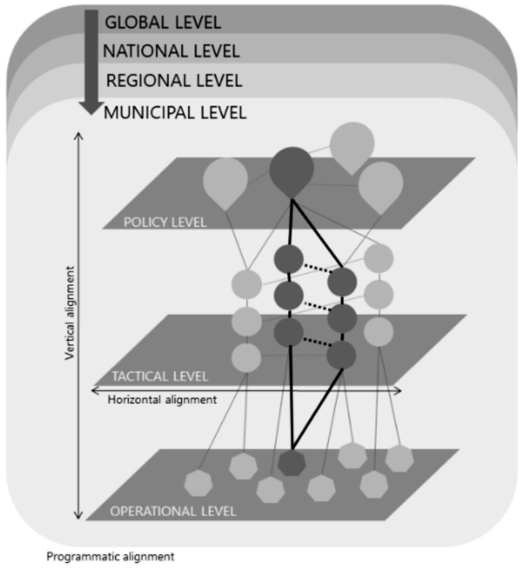


Figure 2.4. Horizontal, vertical and programmatic alignment of the three organisational levels in Nordic municipal organisation, adapted from (Nordregio et al. 2024:72).

Based on Nordgreen's research, I concluded that from a planning perspective, the autonomous organisational structure of Nordic municipalities along with relatively coarse data-sets, would make it challenging to implement nationwide NBS in Nordic countries like Sweden. Additionally my literature review pointed out that the design and effectiveness of NBS is also strongly contingent upon local spatial and climatic circumstances.

Therefore, I have decided to narrow the scope of my further research to my nearest metropolitan region: Stockholm County. Stockholm represents nearly one quarter of Sweden's total population with approximately 2.45 million inhabitants (SCB 2023). This makes it the largest city in the Nordic region and by far the most densely populated and fastest-growing region in Sweden, expected to increase its population by 50% until 2050 (Stockholm County Council. 2025).

2.2 Current Planning of Nature-Based Solutions in the Stockholm Region

Stockholm and its surrounding municipalities are made up from large, coherent rural areas and peri-urban green spaces with important social and ecological qualities; but in the central parts of the city and many of its municipalities, green space is often fragmented, threatening ecological connectivity and limiting the provision of ecosystem services. (Täby Municipality 2019; Ekologigruppen 2015). This spatial structure partly results from Stockholm's "green wedges plan", consisting of ten large continuous green areas that stretch from its rural outskirts into the heart of the urban core (Stockholms län Landstinget Regionplane- och trafikkontoret 1991).

The current regional development plan for Stockholm (RUFS 2050), was adopted by the Stockholm Regional Council in June 2018, and serves as the guiding document for long-term physical planning and growth in the region. The plan provides its municipalities with guidance on regional issues of an inter-municipal nature that are important for the use of land and water areas (See Figure 2.5). Since the current plan only remains valid until autumn 2026, I will primarily focus on the key strategies of the upcoming plan (RUFS 2060). The new plan is scheduled to be formally adopted in May 2026 (Stockholm County Council 2025b).

From the consultation responses on the draft of RUFS 2060, it becomes clear that the plan continues to focus on creating a sustainable and cohesive region for an expected population of 3.3 million inhabitants by 2060. Several long-term priorities guide this vision including poly centric growth through eight regional urban centers (See Figure 2.6), Transit Oriented Development (TOD) of "15-minute neighbourhoods," making the Stockholm region fossil-free by 2040, and the need to construct 5000-6000 new homes annually in Stockholm city alone, alongside major expansions of the public transport network. (Stockholm County Council 2025a).

Following these priorities, the densification of central and commuter municipalities through infill development and extensive brownfield redevelopment, is likely to challenge green spaces in both urban and suburban landscapes (Littke 2015; Furberg et al. 2020).

In this context, a focus on VUE trough building-related NBS, such as green roofs, green façades, and living wall systems, could provide an important opportunity to integrate ecological functions and climate adaptation measures into dense urban environments where horizontal space for new green infrastructure is increasingly limited.

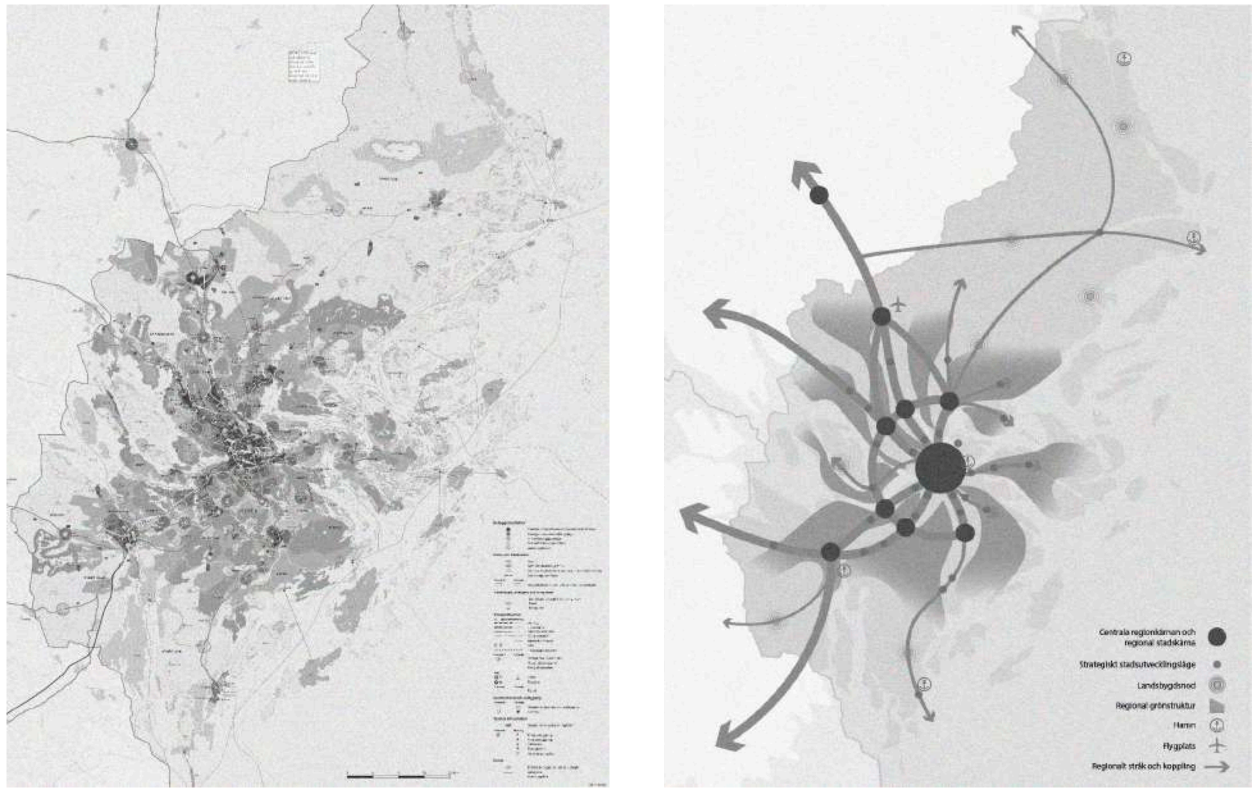


Figure 2.5-6. Land-use map for the Stockholm region in 2050 & Spatial orientation diagram for the Stockholm region in 2050, adapted from (Region Stockholm 2017).

Figure 2.7. Hammarby Sjöstad in Stockholm, Sweden. Adapted from (Fredriksson 2014) (CC BY-SA 3.0).

Municipal Practices for Integrated Planning of NBS in in the Stockholm Region

In a quest to understand the current status regarding the integration of NBS and UGI in Stockholm, I reviewed a paper by Brokking et al. (2021), as they focus on recent urban development projects in the Stockholm region (i.e., Stockholm, Täby and Upplands Väsby). The projects are analysed to gain an understanding of how municipal agencies run the process of developing NBS in collaboration with other public and private stakeholders.

As emphasised in the paper, the Planning and Building Act (PBA), plays a central role in regulating land use in Sweden, providing municipalities with legal instruments such as detailed development plans and building permits (Swedish National Board for Housing, Building and Planning 2010). Through these tools, municipalities can guide urban development, protect green spaces, and promote the implementation of NBS. However, an important limitation remains land ownership.

While municipalities can articulate ambitions to foster ecological and social qualities within development areas, they can usually not impose binding, detailed requirements related to ecosystem services such as green roofs or other NBS measures on private landowners. Fundamental to this legal framework, is the so-called public–private law divide, which is the notion that the state provides the institutional framework for the market, but does not itself act as a market agent. (Olsson 2018).

In contrast, municipalities have full control over publicly owned land, allowing them to directly implement ecosystem service-oriented planning in many urban green areas such as parks, common land, and roadsides (Swedish National Board for Housing, Building and Planning 2021). An important neo-liberal mechanism that expands municipal influence, but might challenge the public–private law divide, occurs when public land is sold to private developers through land allocation processes (Olsson 2018).

In these cases, municipalities can attach contractual conditions to the land transfer, enabling them to introduce far-reaching requirements through civil agreements. This allows municipalities to require developers to integrate green spaces with ecological and social qualities. This legal mechanism has been a key driver behind the increasing integration of NBS in urban development projects across the Stockholm region over the past two decades (Brokking et al. 2020).

Some successful examples of the land allocation mechanism can be found in former brownfield areas such as Hammarby Sjöstad (See Figure 2.7) and the Stockholm Royal Seaport (Norra Djurgårdsstaden). In both cases the municipality owned the land and therefore also was able to control the development and implement ambitious sustainability goals. These goals were used to define the requirements and criteria in land allocation competitions, where developers were invited to submit bids. Because of the attractive central location of these sites, the municipality received multiple competitive bids and was able to pick projects that fulfilled the requirements and criteria in the best and most ambitious way. (Brokking et al. 2021).

In peri-urban locations, it however tends to be more difficult to attract developers. In projects such as Fyrklövern and Täby Park, municipalities therefore had to be more creative with alternative development processes and co-creation activities. Väsby for instance set up a point system for the assessment of project proposals, through which developers could gain a rebate on the land price for projects that meet the quality criteria (Drotte & von Hofsten 2016). The discount created room for investors to test innovative solutions related to urbanity, energy efficiency, co-creation and citizen involvement (Brokking et al. 2021).

Stockholm's RUFS, currently emphasizes the importance of maintaining a cohesive green structure and robust aquatic systems to support biodiversity, climate adaptation, recreation, and storm water management across the region (Stockholm County Council. 2025). Several recent (primarily public) projects in the Stockholm region illustrate how these ambitions are translated into NBS within the existing public realm. The redevelopment of Sjödalsparken in Huddinge, for example, integrates storm water management, biodiversity habitats, and recreation through a system of visible water channels, meadows, and planting areas that manage runoff from the surrounding urban district (See Figure 2.8). Similarly, the new Årstafältet park design integrates storm water ponds, vegetated infiltration zones, and blue-green corridors within a large urban park landscape to treat runoff while enhancing biodiversity and recreation (See Figure 2.9) (LAND Arkitektur n.d.) In addition, Stockholm city has pioneered structural soil systems that allow street trees to retain and store rainwater beneath pavements, enabling streets themselves to function as components of the city's blue-green infrastructure network (See Figure 2.10).

Figure 2.8. Site visit Sjödalsparken with studio water environments SLU, September 2025.

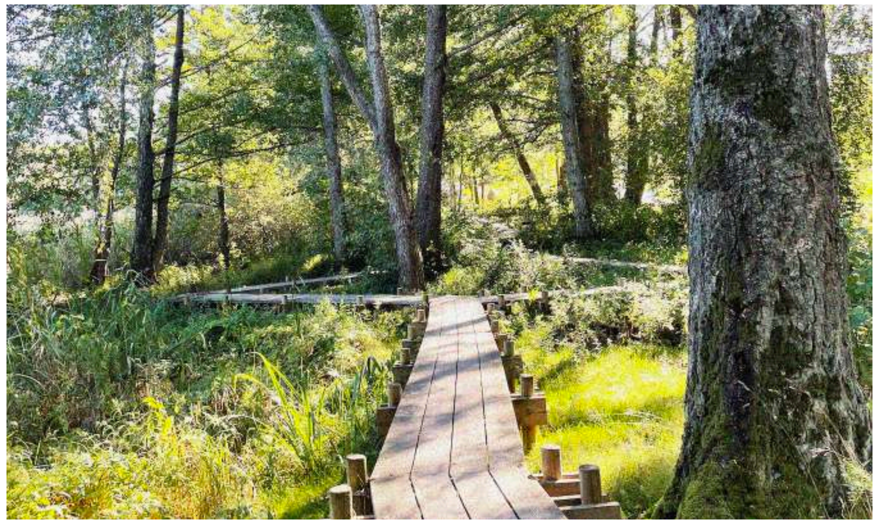


Figure 2.9. Site visit Årstafältet park with studio water environments SLU, September 2025 .

Following the insights, it becomes clear that the implementation of NBS in new developments and the public realm in Stockholm is becoming standard practice. However, large-scale urban redevelopment projects often take decades to realize. Hammarby Sjöstad, initiated in the early 1990s, was completed only in 2017, while Norra Djurgårdsstaden, planned since the early 2000s, is not expected to be finished before 2030 (City of Stockholm 2024).

In light of the ambitious EU environmental targets in the coming decades, relying primarily on new urban developments and the public realm to transform the ecological performance of cities, may therefore be insufficient. Given the long time lines of large-scale development projects, I strongly believe that therefore greater attention must be directed toward the ecological transformation of the existing urban fabric.

Figure 2.10.The sponge city principle of Stockholm. Inlet curb detail to urban tree planters, Hammarby Sjöstad, September 2025.

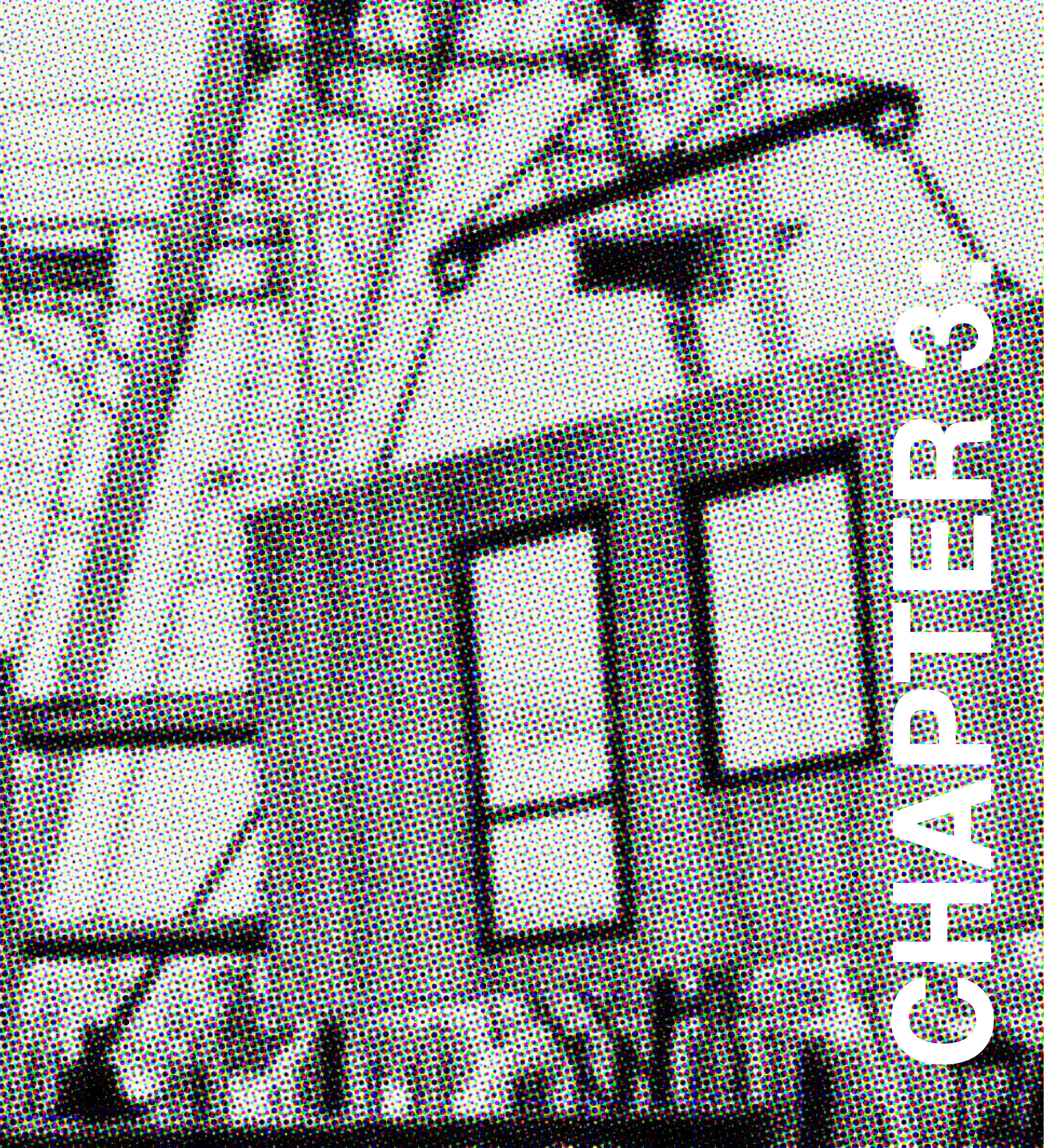
From Blue-Green Infrastructure towards Vertical Urban Ecology ?

This chapter illustrates that implementing NBS on public land in Sweden is generally no issue when formal requirements are met, and public funding is secured. Many projects therefore are directed at the level of public space and landscape architecture. On private land however, my research has pointed out that municipalities do generally not have the legal means to require specific designs for buildings or green spaces. As a result, the implementation of NBS outside the public sphere remains limited to large-scale redevelopment projects, while the ecological potential of the rest of the built environment, and especially of the existing building stock, remains largely underutilized.

Since research has shown that private land can play a vital role in supporting ecosystem services and biodiversity, while an increasing share of land and building stock in Sweden is falling in private hands; This creates the need for more innovative urban development processes that can't focus solely on spatial, social and ecological qualities, but also need to generate other benefits for private investors. Depending on the additional costs associated with sustainable urban development, projects may therefore need to be supported by prime locations, lower land prices, higher project densities, etc.

As research shows that rooftops alone account for approximately 40-50% of impervious surfaces in dense urban environments, and when façades are included, the potential surface area increases even further (Mentens et al. 2006; Stovin 2010). We can start to wonder if these building surfaces could be re-conceptualized as part of a layered ecological system, rather than functioning merely as inert architectural envelopes.

In this sense, Vertical Urban Ecology could reveal an enormous latent surface area within the existing urban fabric of Stockholm that could contribute to climate adaptation, biodiversity enhancement, urban cooling strategies, while also supporting the region's social and economic development.



CHAPTER 3:

Nature-Based Solutions - A future for Stockholm’s Million Housing Programme Districts ?

This chapter explores how ageing housing stock, socio-spatial challenges, and ecological ambitions might intersect with Vertical Urban Ecology.

3.1 Background of the Million Housing Program

During the post-war decades, Swedish housing policy was largely in support of its welfare-state framework, aimed at rapid urbanization and affordable housing for its growing industrial workforce. One quarter of Sweden's existing housing stock was built during these decades and in the late modernist period (Stenberg 2013).

The municipal land instrument formed a key regulatory tool within this state-led housing production system. As part of the social democratic full-employment policy, municipalities were granted legal and financial means to acquire land through expropriation rights, supported by state mortgages. By building municipal land banks and planning urban expansion on publicly owned land, municipalities could prevent land speculation and excessive rent extraction ensuring that land remained available for rapid and affordable housing construction (Vedung 1993).

These conditions enabled municipalities to play a decisive role in structuring urban expansion and laid the groundwork for one of the most ambitious housing initiatives in Swedish history. A residential programme from 1965-1974, produced large-scale housing estates characterized by standardized, multi-storey residential buildings across the country (See Figure 3.1). Over one million units of housing were built during a ten-year span, which predictably became known as the 'Million Housing Program' (MHP-Miljonprogrammet).

It is estimated that around one quarter of Sweden's population, about 2 to 2.5 million people, live in the MHP areas today (Malmheden 2020), many of which are located in metropolitan regions such as Stockholm, Gothenburg, and Malmö. In terms of the number of MHP apartments, Stockholm County is at the top, with 143.000 units (Victoriahem 2022).

Figure 3.1. Archive image of the construction of Tensta, Stockholm (Svenskabostader 1967) (CC BY-NC-ND 2.0).

Figure 3.2. Tensta, Stockholm today; many MHP developments are awaiting urgent renovation, April 2026.

*Current Challenges**

Since the building stock from the MHP era has reached an age of 50-60 years, it is currently facing multiple challenges. Many housing estates are dealing with aging building envelopes, high energy consumption, climate vulnerability, and persistent social inequalities, all of which are placing growing pressure on slacking renovation agendas. The four most pressing challenges within the MHP today, as described by Stenberg (2013) are:

(1) The rapid national demographic shift of Sweden from a state with mostly homogeneous nuclear families to a globalized society with a multiplicity of demands, leading to segregation and integration issues.

(2) The technical systems of multifamily housing are in urgent need of long-term maintenance as roofing, piping, ventilation, windows, elevators and balconies need to be replaced or repaired as they are old and malfunctioning (See Figure 3.2).

(3) The majority of multifamily houses built during the million housing era were planned to run on cheap electricity; Global political instability leading to insecurities regarding the suppliance of energy, together with the EU directive to cut 50% of energy consumption by 2050, has become a major driver to better isolate building envelopes, implement more energy efficient heating and cooling solutions, and to promote awareness around responsible energy-usage.

(4) Some buildings are gaining recognition over the years as they are deemed representative of the post-war period, this sometimes leads to classification and protection, this creates a counteracting force to the physical changes brought by the first three challenges.

Even though none of these challenges are new by themselves, the ambition and scale of the MHP era was unprecedented in Sweden and now leads to a situation where all these forces are affecting a large portion of the housing stock at once.

Additionally since the COVID-19 pandemic and the Russia-Ukraine war, construction and renovation costs have increased significantly following sharp increases in the price of key materials such as timber, steel, and cement across Europe (Stenberg 2013; Amca et al. 2025).

Following Stenberg's formulated challenges (2013), I started to wonder what the current state of the MHP renovation agenda is, and how the renovation of buildings in these areas are generally approached. This with the idea that this agenda could possibly overlap with my VUE concept.

Since there was no specific renovation data available in regards to the MHP areas alone, I decided to consult a recent interim report from Boverket, which studies the overall support for renovation and energy efficiency in the rental housing market in Sweden:

3.2 Ownership and Renovation Dynamics in the Swedish Rental Housing Market

In July 2020, the Swedish National Board of Housing was commissioned by the government to evaluate support for renovation and energy efficiency and to analyze ownership conditions in the rental housing market. In their interim report, they refer to the research from Femenías et al. (2018), as they categorize sustainable renovation through: economic, social, environmental and technical sustainability (See Figure 3.3).

Economically, projects should balance investment returns with housing affordability; Socially they should minimize tenant displacement and support resident participation; Environmentally, renovation should reduce energy use, greenhouse gas emissions, and material impacts across the building life cycle; often complemented by considerations of technical reliability and functional performance (Femenías et al. 2018).

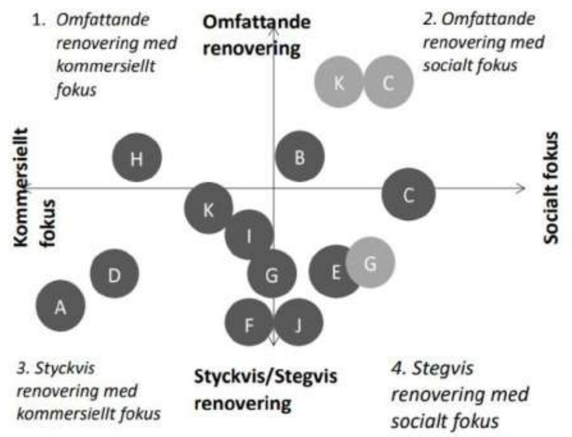


Figure 3.3. Typological division of renovation strategies. The vertical and horizontal lines describe a typology of renovation strategies. The corners of the figure represent four extremes (Boverket 2021:28).

According to the report, how landlords balance these aspects is often dependent on if they are short-term profit-driven or have a more long-term perspective with a focus on own management. Building owners such as municipalities may for instance favour smaller, incremental renovations to limit rent increases, avoiding tenant displacement and reducing financial risk; While private investors might put more emphasis on energy efficiency goals that require more extensive intervention, resulting finally in higher property value and rental income (Boverket 2021).

Alternative strategies such as ‘concept renovation’, where landlords renovate apartments individually after tenants move out, enabling higher rents for new tenants while avoiding direct impacts on current residents; Or strategies offering tenants different renovation options with varying levels of intervention and corresponding rent increases, are seen as possible compromises.

The Linero district in Lund is an interesting case-study as sixteen three-storey houses have been energetically renovated with an eye on limited rent increase as part of ‘CITyFiED’; An EU project focused on developing and demonstrating innovative and cost-effective solutions for improving the energy efficiency of older residential areas (Cityfied n.d.).

In the Boverket’s report’s statistical evaluation (See Table 3.1), it was found that out of a total of 41.501 buildings analysed, approximately 75% fell into the category of “no renovation,” only about 2.941 buildings had undergone some form of renovation. Their statistics further indicate that the most significant improvements in energy performance occur in cases of comprehensive renovation, particularly in buildings owned by private companies, however, such large-scale interventions remain relatively rare (Boverket 2021).

Among the initiatives proposed by the Swedish Energy Agency in its budget documents for 2022-2024, it was also pointed out that the renovation market is currently too fragmented and dominated by small craft-based companies; According to them, increased knowledge and more coordinated solutions are needed to promote deep renovation (Energimyndigheten 2022).

Based on the challenges mentioned in the previous paragraph, and Boverket’s statistics; I conclude that the once primarily government-led million housing portfolio has diversified over the last fifty years, resulting in different ownership groups which have different conditions in terms of finance, organization, knowledge and governance. This makes it challenging to disseminate renovation methods and technical solutions and to promote broad implementation among the many different public and private building owners.

Table 3.1. Proportion of studied buildings that have undergone various types of renovation during the period 2008–2018 by ownership group (Boverket 2021:37).

Ägargrupp	Ingen renovering	Mindre renovering	Större renovering	Total-renovering	N/A
Privata bolag	90,6%	3,8%	3,7%	0,3%	1,6%
Privatägda byggnader	95,0%	1,6%	3,3%	0,1%	-
Sveriges Allmännytta	84,6%	6,5%	6,2%	1,9%	0,8%
Bostads-rätts-föreningar	91,9%	4,5%	2,4%	1,2%	-
Övrigt	93,4%	2,7%	2,7%	0,6%	0,6%
Totalt	**89,4%**	**4,9%**	**3,9%**	**0,3%**	**1,5%**

Figure 3.4-6. Occasional encounters with construction waste and scaffolding along façades in MHP area Tensta, Stockholm indicate ongoing renovation practices. However, many façades show clear aging signs and need for renewal, February 2026.

This evaluation suggests that while the technical potential for substantial energy improvements exists, the majority of the MHP building stock continues to operate with aging systems and envelopes (See Figure 3.4-6). Therefore, the MHP estates today represent a vast but largely untapped field for renovation and transformation. Within this context, approaches that combine technical upgrading with broader ecological and spatial strategies may offer a way to address multiple challenges simultaneously.

Contemporary redevelopment strategies for MHP areas often focus on improving urban structure, activating ground floors, and introducing greater architectural variation (Stenberg 2013). However, ecological retrofitting of the existing building stock remains relatively under explored. Integrating building-related NBS into these regeneration processes could significantly enhance ecosystem services such as storm water retention, urban cooling, biodiversity, and environmental quality without requiring additional land. In this way, VUE could complement current redevelopment strategies by adding an ecological dimension to the social and spatial transformation of these districts.

3.3 Socio-spatial Opportunities of the Million Housing Program areas in Stockholm

In Stockholm, buildings from the MHP are mainly located in large suburban districts built on the metropolitan periphery (See Figure 3.7). Most estates were built around subway lines and placed outside the historic city because large plots of land were needed for rapid construction (Vedung 1993). The modernist buildings designed for these suburbs were usually slab blocks and towers, surrounded by plenty of open green with abundant car-oriented infrastructure. These buildings were originally lauded for their spacious layout, large windows, and generally functionalist ethos, as they were designed for the working- and middle-class Swedish family (Stenberg 2013).

Starting from the 1970s, growing critiques oriented at their monotonous typology and bare materiality set these areas in a rather grim daylight. From the 1980s onward many middle-income households moved out to private housing elsewhere, while vacant rental apartments were increasingly allocated to socially vulnerable populations such as new immigrants and lower-income households. Over the years, suburbs such as Rinkeby, Tensta, Husby, Fittja, and Alby, have become associated with a persistent negative public image. Media representations emphasizing crime, segregation, and social unrest have contributed to territorial stigmatization (Molina 1997).

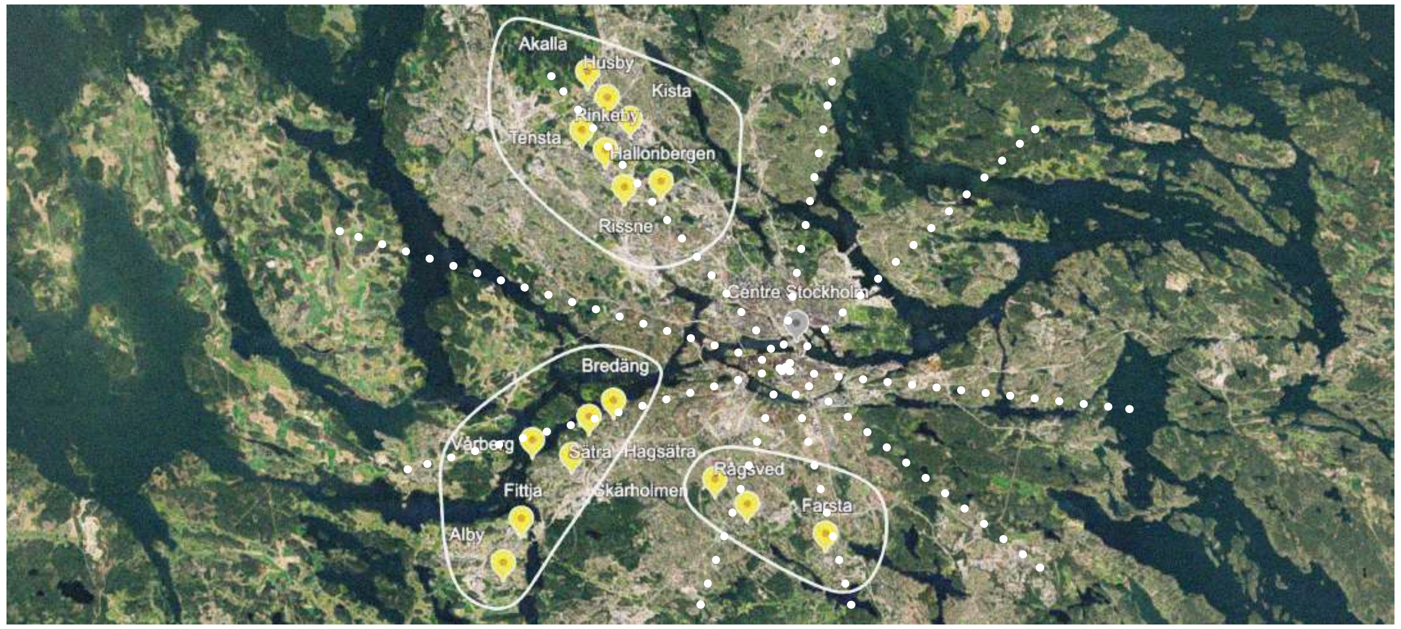
In response, the City of Stockholm has tried to counteract these perceptions through urban development strategies aimed at investing in public space and social infrastructure, improving connectivity, and diversifying housing. Initiatives such as 'Järvalyftet', a comprehensive revitalization plan for the northern Stockholm municipality Järvafältet, initiated by the Stockholm City Council in 2007, for instance focused on upgrading public environments, strengthening local services, and promoting new housing typologies (Svenska Bostäder n.d.). Initial proposals for urban renewal by municipal housing companies, however, triggered strong opposition from residents, as their plans involved large-scale evacuations and rent increases (Sveriges Radio 2007; Svenska Bostäder n.d.). Following public protests, the "Järvalyftet" plan was withdrawn, leading to the development of the "Järva Dialogue," a participatory process in which tenants are more involved in determining the extent and type of renovations.

Stockholm's rapid urban expansion is in the coming years likely to engulf many MHP suburbs within its expanding metropolitan structure, as there is a clear spatial overlap between many of these suburbs and the future eight regional centres identified in the RUFS. Areas such as Rinkeby, Tensta, and Husby are for instance situated between key regional centres like Kista and Barkarby, while southern districts such as Skärholmen, Vårberg, Fittja, and Alby align with transit axes connecting to regional cores like Flemingsberg and Södertälje.

MHP areas that were once located on the urban periphery, are therefore likely to become major players in future peri-urban densification plans (Stockholm County Council. 2025; Stockholm County Council 2025a).

This dynamic could create social opportunities by attracting new residents, general interest, and investment opportunities, potentially helping to diversify the public image of these areas. On a spatial level, this urban expansion will likely pressure existing open green spaces. This creates together with the urgent MHP renovation agenda interesting conditions to experiment with more experimental forms of NBS.

Figure 3.7. The MHP estates in Stockholm form three large peri-urban clusters apart from some smaller satellite areas: One of the largest and best-known clusters is the Järva housing belt along the blue line, northwest of the city center, including Rinkeby, Tensta, Husby, Kista, Akalla, Hallonbergen and Rissne. A second cluster can be found along the red line in the southwest, including Skärholmen, Bredäng, Sätra, Vårberg, Fittja and Alby. In the southern suburbs Rågsved, Hagsätra and Farsta, from a third cluster. (Basemap Google Earth 2023).



3.4 Eco-structural Opportunities of the Million Housing Program areas in Stockholm

In the previous paragraphs of this chapter, the focus has been primarily on societal and economic drivers. In this section, I will focus at last on the larger eco-structural potential embedded within many MHP areas. This based on a case-study by Elmqvist et al. (2004), which explains the greater eco-structural shape of the metropolitan area of Stockholm with special attention for the National Urban Park (NUP).

Stockholm County consists of a total land and water area of 678.500 ha, representing about 2% of the total land area surface of Sweden. The landscape shows much variation ranging from large forested areas to open agricultural land and considerable surfaces of open water. Ten large green wedges extend from the rural parts of the county toward the central parts of Stockholm city (See Figure 3.8). These wedges (or corridors) include areas of social and ecological significance, and bind together core ecological areas. This "wedge plan" constitutes the nucleus of Stockholm's eco-structure and is considered fundamental in physical regional planning since the 1990s (Stockholms län Landstinget Regionplane- och trafikkontoret 1991).

Within this structure, the National Urban Park (NUP), constitutes a 2.700ha green area which is an important ecological artery for the Stockholm region. It holds more than 1.000 species of butterflies, 1.200 species of beetles and 250 species of birds, and the largest population of giant oaks recorded in all of Europe (Bråvander & Jacobson 2003). The area stretches from Southern Djurgarden in the middle of the city, via Northern Djurgarden, Haga, and Brunnsviken to Ulriksdal and Sorentorp in the north (See Figure 3.9).

Even if the Stockholm region has a high coverage of urban green areas according to European standards. During the 1970s and 1980s, about 8% of green areas were lost as an effect of urban sprawl. Within a 30-km-radius from the city's centre, several red-listed species have declined, while since the middle of the 1970s, approximately 200 species disappeared from the most centrally located green areas. This goes together with a sharp decrease in abundance of many common species, such as amphibians, reptiles, and some bird species (Gothnier et al. 1999).

This trend also became visible in the NUP, as the industrialization strongly influenced the area by diminishing unexploited parts. In 1963, 50% of the green parts from 1913 had disappeared in Djurgarden, with core areas for biodiversity decreasing with 13% since 1947 (Löfvenhaft et al. 2002). However the exploitation of the NUP itself halted in 1995, as its land and nature values became legally protected.

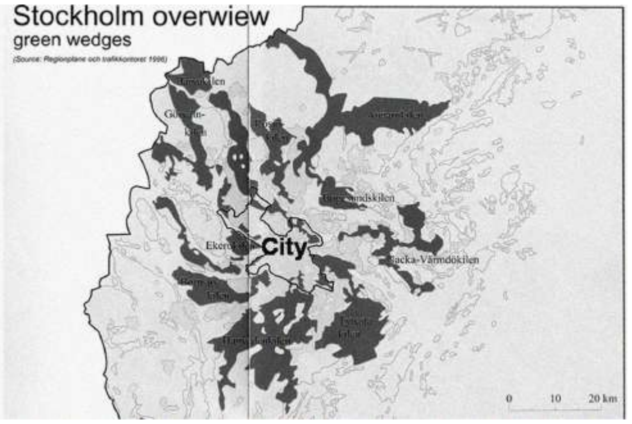


Figure 3.8. Overview of the Stockholm metropolitan area with the location of the green wedges (Elmqvist et al. 2004:310).

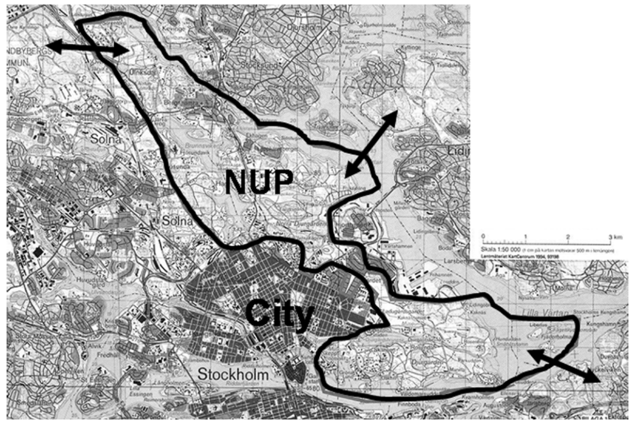


Figure 3.9. Perimeter of the national urban park in Stockholm (Elmqvist et al. 2004:311).

The primary ecological concern in Stockholm today is based on the fact that continued peri-urban densification, might increase further isolation of valuable ecological areas like the NUP (Elmqvist et al. 2004). In the bigger ecological picture, it is therefore essential to protect areas like the NUP as they serve crucial roles as dispersal corridors and facilitate migration movements (Elmqvist et al. 2004).

Two of the major regional green infrastructure initiatives in Stockholm County today, are therefore focused on **(1)** strengthening the weak connections of Stockholm's "green wedges plan", as these corridors are deemed vital to securing recreational paths, creating access to larger strolling areas, and maintaining ecological connectivity to the major green core areas (Colding et al. 2012; Stockholm County Council. 2025).

And **(2)**, a regional action plan that sets priorities among different nature conservation activities, and concretes goals and approaches to different areas; This plan is published by the Stockholm County Administrative Board, which is the State representative responsible for regional green infrastructure aimed at maintaining biodiversity and promote ecosystem services in Stockholm County (Stockholm County Administrative Board 2019);

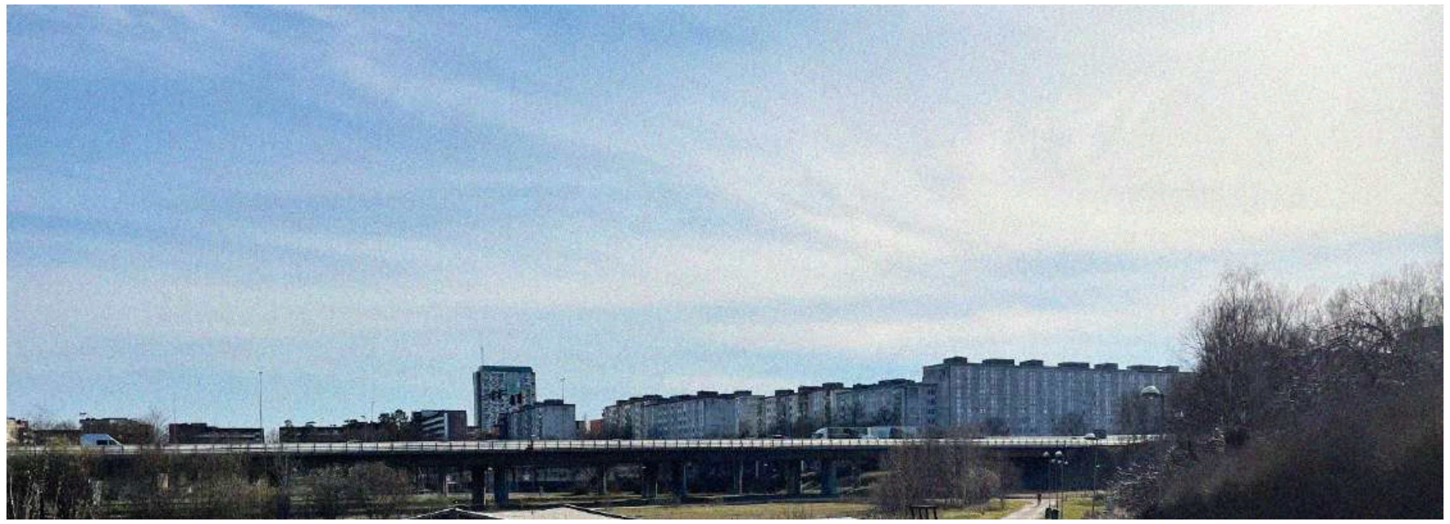
The main difference among the two initiatives, is that the regional action plan is primarily based on a mapping of ecological qualities, while the Stockholm green wedges include a wider range of functions such as recreation, health and attractiveness (Oliveira 2017; Stockholm County Council. 2025).

While the ecological structure of Stockholm has traditionally been understood through large-scale landscape systems, comparatively little attention has been given to the potential ecological role of the existing building stock within this network.

At the same time, many MHP districts form an extensive yet underutilized ecological interface with adjacent nature reserves and urban green corridors due to their peri-urban location. A clear example is the hard edge between Järvafältet and neighbourhoods like Tensta and Rinkeby (See Figure 3.10-13).

This suggests a need to reconsider their role within a future urban context increasingly shaped by infill development, landscape fragmentation, and biodiversity decline. Rather than being understood solely as residential enclaves, these neighbourhoods could instead represent an opportunity to strengthen ecological connectivity by improving matrix permeability on a neighbourhood scale.

Figure 3.10-13.
Views from Järvafältet towards Tensta illustrating the hard edge between nature and the city. High concrete façades reflect the noise from the E18 highway, reinforcing both a visual and acoustic barrier between the urban fabric and the surrounding natural landscape, April 2026.



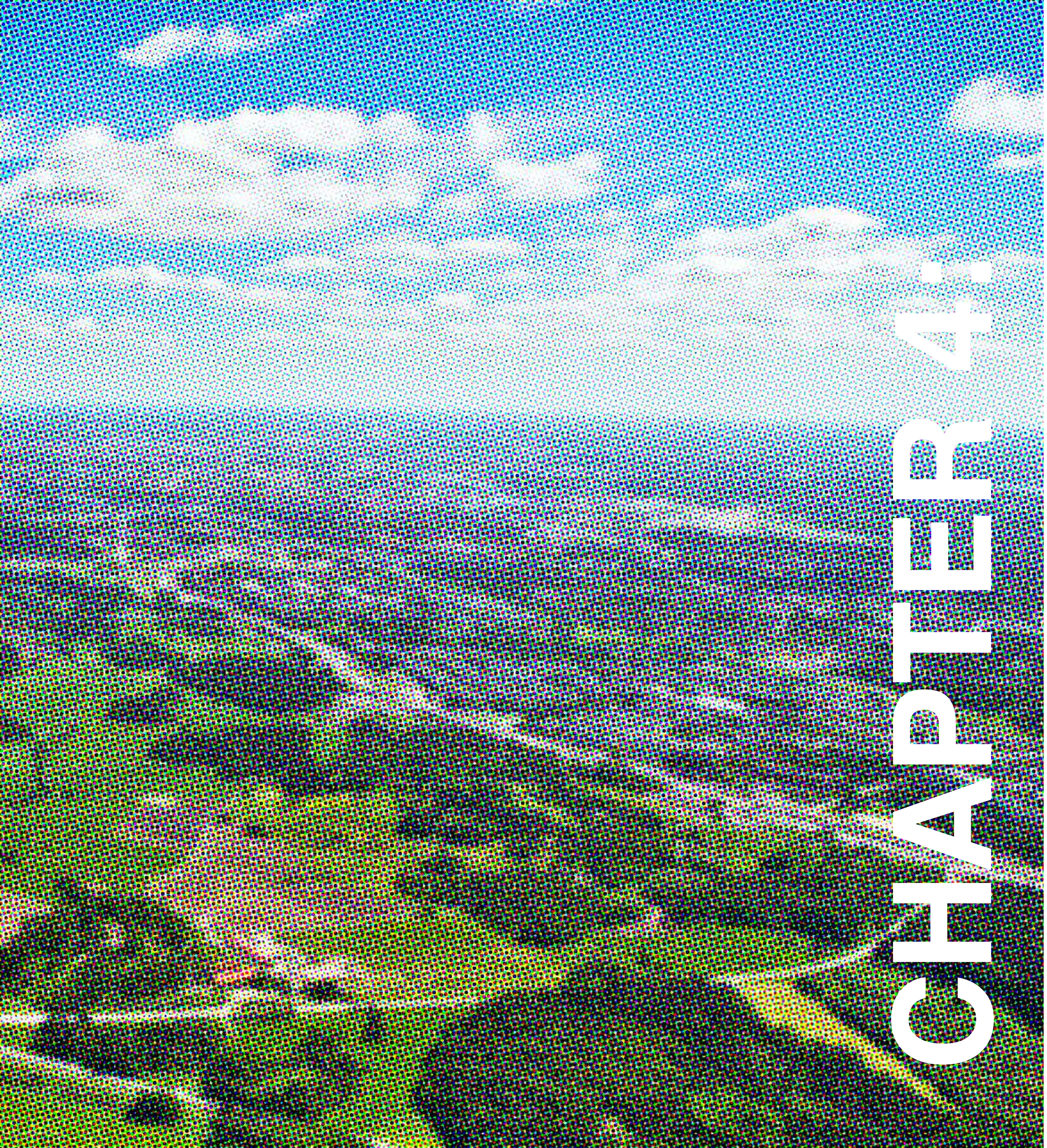
Nature-Based Solutions, a future for Stockholm's Million Housing Programme Districts ?

In conclusion, the urgent renovation agenda of the MHP building stock presents a strategic opportunity to integrate building-related NBS, both as technical support for building envelopes, as socio-economical interventions, and in support of the larger eco-structural landscape characteristic of Stockholm.

The large, modernist slab buildings, with vast roofs and predominantly south- or west-facing façades, seem particularly well-suited for NBS such as green roofs, green façades and living walls. As Muntean et al. document in their study of similar Romanian prefabricated concrete panel buildings from the 1970s, the area ratio for potential vertical green intervention on such façades can be as high as 53-78%. This finding might be directly transferable to the Swedish MHP context, where similar prefabricated panel systems were employed (Muntean et al. 2017).

Apart from the buildings themselves, their outdated implementation into a primarily car oriented landscape might open up opportunities to renegotiate the structural, ecological, and social conditions of these spaces as well.

In order to operationalize my VUE concept, the following chapter will focus on the municipal greening plans for the Spånga-Tensta district, one of Stockholm's 13 district areas located about eleven kilometers northwest of Stockholm city. Accordingly I will further zoom in on the inner urban area of Tensta, as within the context of Sweden's MHP, this area embodies one of the densest modernist planning areas in Sweden.



CHAPTER 4:

Vertical Urban Ecology on a District Scale - Focus Spånga-Tensta

Through large-scale landscape analysis and municipal guiding documents, this chapter investigates the ecological, social, and structural conditions that make Spånga-Tensta a relevant testing ground for Vertical Urban Ecology.

4.1 Focus Spånga-Tensta

Continuing on the ‘Järvalyftet’ plan discussed in the previous chapter. I decided to revisit the current plans for the Järva region in Stockholm, as I believe this district holds the most potential for testing my VUE concept in regards to MHP areas.

The city’s plans for the region are currently collected under the ‘Focus Järva’ program, which turns out to be one of the city’s major urban development initiatives with 15.000 new housing units planned and many public environments and buildings under renovation to serve an estimated 104.610 inhabitants in 2034.

As discussed in the plan, Järva is an area with great qualities and strong local commitment, but the differences in living conditions compared to other parts of Stockholm, make that there is concerted effort needed for the area to further develop (Stockholms stad 2025b).

Within the Järva region, I will focus specifically on the municipal greening plans for the Spånga-Tensta district, one of Stockholm’s 13 district areas located about eleven kilometres northwest of Stockholm city, along the Mälaren railway (See Figure 4.1). The areas that make up the Spånga-Tensta district are Tensta, Hjulsta, Lunda, Solhem, Bromsten, Flysta and Sundby as well as part of Järvafältet.

Accordingly I will further zoom in on the inner urban area of Tensta, as within the context of Sweden’s MHP, this area embodies one of the densest modernist planning areas in Sweden (Hallberg 2006).

(Stockholm’s Spånga-Tensta Park Plan is a municipal guiding document that describes how the green structure within the district area should be maintained and developed for the future (Stockholms stad 2021). In this extensive document I studied the historical and existing landscape characteristics of the district, and identified the municipal goals for the area in regards to green space provision and accessibility.)

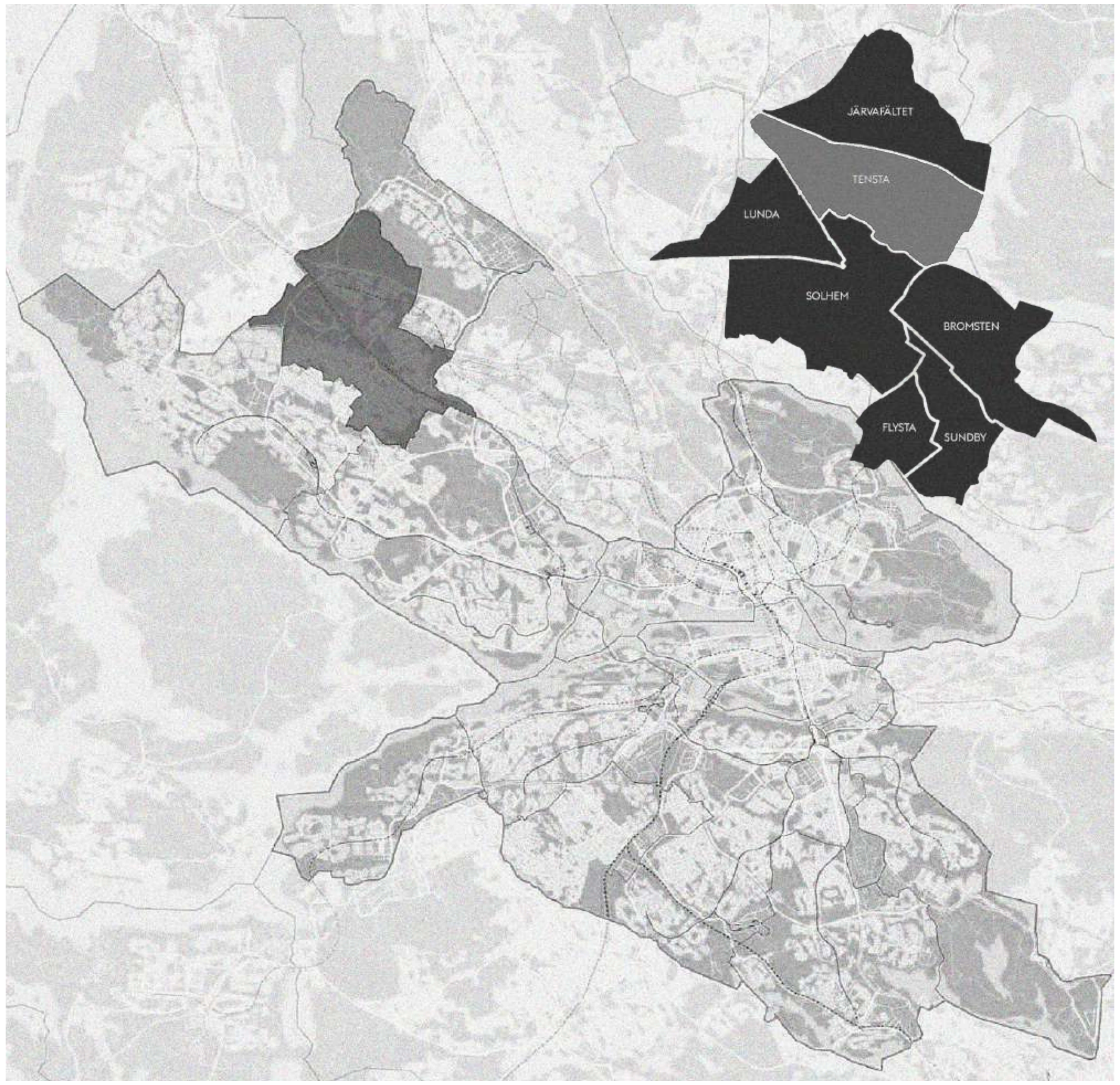


Figure 4.1. Location and outlines of the Spånga-Tensta district in Stockholm, adapted from (Stockholms stad 2021:9).

4.2 Spånga-Tensta’s Large-scale Landscape Characteristics

The overall Stockholm landscape can be seen as a result of its geographical location at the intersection of Lake Mälaren and the Baltic Sea. Water surfaces, fault escarpments, ridges, shorelines and valleys create strong landscape elements. The Spånga-Tensta district can therefore be recognized by alternating elevated plateaus and large open valley parks, producing a pronounced, directional landscape of ridges, slopes, and expansive green corridors. This rift valley landscape with a clear Northwest-southeast orientation, followed by major infrastructures such as the railway and E18, holds broad valleys such as Järvafältet and Tenstadalen, which form extensive “green floors” primarily used for recreation and ecological connectivity, while wooded slopes and escarpments create “green walls” along their edges (See Figure 4.2).

Surrounding plateaus, usually previously forested heights, are now largely inhabited and frame the valleys like in Tenstadalen and Spångadalen. Spånga contains mostly garden-city-style residential buildings and Tensta-Rinkeby can be characterized by metro suburbs with large-scale apartment buildings (See Figure 4.4-6) (Stockholms stad 2021).

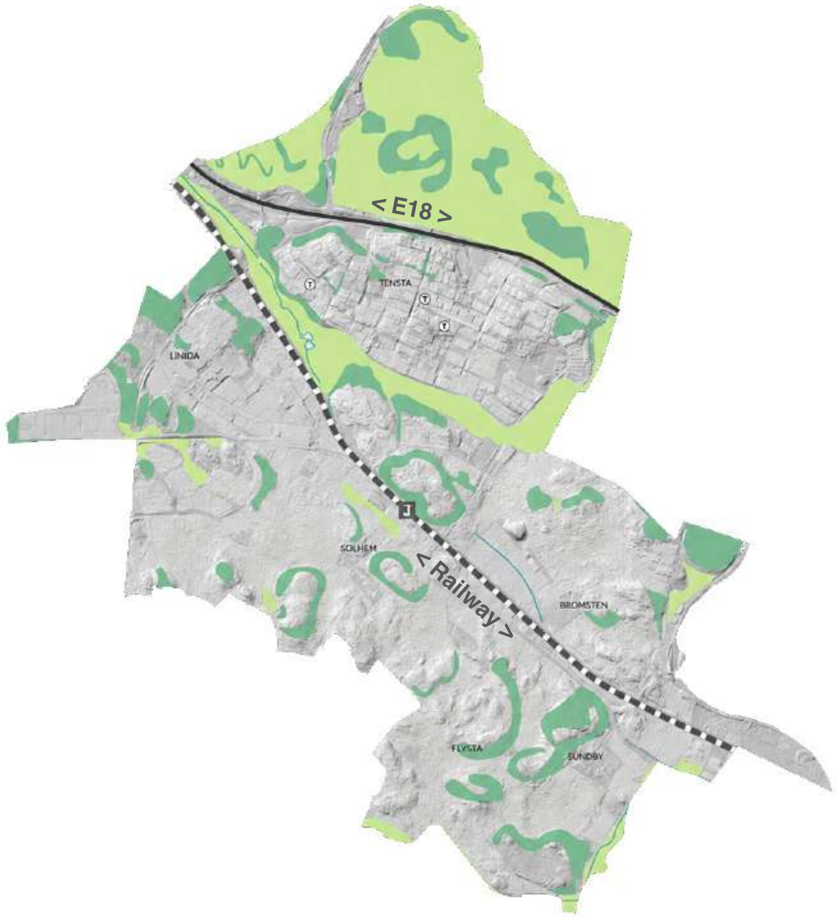


Figure 4.2. Topographic map rift valley landscape Spånga-Tensta, adapted from (Stockholms stad 2021:16).

Figure 4.4-6. Parks & residential areas (Google Earth 2023).

Figure 4.3. Large scale landscape characteristics vs human structures (Google Earth 2023).

4.3 Spånga-Tensta Park Plan - Municipal Goals for Green Space Access & Provision

Spånga-Tensta has with its total area of 1.265 ha, including 323 ha (26%) of publicly accessible park and nature land, a rather generous supply of green space. However, it needs to be noted that a large part of Järvafältet is included in these calculations. Tensta might be adjacent to large natural areas, but busy roads and railways continue to form barriers that separate the district. Especially the prominent E18, Bergslagsvägen and the railway constitute the largest spatial barriers and noise sources within the district area (See Figure 4.7).

One of the main spatial goals in the Spånga-Tensta parkplan therefore revolves around reducing these barriers so that a more cohesive urban image can be achieved. The design of the border zone between buildings and greenery but also how public spaces and street environments contribute to the urban landscape through improved connections, and a more fine-meshed network of tree-lined streets are deemed essential (Stockholms stad 2021).

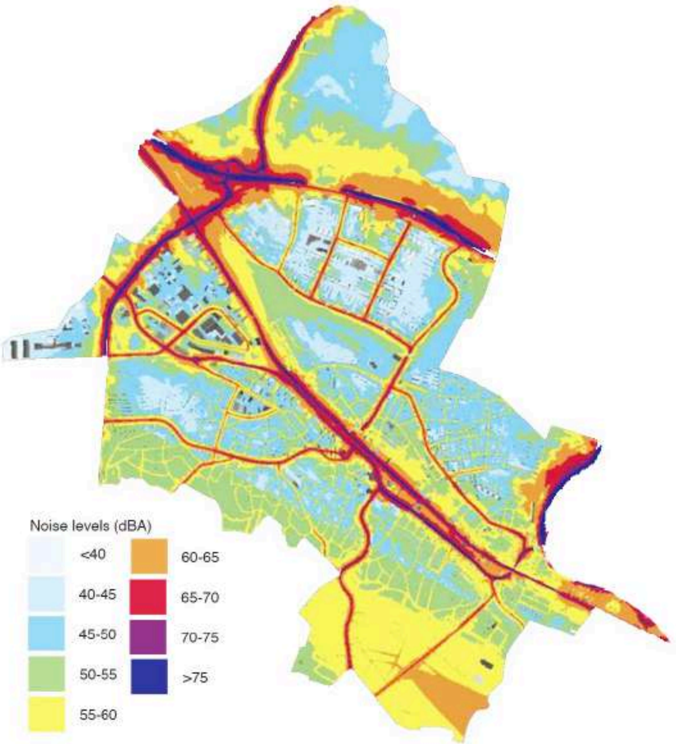


Figure 4.7. Map with noise levels Spånga-Tensta, adapted from (Stockholms stad 2021:52).

The parkplan primarily refers to the city's "Greener Stockholm" guidelines (2017) in regards to green space access and quality goals. These guidelines state that Stockholmers should have at most 200 meters to the nearest park, 500 meters to the nearest neighbourhood park, 1000 meters to an outdoor recreation area, or the ability to easily get to one by public transport. (Stockholms stad 2017).

Additionally it is stated that the amount of parkland must be large enough to meet the recreational needs of residents and has to be able to cope with the high visitor pressure (ibid.).

The parkplan differentiates four types of green space:

Figure 4.8. Outdoor recreation area containing the socio topic values of walking, wild nature, tranquillity and forest feeling. For Tensta this refers primarily to the Järvafältet nature area in the north.

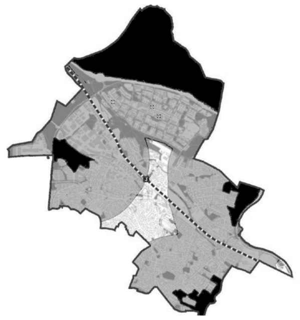


Figure 4.9. District parks that serve as a destination and social meeting place for a neighbourhood. Currently, only Nydalsparken just south of Tensta's urban centre meets the requirements

Figure 4.10. Smaller parks that act as social meeting places for clustered areas of the district. Erikslundsparken, Gullingeparken, the play area next to Spånga church, Spångadalen and Tenstadalen form the most prominent park areas.

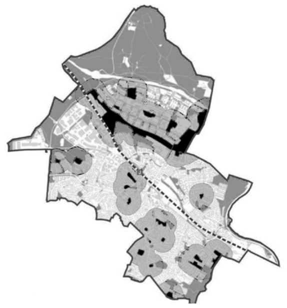


Figure 4.11. "Other green areas", encompassing all public green spaces that cannot be classified as open-air recreation areas, district parks or parks. The city has no qualitative guidelines for these areas.

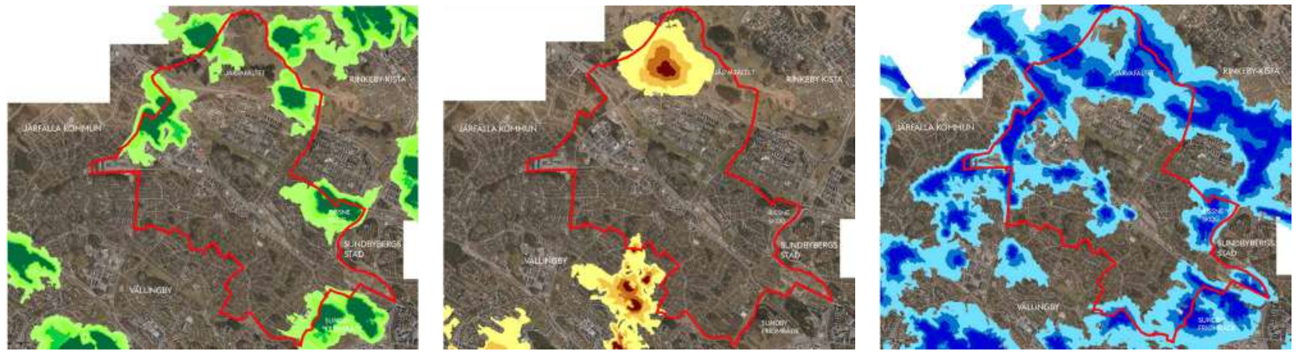
In the parkplan is further defined that In order to preserve the district's biodiversity, it is important to ensure both access and habitats for all sorts of species. Coniferous birds for instance prefer dense vegetation cover to protect themselves from birds of prey, several endangered and rare insect species need old and hollow oaks, and amphibians are sensitive to barriers in the form of infrastructure and are in need of more small bodies of water (Stockholms stad 2021).

The nature area Järvafältet forms a core area with habitats for many plant and animal species, but when looking at the habitat network maps (See Figures 4.13) it becomes clear that the inner urban areas of Spånga-Tensta are today largely excluded from the ecological functioning of the landscape.

Also on the biotope map produced by the municipality (See Figure 4.12), almost the entire urban area of Tensta is coloured in grey or dark grey, which refers to "dense buildings with or without elements of vegetation". Therefore the parkplan encourages the development of long-term sustainable ecological infrastructure aimed at a fine-meshed habitat network (ibid.).

Some other NBS mentioned in the parkplan revolve around investment in storm water systems in parks to handle increased precipitation and downpours, and the planting of a greater variety of trees, shrubs and flowers providing better resistance to climate change and diseases. At last the plan also promotes maintenance schemes in support of biodiversity, citizen participation projects and opportunities for urban farming.

Figure 4.12. Biotope map Spånga-Tensta, adapted from (Stockholms stad 2021:93).



Figures 4.13. Coniferous birds, insects and amphibian habitat networks in and around Spånga-Tensta (Stockholms stad 2021:96-98).

**Although the plan emphasizes green space quality access and the development of long-term ecological infrastructure, it does currently not define specific targets related to land cover, canopy coverage, or urban ecological performance.
At the same time, several maps show that many urban areas within the district remain largely disconnected from the natural realm. This suggests that the introduction of VUE, particularly in dense urban areas, could provide a valuable addition to the district's ecological infrastructure. To further explore the potential of VUE in relation to dense MHP areas, we will from here on focus on the inner urban area of Tensta.**

Figure 4.14-15.

Out of curiosity I used an AI image generator (KREA.ai) to transform a 3D perspective (Google Earth 2023) from the Tensta MHP area in Stockholm by using the conclusion from the previous chapter together with the image below as a prompt, the generated result emerged as an interpretation of the concept of VUE. Although the image presents an idealised representation, it nevertheless portrays a thoughtful illustration of what I am aiming for.

The previous chapters demonstrated that the science, knowledge, necessity, and potential already exist to guide our cities in this direction. Together, these chapters therefore constituted the "WHY."

The question that now arises is: HOW do we actually make this happen?

CHAPTER 5:

Vertical Urban Ecology on a Neighborhood Scale - Focus Tensta

This chapter develops the Vertical Capacity Model as a tool for quantifying, classifying, and evaluating the three-dimensional ecological potential of the built environment.

5.1 Focus Tensta

Located at the out-end of the blue metro line, about 20 minutes from the center of Stockholm we find Tensta, an area which used to be farmland and military training ground, but which was reprogrammed in the 60’s to house 16.000 people resulting in the single largest housing development of the MHP era in Sweden. The first sod was broken on November 2, 1966 and the general plan for the area exemplified the “new urban planning” ideals of the period (Hallberg 2006).

In the original plan for Tensta, the aim was to move away from the functionalist ideas of houses in parks, with the aim of creating a higher level of urbanity and exploitation. In regards to families with children, more “low-rise” houses were advocated instead of a few high-rise ones, as was the case in for example Bredäng built a few years earlier (Stockholms stad 2021).

In order to implement this denser, more horizontal urban structure and to enable the application of the prefabrication techniques of the time, the existing terrain had to be heavily reworked (See Figure 5.3). As I compare the aerial images on Lantmateriet from 1960 and 1975 (See Figure 5.1-2), it becomes clear that almost no natural land was spared, which was justified by the fact that the wider surrounding nature was what was important (ibid.).

Streets for vehicular traffic were lowered, while pedestrian routes were elevated. In central streets, this resulted in a system of “submerged” lanes, with pedestrian bridges spanning above them (See Figure 5.4). The housing typologies in Tensta remain until today, largely dominated by prefabricated slab blocks of 5-7 storeys, lamella houses of 1-3 storeys, and loft-access buildings ranging from 3-7 storeys.

The panel houses were usually constructed using concrete “bookshelf” systems, resting on large partly or fully embedded parking structures in the terrain. This produced artificial courtyards between the buildings, with garages hidden beneath or besides the buildings. Shrubs and trees on these decks were often planted in shallow, constructed beds (Stenberg 2013).

**Over time, Tensta’s urban planning and architecture received great criticism for being too monotonous, gray and drab, something that the good apartment solutions failed to compensate for.
As the city continued its expansion of Järvafältet, planning ideals therefore gradually returned again to greater variety in both housing types and heights as well as colors and shapes, with the residential areas in Kista being the clearest example (Stockholms stad 2021).**

Figure 5.1-2. Tensta 1960 vs 1975 (Lantmateriet).

Figure 5.3. Construction of Tenstastraket (Kallbergberg 1968) (CC BY 4.0)

Figure 5.4 Tensta allé (Petersens, L. af.1971) (CC BY 4.0)

Figure 5.5. New gable buildings attached to the windowless ends of older slab buildings along Tensta Allé, April 2026.

Today, Tensta is undergoing a significant phase of transformation. As Stockholm’s population continues to grow, the city’s master plan proposes the development of new housing, public services, and new meeting places to strengthen the strategic link between Tensta, Rinkeby, and Spånga. Spånga city centre functions as an important hub with both a commuter rail station and a bus terminal, and is consequently targeted for continued expansion through larger development areas as well as infill within existing residential neighbourhoods (ibid.).

In line with these developments, densification is occurring through the transformation of former industrial land into mixed-use districts, such as nearby Bromstensstaden. But also through multiple “infill projects” including gable buildings attached to the windowless ends of older slab buildings along Tensta Allé (See Figure 5.5), a new student tower at Spånga city centre completed in 2017, the Tenstaterassen project spanning the E18 and Hjulstavägen, and plans led by housing companies such as Familjebostäder including the addition, renovation and extension of existing buildings in Övre Tensta.

When looking at Tensta’s 2025 population statistics, we see that roughly 18.000-19.000 residents are living in the district of which 21% are children (0-15), 22% youth (16-29), 46% working age (30-64) and 11% seniors (65+) (Stockholms stad 2025a). Tensta therefore has a rather young, family-dominated population, with nearly half of residents under 30 and a relatively small elderly population, indicating a strong demand for schools, youth infrastructure, and everyday neighbourhood services. Public space investments are therefore oriented towards park upgrades, schoolyard greening, and new recreational infrastructures which contribute to a more social urban landscape (See Figure 5.6). Tenstadalen, a park covering a large area in the long valley between Tensta and Spånga, is a recent example of the city’s “Greener Stockholm projects” with the aim of creating renewed green spaces for all ages. While inner city projects such as the renovation of Gullingeparken and Taxingeplan are aiming for safer, better accessible and more inviting public environments (Stockholms stad 2023).

Figure 5.6. Tenstaplan, an example of a renewed social urban landscape in Tensta, April 2026.

5.2 How Green is Tensta Today?
Quantifying Land Cover and Tree Canopy Cover

As the municipal parkplan doesn't contain specific goals or data in regards to the amount of green surface or Tree Canopy Coverage (TCC) in Tensta, I decided to quantify the current land cover myself based on Near-Infrared (NIR) aerial imagery obtained from Lantmateriet (See Figure 5.7).

> *(NIR captures light beyond the visible spectrum which is strongly reflected by healthy vegetation but absorbed by water and shadows. In mapping, this results in a "false colour" composite where vibrant red indicates dense, healthy plants and cyan or grey represents urban infrastructure. This allows for a relatively precise calculation of "green cover," distinguishing living biomass from inert surfaces.*

Since I planned to convert all 2D vegetated surfaces into a measurable surface, I first imported the NIR image from Tensta into Adobe Photoshop, where I selected all vegetated (red-toned) surfaces with a colour-based tolerance of 100. All non-vegetated (grey-blue) areas were removed, resulting in a raster cut-out of the vegetated surfaces (See Figure 5.8). This raster cut-out was accordingly imported into Adobe Illustrator, where the silhouette function was used to produce a vectorized representation of the green areas.

The resulting geometry was finally imported in Vectorworks to obtain the surface areas of all individual vegetated areas (See Figure 5.9).

The vectorised polygon layer was clipped to the boundaries of a selected study area in Tensta. This area comprises the inner urban fabric, situated between the E18 highway to the north and Northwest, the Spånga green wedge to the east, and Tenstadalen to the south (See Figure 5.10). This selection was intentionally chosen, as VUE focuses on the ecological functioning within urban environments. Including the entire Tensta area, much of which consists of large parts of the surrounding natural land, would produce a misleading representation of the availability of green space within the urban living quarters.

The polygon analysis indicates that today approximately 48% of the selected study area is covered by vegetation, including all forms of green cover such as grass, shrubs, and trees. The remaining 52% consists of non-vegetated, or "grey," surfaces. In Tensta, these primarily refer to impervious and built surfaces occurring across both built and un-built land.

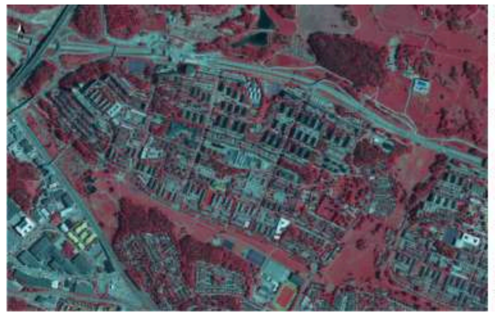


Figure 5.7. NIR imagery Tensta (Lantmateriet).

Figure 5.8. Raster cut-out vegetated areas.

Figure 5.9. Vectorised polygon layer vegetated areas.

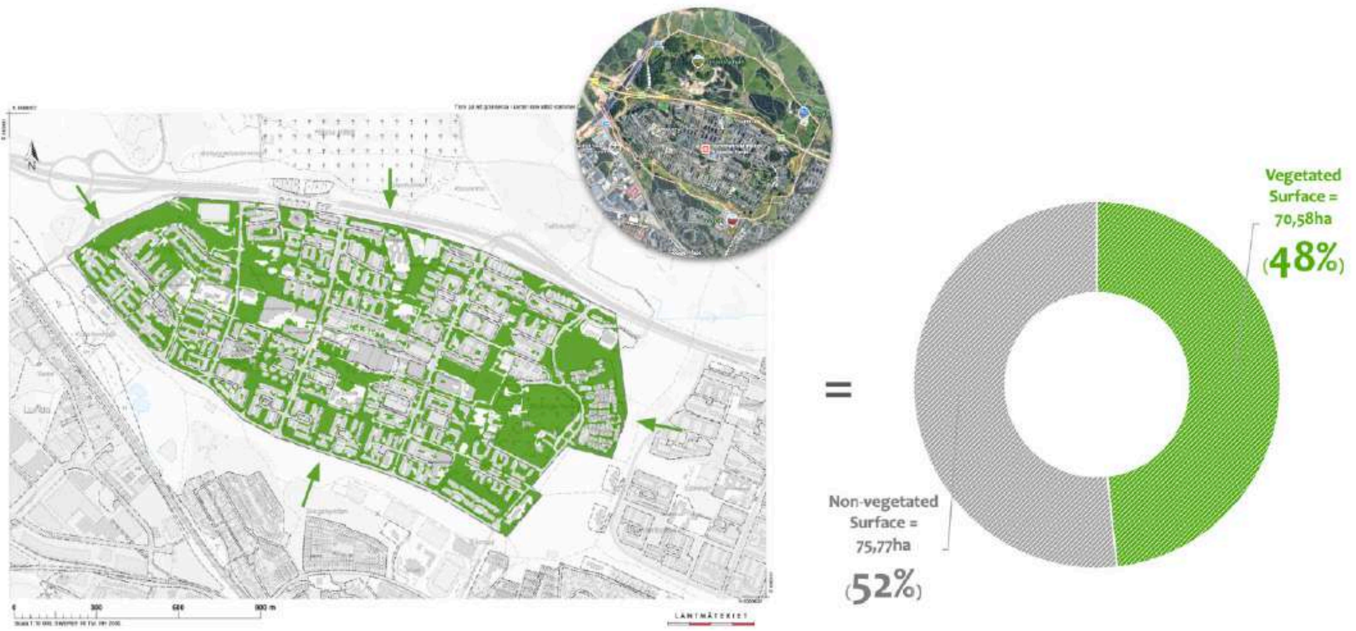


Figure 5.10. Vectorised polygon layer clipped to the boundaries of a selected study area in Tensta.

Figure 5.11.Tree canopy coverage calculation model.

As in traditional urban forest assessments, low-lying vegetation is excluded (TCC usually requires vegetation to be minimum 3 meters tall), I had to filter the trees from the vegetated surface area yo obtain a TCC value for Tensta's urban area. Two representative zones, each covering 10% of the selected area were used to estimate the average tree coverage in relation to the previously mapped vegetated surfaces. The central zone, representing one of the least green areas, exhibits approximately 30% tree coverage, while the western zone reaches around 40%. Based on these samples, an average tree coverage of 35% was assumed for the entire vegetated area (See Figure 5.11).

The resulting canopy cover for Tensta corresponds to roughly 17% of the total study area. This places Tensta at the lower end of commonly referenced international canopy targets, which typically range between 20% and 40%.

However, it is important to note that this number is highly sensitive to the scale of analysis, as well as to the delineation of study boundaries and the methods used to define and measure canopy cover.

Since the municipal documents don't state specific goals for Tensta in relation to TCC, I will use the international 30% benchmark as my target for the selected area. With a current TCC of 17%, I therefore count a deficit of 13%, or 19.21ha. If I were to convert this surface area to individual mature trees (25m2 per mature tree as counted in the Stockholm GSF) 7.682 trees would have to be added to the selected inner city area of Tensta.

Much of Tensta's dense urban structure and extensive subsurface infrastructure however limits opportunities for planting large, long-lived trees. Restricted soil volumes together with high public investment and maintenance demands will therefore likely make it difficult to reach a 30% TCC target through tree planting alone, meanwhile most trees require 15-30 years to reach substantial canopy cover.

In contrast, green roofs and vertical green structures could provide extensive vegetation cover within just 3-5 years, often with minimal ground space and many other social, economical and technical benefits as discussed in the previous chapters. Through the lens of VUE, I therefore question if greening the existing roofs and façades of Tensta could work as a form of "Canopy Cover Equivalent".

5.3 A Shift from Horizontal to Vertical Green Infrastructure ?

During my walks through Tensta and while analysing the biotope map, it becomes evident that apart from the public space, the built environment with its courtyards, façades and surrounding greenery constitute a large share of residents' everyday life, yet offers considerable potential for ecological and social improvement.

Much of this environment does not fall directly under municipal planning authority, yet the municipal park plan mentions that the green and blue qualities also need to be strengthened in the built environment, for example with permeable soil materials, local storm water retention, solutions like green roofs and walls, green noise barriers and trees in street environments (Stockholms stad 2021).

Currently many buildings and their direct surroundings, can be characterised by high, concrete or plastered façades, landing into impermeable pavement, neatly mown grass, or poorly vegetated inner courtyards (See Figures 4.20-24). These building volumes tower above highly manicured vegetation patches, while the variety in plant species and structure of vegetation between buildings is rather scarce.

Tensta therefore presents a compelling case for exploring VUE within the renovation context of Sweden's MHP areas, as it embodies outdated modernist planning ideals, struggles with challenges such as mono-functionality, underutilized ground floors, and fragmented social and spatial connections.

In response, I decided to start mapping Tensta's current "vertical potential" by developing a Vertical Capacity Model (VCM) (See Figure 5.12).

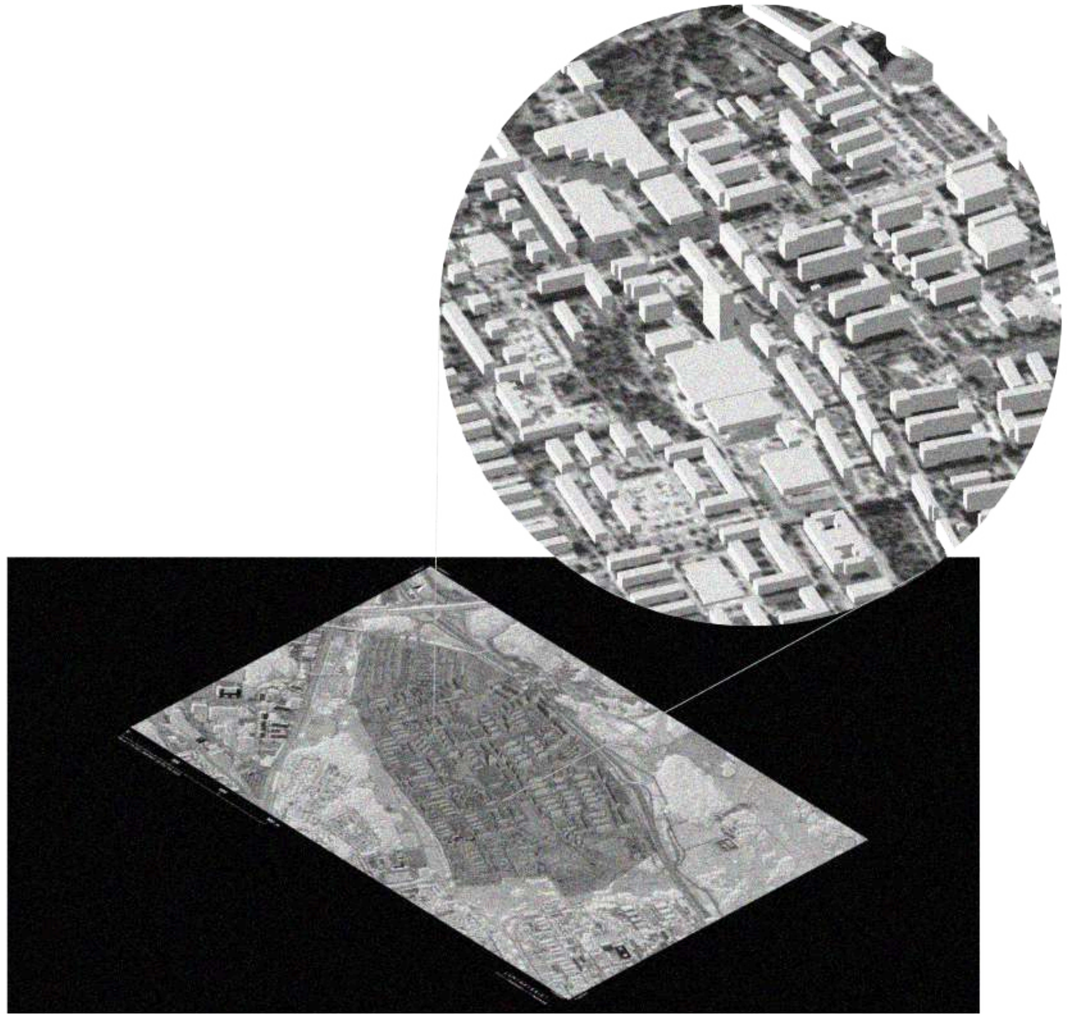


Figure 5.12. Initial development of the vertical capacity model in SketchUp.

Figure 5.13 -17. Currently many buildings in Tensta can be characterised by high, concrete or plastered façades, landing into impermeable pavement, neatly mown grass, or poorly vegetated inner courtyards, April 2026.

5.4 Introducing a Vertical Capacity Model

The Vertical Capacity Model (VCM), is a simplified volumetric representation developed to both map, classify and valuate the three-dimensional surface potential of Tensta's urban environment in regards to NBS on buildings. To create this model, 3D vector data (shapefiles) was obtained from the Stockholm data portal which includes reliable building volume information derived through photogrammetry and laser scanning techniques. The dataset represents buildings in a simplified manner, with roofs and overall forms modelled as box-like volumes (See Figure 5.18). While this abstraction reduces geometric detail, it provides a consistent and computationally efficient basis for surface calculation and three dimensional spatial analysis.

In an initial surface comparison in SketchUp, the total building envelope surface (comprising all façade and roof areas) was calculated and set against the ground surface area of the study area (excluding the building footprints). The result reveals that building envelopes account for approximately 45% of the total available horizontal and vertical surface area in Tensta, highlighting their potentially significant spatial and environmental impact. While the building footprints cover roughly 23ha, the total building envelope amounts to approximately 92ha, indicating that the exposed surface area of buildings is nearly four times larger than their ground occupation (See Figure 5.18).

Figure 5.18.
Surface comparison in
Vertical Capacity Model (VCM).

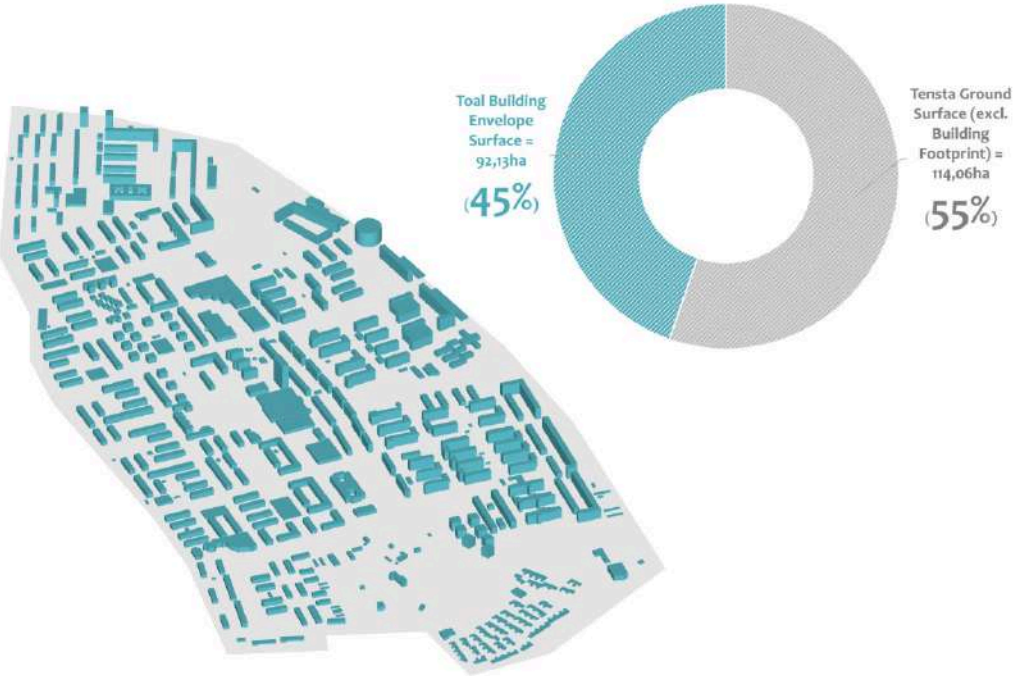


Figure 5.19. When importing the vegetated surface area from the earlier 2D land cover calculation, a new comparison can be made between vegetated ground surfaces and the combined non-vegetated ground plus building envelope surface.

This allows for a more nuanced understanding between ecologically active and non-active interfaces in the urban environment.

The outcome is predictable: as buildings are extruded, the total grey surface increases significantly, while the green surface remains constant. As a result, the proportion of vegetated surfaces drops from 48% in 2D to 34% in 3D.

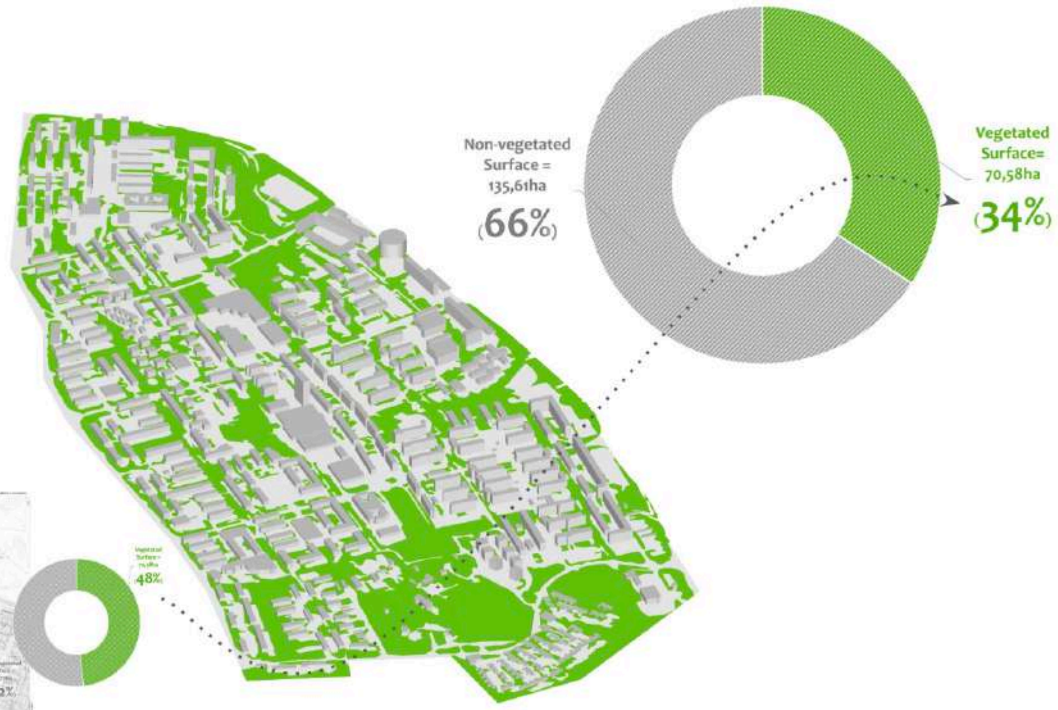


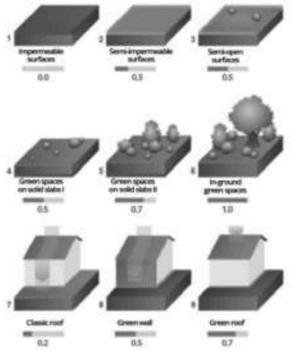
Table 5.1-2 Canopy-equivalent values derived from the Singaporean GnPR (URA 2017) and the German BAF (Becker Giseke Mohren Richard Landscape Architects 1990)

Green Plot Ratio (GnPR)

Feature Type	Typical LAI	Weighted Factor (=Canopy equivalent)
Standard Urban Tree	3.5	1.0
Intensive Green Roof	2.5 - 3.0	0.7 - 0.8
Extensive Green Roof	1.5 - 2.0	0.4 - 0.5
Vertical Green Wall	2.5	0.7
Green Facade (Climbers)	1.0 - 2.0	0.3 - 0.5

Biotope Area Factor (BAF)

Surface Category	Weighting Factor (=Canopy equivalent)
Sealed Areas	0.0
Partially Sealed Areas	0.3
Semi-enclosed Areas	0.5
Vegetation (Not connected to soil, substrate >80cm)	0.5
Vegetation (Not connected to soil, substrate <80cm)	0.7
Roof Greening	0.7
Green Vertical Areas (>=10m)	0.5
Vegetation (Connected to soil)	1.0



Since vegetation is not purely planar, and also occupies volume through its leaves, branches, and canopy structures, we can question whether this constitutes a fair or meaningful comparison. Attempting to represent vegetation through the same surface-based logic as built mass introduces a fundamental misalignment. While buildings can be quantified as enclosed, surface-producing objects, vegetation operates through porosity, volume, and atmospheric exchange. As such, treating vegetation purely as a 2D surface underestimates its spatial and ecological capacity, while translating it into equivalent 3D surface metrics risks misrepresenting its inherently diffuse and non-enclosed nature.

As the Stockholm GSF proved too detailed and complex for my Tensta case-study, I decided to use the canopy-equivalent values embedded in the German and Singaporean frameworks (See Table 5.1-2) to build a hybrid framework that valuates NBS on buildings against trees in full soil (See Table 5.3). This surface value framework will later on help me determine how much building surface needs to be retrofitted to reach my previously set 30% TCC target:

=

Table 5.3 Hybrid canopy equivalent framework

Hybrid Framework:

Feature Type	Weighted Factor (=Canopy equivalent)
Tree Canopy in full soil.	1.0
Intensive Green Roof	0.7
Extensive Green Roof	0.5
Living Wall (Substrate)	0.7
Green Facade (Climbers)	0.5

5.5 Classifying Building Envelope Surfaces

Before I was able to calculate how much building surface I have to "activate" in order to reach my TCC target, I first had to understand what types of surfaces are available, and how much of each surface type is actually present today.

Trough observations from both aerial perspectives, and on-site visits, it becomes clear that Tensta's built environment is composed of a heterogeneous mosaic of surfaces. This spatial diversity raises critical questions regarding the suitability of different surfaces for specific greening strategies, the varying degrees of human and ecological interaction they enable, and their contribution to the overall ecological capacity of Tensta.

In response to these considerations, I developed a classification system to differentiate building surface types based on their physical characteristics, functional role, and potential for ecological activation.

The classification system is organized into four categories:

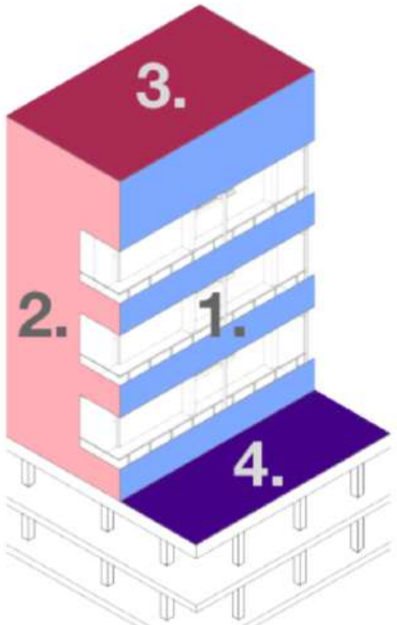


Figure 5.20. Diagram clarifying the surface categories.

1. Active Façade Surface:

Façade areas with ≥10% openings or glazing, enabling visual, spatial, and climatic exchange between interior and exterior. These surfaces are inhabited and interactive, typically including windows, doors, and balconies.

2. Inert Façade Surface:

Façade areas that are predominantly opaque and closed, with minimal or no openings. Often located on gable ends, these surfaces are non-interactive and represent latent potential for ecological transformation.

3. Inert Roof Surface:

Horizontal or slightly inclined surfaces (≤20°) that are inaccessible and primarily technical in function. These include conventional rooftops with potential for future activation, such as green roofs, water retention, or energy systems.

4. Active Roof Surface:

Horizontal surfaces that are accessible and/or in use, such as courtyards, terraces, or parking decks. These function as a form of elevated or artificial ground, possibly supporting social activity, movement, or emerging ecological functions.

Figure 5.21. Images clarifying the surface categories (Google Earth 2023).

5.6 Quantifying Building Envelope Surfaces

Due to the relatively uniform urban character of Tensta, it was possible to visually identify and categorise all buildings and their façades into one of the four categories by using the fly-over tool of Google Earth. Subsequently, within the VCM model, the surfaces of each building block were manually assigned a category-specific colour. This enabled the selection and surface measurement of all planes belonging to the same category at once, allowing for a quantitative comparison between the different surface types.

The results of this analysis (See Figure 5.22) show that approximately 63% of the total building envelope can be classified as "active surfaces", while 37% remains "inert". The high proportion of inert surfaces like roofs and building out ends, is particularly relevant, as these areas offer strong potential for the application of NBS.

Additionally, parking decks, which are essentially accessible roofs, account for nearly 10% of the total building surface, highlighting a significant spatial resource whose future use may shift in response to declining car ownership.

Important note: this initial comparison still included surface openings (e.g. windows, balconies, gates). To account for their impact on the effective surface area, an "Opening-to-Solid Ratio" is introduced.

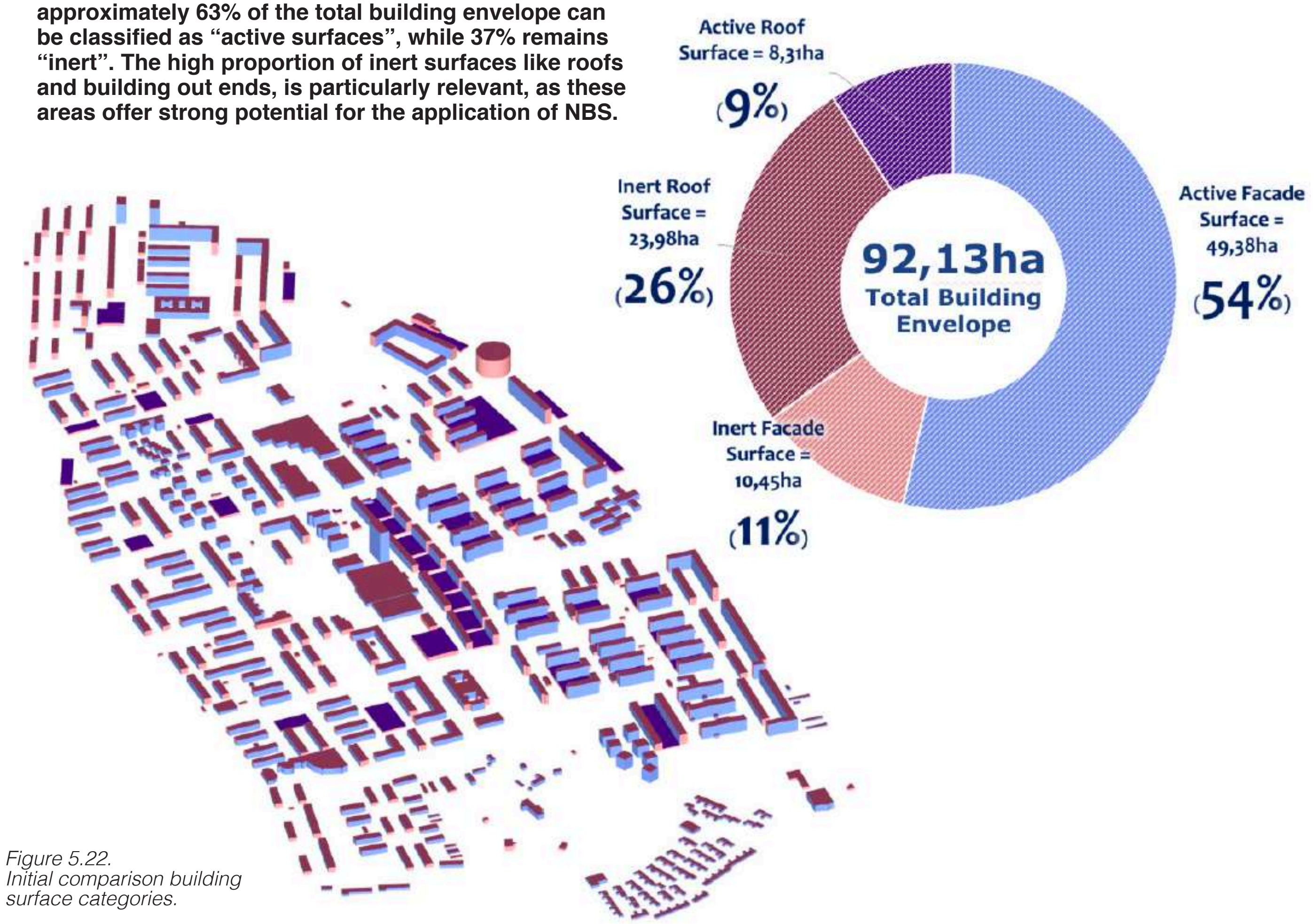


Figure 5.22. Initial comparison building surface categories.

Opening-to-Solid Ratio (OSR)*

The OSR is a metric which I developed to quantify the degree of openness within the envelope of the built environment. This index is inspired by the Window-to-Wall Ratio (WWR), commonly used in building energy performance assessments (Sayadi et al. 2021); While WWR only evaluates the proportion of glazing within a façade, the proposed OSR expands this logic to encompass the full building envelope, including both windows and spatial voids such as balconies and loggias.

A key motivation for introducing this metric is to ensure that strategies for vertical greening do not negatively impact essential building functions. Openings within building envelopes usually play a critical role in providing natural light, ventilation, general accessibility, and therefore must be carefully considered when evaluating the vertical capacity for ecological interventions.

When it comes to inert facade surfaces, and roof surfaces, I will in this study presume that they are largely solid, with exception of some roof lights, or for instance the presence of an emergency door in a gable end. To count in these minor surface exceptions, I will count these surfaces with an OSR of 0,05; or 5% "open".

When it comes to the active facade surfaces their OSR is evidently much more dependent on the building typology. (The OSR of an all-glass office curtain wall, will for instance be much higher than the solid facade of a modernistic slab building with punched windows.)

Due to the urban character of the Tensta, as it consists largely of similar typology residential slab buildings built around the same time period. I finally decided to determine an overall OSR for all active facade surfaces approximated through 20 representative sample façades (See Figure 5.23).

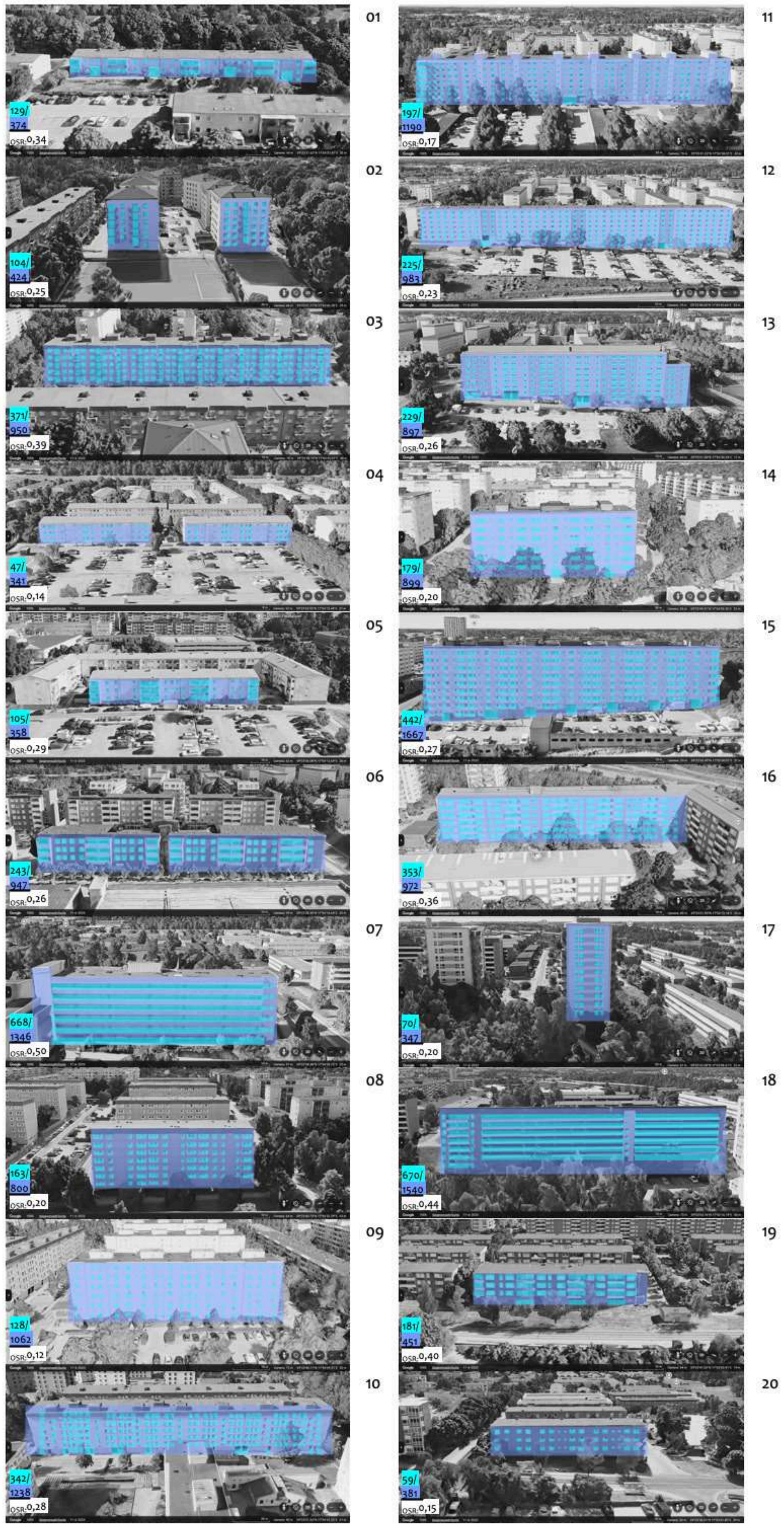


Figure 5.23

The resulting OSR values cluster between 0.20 and 0.35. The average OSR turned out to be 0.27, or in other words 27% open and 73% closed. The median value (0.26) closely aligns with the mean (0.27), indicating a consistent façade typology across the different samples. These numbers indicate a predominantly solid façade composition with significant potential for vertical greening interventions.

(Google Earth 2023)

After applying an OSR to all building surfaces, the final result reveals that building envelopes in Tensta constitute a substantial and differentiated spatial resource (See Figure 5.24).

The active façades (47%) still are the largest impact field as they continue to hold the biggest surface. These surfaces should therefore be my primary intervention layer.

Inert roofs (30%) hold the second biggest untapped reserve. These large unused surfaces with low conflict to existing usage may hold my most efficient transformation potential, yet their implementation potential is heavily dependent on the structural capacity of the structures below.

Inert façades (13%) are smaller in share, but likely easier to retrofit, while active roof surfaces (10%) may hold the most socio-ecological potential in the coming years.

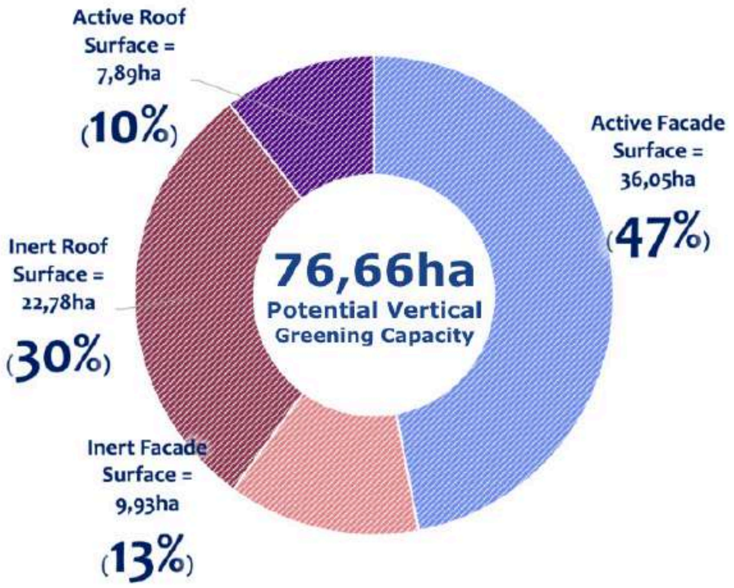


Figure 5.24.
Final surface comparison building surface categories Tensta.

5.7 System-Surface Design Matrix & Spatial Scenario’s

Having established the typology and extent of the building envelope surfaces in Tensta, two final questions emerge:

1. **What greening systems are most suitable for each surface category?**
2. **How much of each surface category should be activated to reach my 30% TCC target?**

In order to provide an answer to these questions I combined the design characteristics of the most common Green Roofs (GR’s) and Vertical Greening Systems (VGS), (See 1.2, Chapter 01) together with the greening potential of each of my four building surface categories.

This resulted in the following system-surface design matrix:

	1. Active Façade Surface	2. Inert Façade Surface	3. Active Roof Surface	4. Inert Roof Surface
Core Role	Human interface + micro-climate regulation	High-impact retrofit surfaces	Social-ecological platform	Large-scale infrastructure (water & ecology)
Primary Interventions	* Climbing green façades (trellis / cable systems) * Balcony-integrated planting systems * Semi-transparent green screens	* Living wall systems (modular / hydroponic) * Direct green façades (ground-rooted climbers) * Habitat-integrated (bird boxes, insect niches)	* Intensive green roofs / roof gardens * Urban agriculture (community gardens) * Biodiverse habitats (pollinator roofs)	* Extensive green roofs (low maintenance) * Blue roofs (storm water retention) * Bio-solar roofs (green + PV synergy)
Design Guidelines	* Avoid blocking daylight / ventilation * Use seasonal vegetation (deciduous for solar gain control) * Integrate with user control (residents maintain/interact) * Prioritize solar-exposed orientations	* Target dark, south oriented uninsulated walls * Use low-tech systems where possible (cost-efficient scaling) * Combine with rainwater & grey water harvesting *Increase structural and substrate diversity	* Design for multi-functionality (social + ecological stacking) * Ensure safe access + circulation * Maximize soil depth diversity * Include water retention + reuse systems	* Prioritize large, flat roofs for maximum impact * Combine water + energy systems * Optimize for coverage over intensity * Use lightweight substrates where needed
Constraints	* Structural limits * Maintenance responsibility * Safety regulations	* Installation cost * Irrigation dependency * Maintenance & access	* Structural load capacity * Accessibility regulations	* No direct social use * Visibility is low * Retrofit feasibility varies

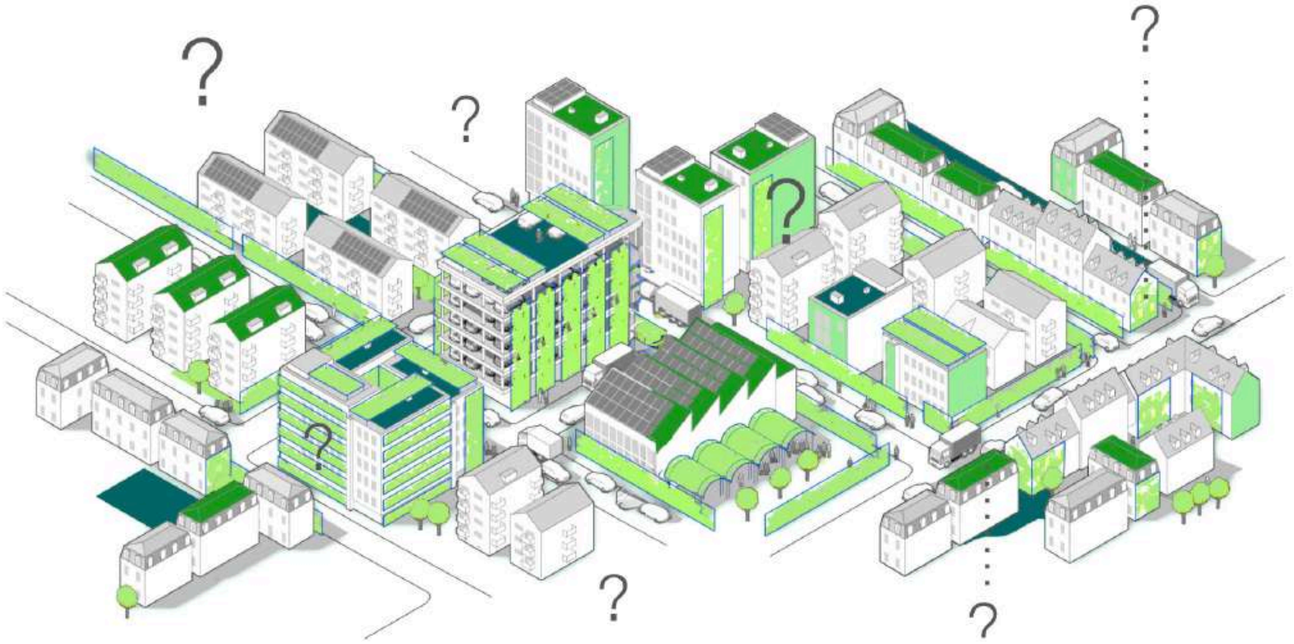


Figure 5.25.
Conceptual illustration system-surface analysis (SketchUp).

According this matrix, I conclude that the system and surface type characteristics overlap relatively well, and therefore each surface category could be paired with a specific greening strategy and corresponding canopy equivalent (CE) value (as established in section paragraph 4.7); For simplified calculation:

> Active Façades can be paired with climbing systems (0.5 CE) to prioritize human interface.
> Inert Façades can be paired with living walls (0.7 CE) for high-impact technical retrofitting.
> Active Roofs can be paired with intensive green roofs (0.7 CE) to create social platforms.
> Inert Roofs can be paired with extensive green roofs (0.5 CE) for large-scale infrastructure.

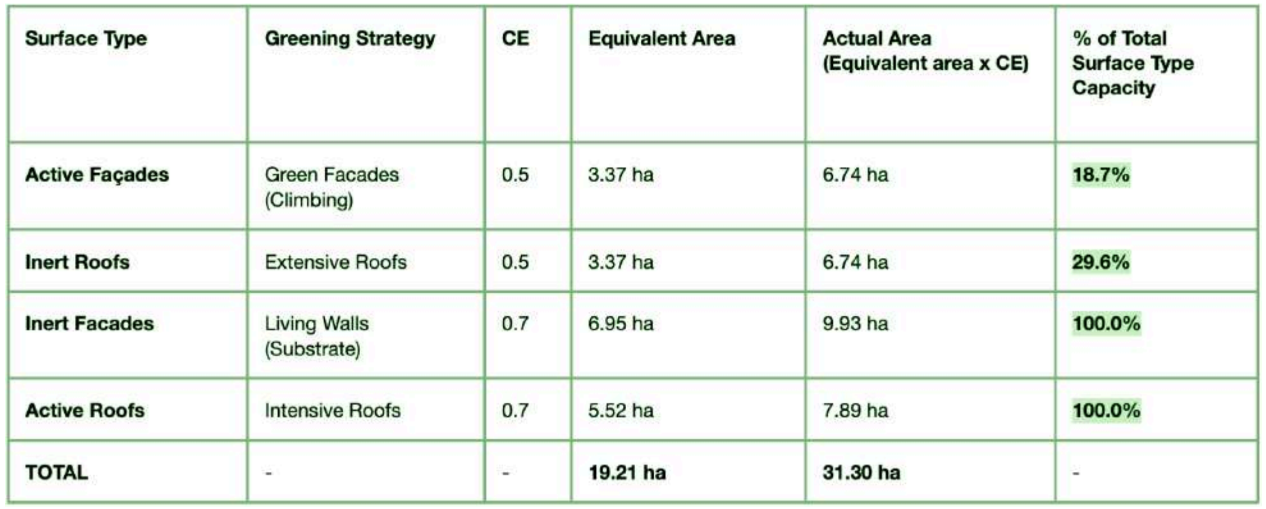
These system-surface pairings, together with the surface quantity study, allow me to define spatial scenarios where the 13% TCC (19,21ha) deficit would be fully or partly provided by different sorts of envelope greening:

Scenario 1: Balanced Proportional Approach

Surface Type	Greening Strategy	CE	Equivalent Area	Actual Area (Equivalent area x CE)	% of Total Surface Type Capacity
Active Façades	Green Facades (Climbing)	0.5	9.03 ha	18.06 ha	**50.1%**
Inert Roofs	Extensive Roofs	0.5	5.76 ha	11.52 ha	**50.6%**
Inert Facades	Living Walls (Substrate)	0.7	2.50 ha	3.57 ha	**36.0%**
Active Roofs	Intensive Roofs	0.7	1.92 ha	2.74 ha	**34.7%**
TOTAL	-	-	**19.21 ha**	**35.89 ha**	-

Table 5.4.
In the first scenario, I followed the existing ratio of available urban surfaces (47% façades, 30% roofs, etc.) This would create a distributed impact across all building types. However, the greening strategies paired with the most available surface types also have the lowest CE values. As a result, this scenario relies heavily on climbing greenery and extensive roofs. Since up to 50% of active façades and inert roofs would need to be activated, this scenario is unlikely to occur in practice.

Scenario 2: High-Efficiency Priority



Surface Type	Greening Strategy	CE	Equivalent Area	Actual Area (Equivalent area x CE)	% of Total Surface Type Capacity
Active Façades	Green Facades (Climbing)	0.5	3.37 ha	6.74 ha	**18.7%**
Inert Roofs	Extensive Roofs	0.5	3.37 ha	6.74 ha	**29.6%**
Inert Facades	Living Walls (Substrate)	0.7	6.95 ha	9.93 ha	**100.0%**
Active Roofs	Intensive Roofs	0.7	5.52 ha	7.89 ha	**100.0%**
TOTAL	-	-	**19.21 ha**	**31.30 ha**	-

Table 5.5.
In a second scenario, I prioritized the most space-efficient greening strategies by focusing on surface types with higher CE values. If these surfaces are utilized to their full capacity (100%) we could reduce the required implementation rates for active façades and inert roofs and minimize the total area that needs to be greened to reach the TCC target. Requiring the full deployment of living walls and intensive roofs may however introduce its own challenges, as these systems are typically more technically complex, structurally demanding, and costly to implement and maintain.

Scenario 3: Uniform Capacity Approach

Surface Type	Greening Strategy	CE	Equivalent Area	Actual Area (Equivalent area x CE)	% of Total Surface Type Capacity
Active Façades	Green Facades (Climbing)	0.5	8.27 ha	16.53 ha	**45.9%**
Inert Roofs	Extensive Roofs	0.5	5.22 ha	10.44 ha	**45.9%**
Inert Facades	Living Walls (Substrate)	0.7	3.19 ha	4.55 ha	**45.9%**
Active Roofs	Intensive Roofs	0.7	2.53 ha	3.62 ha	**45.9%**
TOTAL	-	-	**19.21 ha**	**35.14 ha**	-

Table 5.6.
In a third scenario, I equally distributed the required greening effort across all surface types. Also this scenario still requires a relatively high implementation rate, with almost half of each available surface needing to be greened. This may still be challenging in practice due to structural limitations, ownership fragmentation, regulatory constraints, and maintenance capacity.

Since the previous scenario's show that I have to activate a relatively high and possibly unachievable percentage of building surface in order to reach my TCC target, and for planting 19.21 ha of tree canopy, or roughly 7.684 trees, there is likely not enough public funding, support or unsealed ground; It makes most sense to develop a fourth hybrid scenario where a combination of tree planting and envelope greening is employed:

Final Scenario: Hybrid Approach

Surface Type	Greening Strategy	CE	Equivalent Area	Actual Area (Equivalent area x CE)	Count/ % of Total Surface Type Capacity
New Trees	Tree planted in full soil	1.0	9.61 ha	**9.61 ha**	**3,842 Trees**
Active Façades	Green Facades (Climbing)	0.5	4.13 ha	**8.26 ha**	**22.9%**
Inert Roofs	Extensive Roofs	0.5	2.61 ha	**5.22 ha**	**22.9%**
Inert Facades	Living Walls (Substrate)	0.7	1.59 ha	**2.28 ha**	**22.9%**
Active Roofs	Intensive Roofs	0.7	1.27 ha	**1.81 ha**	**22.9%**
TOTAL	-	-	**19.21 ha**	**27.18 ha**	-

Table 5.7.
By splitting the TCC deficit by incorporating 50% tree planting (ca. 9.61 ha or 3.841 trees) alongside a uniform greening effort across all building categories; a multi-layered, three-dimensional urban greening model could be achieved. Further this also reduces the activation requirement of the four surface types to a more modest 22.92%, which makes this scenario significantly more achievable and equitable.

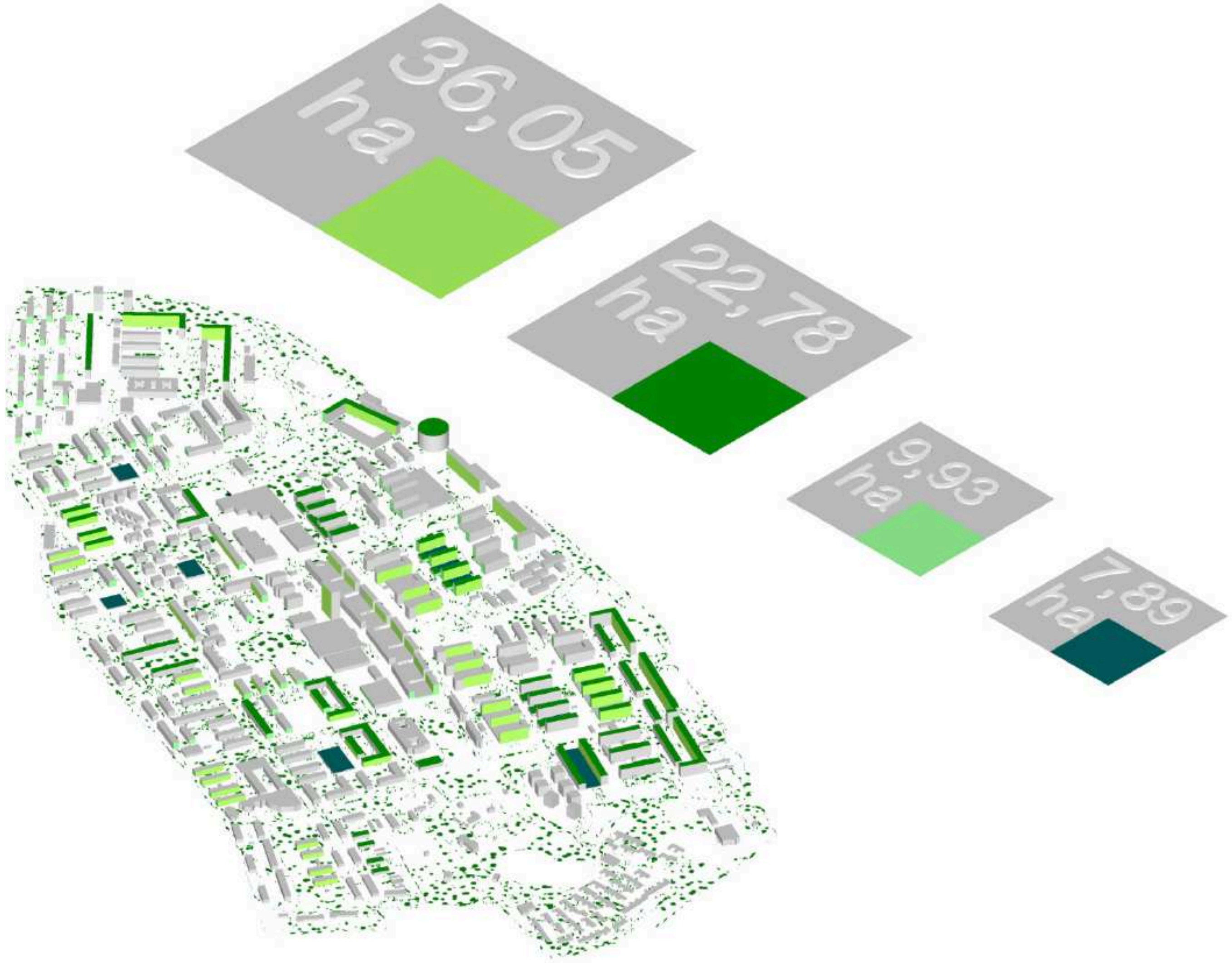


Figure 5.26.
Visualization of the final greening scenario in VCM.

When visualised in the VCM (See Figure 5.26), the final spatial scenario reveals an abstract image of how Tensta's urban landscape would be impacted. At the same time, it highlights the significant challenge of gaining support from municipal authorities, private property owners, and thousands of residents for the implementation of many hectares of NBS in their city.

In the final chapter, the focus will shift to the development of four pilot projects (one for each surface category) demonstrating the possible potential of VUE on a building-neighborhood scale. These pilots are meant to inspire both policy makers, residents, designers and developers.

CHAPTER 6:

Implementation Strategies, Pilot Projects & Mock-up

Through pilot projects, governance analysis, and physical prototyping, this chapter explores how Vertical Urban Ecology might move from a conceptual and volumetric framework to practical intervention.

Note on AI Usage*

In this chapter, generative AI tools were used to transform and reinterpret selected Google Earth perspectives into speculative visualizations. The AI-generated images functioned as interpretative and exploratory tools, helping to visualize scenarios that are difficult to communicate through conventional drawings alone.

The outputs were critically evaluated in relation to the project's theoretical framework, site analysis, and design intentions. All final images were edited and selected manually. Indicative prompts and the AI tools used are documented in the image captions and reference list.

> An additional reflection regarding AI image production, detailed prompts and process were also added in the appendix of this thesis.

6.1 Analytical Framework for Pilot Evaluation

The implementation and governance of VUE in Tensta will, apart from spatial potential, depend strongly on ownership structures, governance arrangements, financing mechanisms, maintenance regimes, and resident acceptance. As discussed in Chapter 02, the implementation of NBS on existing privately owned property can currently only be secured through voluntary commitments formalised in agreements (Brokking et al. 2021). Under current Swedish and Stockholm planning conditions, municipalities have limited control over privately owned property, meaning that building-integrated NBS generally cannot be legally imposed on existing housing stock in the same way as in public space.

If VUE relies solely on voluntary action by individual property owners, large-scale implementation is likely to remain challenging. As discussed in the previous chapter, green roofs, green façades, and living wall systems introduce additional costs, maintenance responsibilities, and technical risks. For this reason, there is a need to develop implementation strategies and pilot projects that translate the possible benefits identified in the literature into feasible projects for Tensta's existing built environment and all actors involved.

The NBS benefits discussed in Chapter 01: (I) thermal performance, (II) climate adaptation, (III) water management, (IV) biodiversity support, (V) human well-being, and (VI) socio-economic value; will therefore be employed in this chapter as analytical parameters for evaluating the opportunities and limitations of different proposals (See Diagram & Table 6.1).

These parameters represent the most consistently documented benefits associated with building-integrated NBS. Together with the governance, ownership, and renovation dynamics discussed in Chapter 02 and Chapter 03, they provide a framework for assessing how different implementation scenarios respond to both the opportunities and constraints of the Tensta context.

Diagram 6.1.
Outlines spider diagram for evaluating the opportunities and limitations of pilot projects.

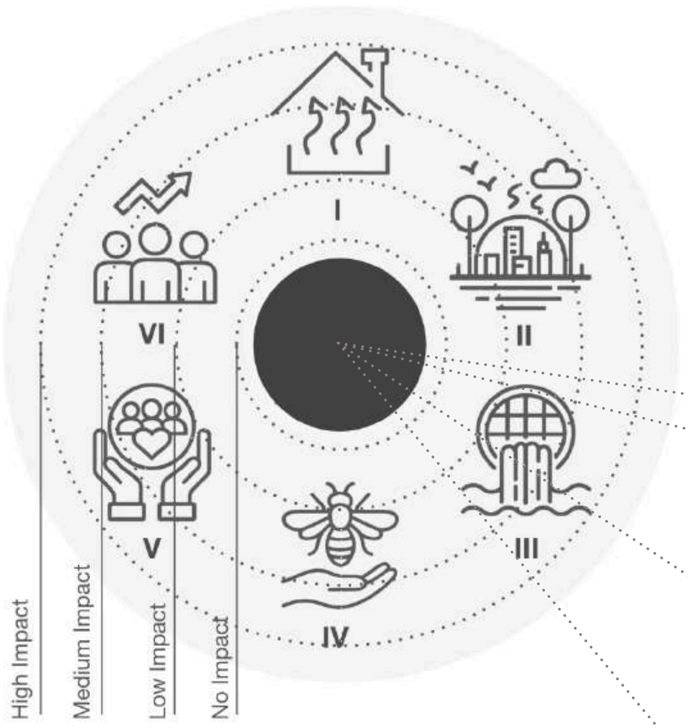


Table 6.1.
Analytical parameters for evaluating the opportunities and limitations of pilot projects.

Parameter		Evaluation
I.	**Thermal Performance**	Does the intervention improve thermal comfort or building performance?
II.	**Climate Adaptation**	Does it contribute to cooling, resilience or climate adaptation?
III.	**Water Management**	Does it retain, infiltrate or reuse water?
IV.	**Biodiversity Support**	Does it provide habitat, connectivity or ecological value?
V.	**Human Well-being**	Does it improve environmental quality and resident experience?
VI.	**Socio-econo mic Value**	Does it support stewardship, participation or neighbourhood regeneration?

6.2 Governance Pathways for Vertical Urban Ecology

While the analytical parameters extracted from the literature highlight the possible benefits and limitations of the pilot's, they do not automatically explain how such interventions might be realised in practice. Consequently, the question shifts towards understanding which actors, institutions, and governance arrangements are capable of initiating, funding, implementing, and maintaining these interventions over time.

In this regard, several governance pathways could be imagined, each characterised by different distributions of responsibility, decision-making power, and implementation capacity.

From this perspective, the pilot projects in this thesis should not be seen as stand-alone design proposals but rather as strategic governance tests. Each pilot explores different implementation conditions: municipal leadership, private-owner negotiation, resident participation, utility-company involvement, or bottom-up prototyping.

1. Top-down municipal approach

This governance model involves stronger policy requirements, subsidies, ecological standards, and renovation-linked incentives and could include municipal green roof programmes, climate adaptation grants and publicly funded renovation projects. This approach is strongest where the municipality or municipal housing companies own the land or buildings.

2. Negotiated public-private approach

This governance model relies on agreements between the municipality, private property owners and resident associations. In this model, VUE measures would need to be framed not only as ecological improvements, but as multifunctional investments that contribute to for instance storm water management, reduced infrastructure pressure, biodiversity, improved living environments, and long-term asset resilience. However, this approach requires clear distribution of costs and benefits between actors.

3. Bottom-up/ Community-based approach

This governance model can be characterized by local interventions such as façade planting, courtyard gardening, biodiversity monitoring, citizen science, and stewardship programmes. These strategies are unlikely to achieve district-scale ecological targets on their own, but they may strengthen local ownership, environmental awareness, and long-term care. They are therefore especially relevant when combined with larger institutional investments.

4. Hybrid governance approach

This governance model is what we would strive for on a district level; The municipality sets strategic ecological goals and provides incentives; public housing companies test and demonstrate scalable solutions; private owners are encouraged to participate through renovation-linked agreements; and residents are involved through consultation, stewardship, and monitoring. This approach would shift VUE from a purely voluntary greening strategy towards a coordinated effort on a neighbourhood scale.

6.3 Tensta’s Ownership Structures

Having established the analytical framework and possible governance pathways for VUE, the next step was to examine how these conditions manifest within the study area itself. To gain a better understanding of potential implementation locations and governance pathways, the existing ownership structure within the selected study area was mapped. In Tensta, approximately sixteen major actor groups could be identified and broadly categorised as public, private, cooperative, or tenant-owned. When visualising these legal and organisational structures, several patterns emerged:

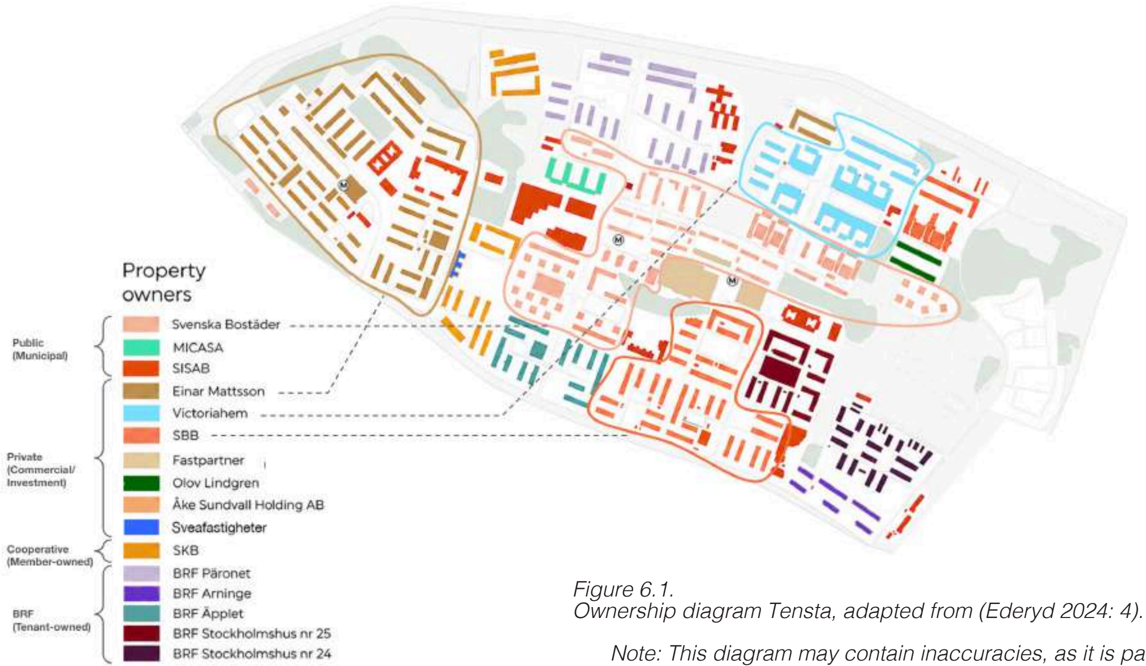


Figure 6.1.
Ownership diagram Tensta, adapted from (Ederyd 2024: 4).

Note: This diagram may contain inaccuracies, as it is partly based on a former student study and not all property transfers are publicly available.

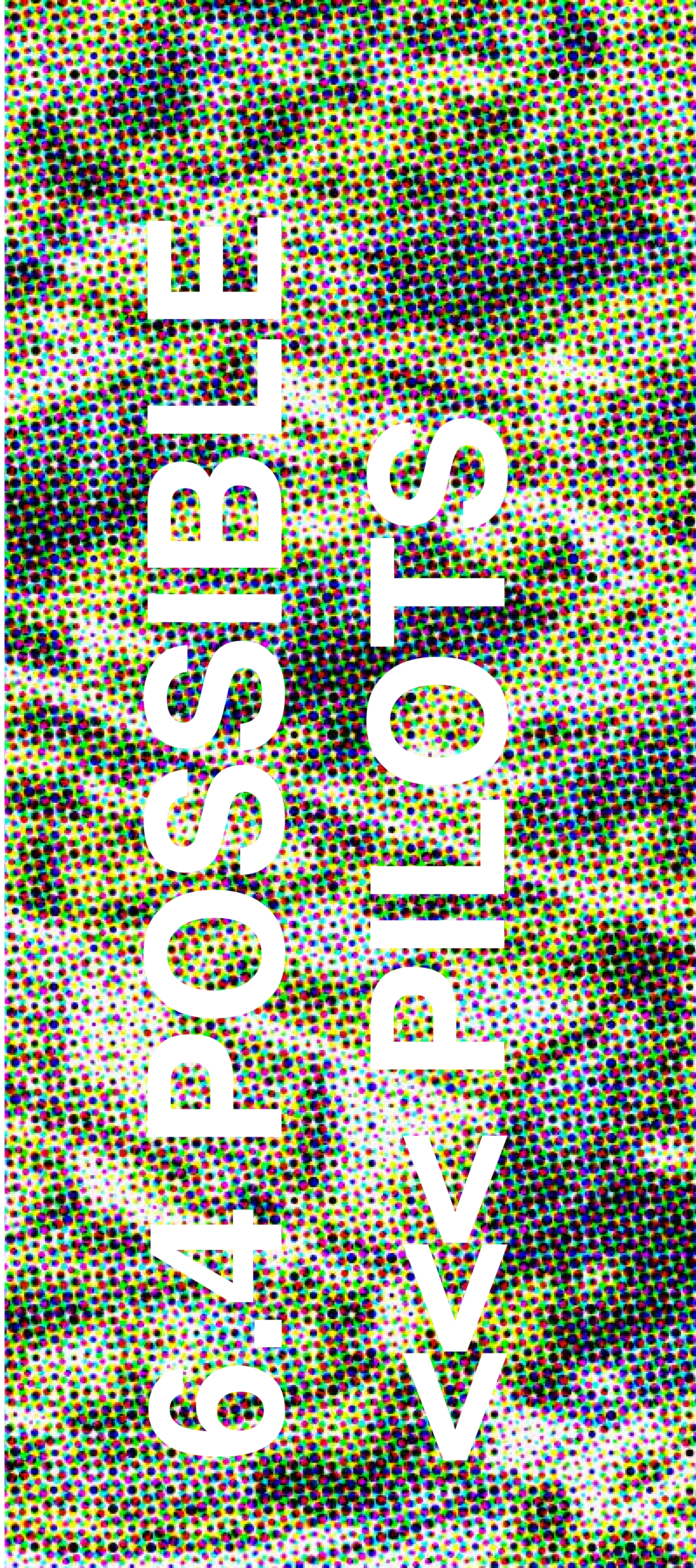
At first, the diagram shows that large, contiguous residential areas are controlled by single actors, particularly in the western, central, and north-eastern parts of the site. These zones are owned and managed by large landlords like family-owned real estate company Einar Mattsson AB, publicly listed real estate company SBB (Samhällsbyggnadsbolaget i Norden AB), publicly owned municipal housing company AB Svenska Bostäder, and private residential real estate company Victoriahem AB. This legal and spatial structure, forming defined neighbourhood-scale clusters, might provide good conditions for pilot districts, where greening systems can be deployed at larger scales and generate visible spatial impact. Many of these actors also manage extensive property portfolios beyond the study area, which opens up the potential for larger urban implementation strategies, where successful interventions could be scaled and replicated across their holdings.

Second, the southern and northern parts of the district show a more fragmented structure composed of smaller BRF (bostadsrättsförening) clusters. These are housing cooperatives where residents buy a share in the association. The BRF owns the property and is responsible for maintenance, financing, and common areas, while residents pay a monthly fee to cover shared costs and any association loans. As these organisations are democratically run by their members, and each property involves separate decision-making processes; implementation will be dependent on incentives, demonstration effects, and the social dynamics within the BRF.

While the fragmented ownership structure of the BRF may complicate large-scale implementation, it simultaneously creates opportunities for bottom-up approaches and more experimental smaller-scale interventions such as façade planting, biodiversity monitoring, wildlife gardening, and community-led greening projects.

Third, we can address how municipal companies like SISAB (Skolfastigheter i Stockholm AB), a property company which owns and manages most school properties in the area; or private investment company Fastpartner AB, which owns and manages Tensta’s commercial center; could form strategic partners as their properties are more dispersed and located in public areas where a wider range of residents can be introduced to the VUE concept. From a governance perspective, these actors highlight the importance of negotiated public-private implementation pathways.

These findings suggest that the implementation of VUE in Tensta will require a combination of governance pathways rather than a single implementation model. While large ownership clusters offer opportunities for district-scale interventions, public sites and BRF areas provide important platforms for demonstration projects, stewardship, and community participation. The following pilot projects build upon these conditions and explore how different governance pathways may support different forms of VUE.



6.4 POSSIBLE <<< PILOTS

PILOT 01: “Tensta Takterrängen” - Rooftop Parkfarms on Parking Decks

Tensta’s shopping district with its adjacent parking structure and surrounding streets and squares are among the most “grey” zones in the district with vast impermeable surfaces characterizing both streetscapes, façades and roof structures (See Figure 6.2).

The shopping centre and adjacent parking are currently owned and managed by Fastpartner AB. On their website, I found that the centre was inaugurated in 1969 and up until today stands as a welcoming heart in the middle of Tensta. Their goal is to encourage everyone to contribute to an environment where shops and restaurants can flourish and residents and visitors can thrive. Since Tensta Centrum plays an important public role, it is a strategic location for fostering initial awareness and understanding of the VUE concept.

During my walks in the district, especially the large four-deck customer parking on the east-side of the shopping centre captured my attention. This multi-storey garage holds today about 350 parking spots, of which about 100 on its rooftop level.

A review of aerial imagery on Google Earth, from the early 2000s to the present, suggests that the rooftop level has remained largely unused, consistently appearing without parked cars. This observation was further supported by multiple site visits, during which the upper deck was unoccupied each time and concrete blocks had even been positioned to block almost half of the rooftop surface (See Figure 6.3-4).

At the same time, local reporting has highlighted the deteriorated condition of the parking structure, describing visible wear, soot marks from earlier fire incidents, and an overall sense of neglect, despite the building still being considered structurally safe (Johansson 2026).

This further raises the question whether this rooftop (approximately 50×65m) could be re-purposed instead of remaining an underused concrete surface. Within the framework of my “active roof surface” category, the rooftop presents clear potential for intensive greening, given its central location, structural characteristics, and public accessibility.

Figure 6.2. Tensta’s shopping district with its adjacent parking structure (Google Earth 2023).

Figure 6.3-4. Vacant rooftop level parking Tensta Centrum, May 2026.

Figure 6.5. Heerlen Rooftop Project. (Schunck 2022) (CC BY 4.0).

Learning from Others: ‘Heerlen Rooftop Project’, NL*

To get a better understanding on how to initiate this pilot, I consulted Andrea Croé, Senior curator architecture & urbanism at Schunck, a multidisciplinary cultural institution in Heerlen in the Netherlands. Andrea was one of the initiators and project leaders of the ‘Heerlen Rooftop Project’, a reconversion project of a rooftop parking lot of Q-Park Putgraaf Heerlen in the Netherlands (2022-2026). In this project, the Amsterdam-based collective ‘Selvatico’ was selected to transform an existing car park rooftop into an urban garden that invites the re-appropriation of existing roof space by local citizens.

The parking deck in Heerlen (See Figure 6.5), also titled ‘The Countryside’ was designed to form a recreational area that draws inspiration from the crop patterns that characterize the Dutch countryside. On a 1200 m2 concrete roof, 57 varieties of plant species were grown in 250 movable wooden crates. Apart from planters, social spaces for spontaneous meetings and interactions were introduced in different ‘room’ types: ‘Wilderness’, ‘Tea’, ‘Chromatic’, ‘Edible’ and ‘Aphrodisiac’; each defined by the density, smell, height, color, texture, and use of the plants that they host. The ideology behind this rooftop project was to inspire the residents of Heerlen to play a key role in the sustainable climate adaptation of their city (Azaria 2022).

> “ *During my interview with Andrea Croé (May 8, 2026), she explains that the final rooftop project emerged as the concentrate of a broader design competition in which many international designers submitted proposals for greening the roofs of Heerlen. Following a structural analysis of several buildings across the city, the Putgraaf parking complex was selected and an agreement was reached allowing the roof deck to be used free of charge during the summer of 2022.*
>
> *The installation, management, and maintenance of the project were organised by the museum in collaboration with numerous other, often voluntary, parties. During that summer, the project was initiated by Schunck, which hosted a wide range of social and cultural activities; including dance performances, music events, lectures, and public gatherings. In the autumn of 2022, responsibility for the project was transferred to the municipality and the organisation ‘Stadstuin’, which had already played an important role in the realisation-period. A three-year extension agreement was established and eventually terminated in 2025.*
>
> *Andrea believes that the absence of direct financial benefits for the building owner and parking operator, aside from the positive public image, ultimately became one of the primary reasons for the project’s termination. At the same time, the high location of the parking deck created practical difficulties for the operating organisations, making basic maintenance both challenging and expensive. Additionally, the project relied entirely on municipal water supply because installing a rainwater harvesting system proved technically complex and financially unfeasible, further complicating the long-term viability of the initiative.*
>
> *At last Andrea considers the project highly valuable for generating awareness and enthusiasm around green rooftops and elevated urban landscapes. Nevertheless, technical, practical, and economic considerations are essential for developing sustainable long-term rooftop activation strategies. She therefore advocates for longer-term spatial use agreements, which would allow rooftop communities and ecosystems to evolve more organically over time, while also encouraging stronger financial alignment with building owners and operators.* ”

Figure 6.7. Granholmens koloniträdgårdsförening Tensta, April 2026.

Program & Organizational Outlines*

A temporary, and potentially permanent, intensive green roof project on the Tensta Centrum parking deck could offer significant social, ecological, and economic benefits. As outlined in the Spånga-Tensta park plan, the allotment gardens in Tenstadalen and Järvafältet (See Figure 6.7) are highly popular, with long waiting lists and only a limited number of residents able to obtain a plot.

Bringing opportunities for gardening and food production closer to the dense urban centre, would therefore likely be well received by local residents and would contribute to increased biodiversity and improved public health. In that sense, the Heerlen Rooftop Project forms an inspiring blueprint for a socio-ecological awareness-pilot project in central Tensta.

From an economical perspective, just as in Heerlen, the parking structure is owned by a private property holder (Fastpartner AB) and rented by a parking operator (Svea P-Service AB). Establishing a long-term "roof-use" agreement with these parties, the municipality and local grower associations could possibly create a mutually beneficial arrangement.

Associations or resident groups could take responsibility for the day-to-day maintenance of cultivation plots, fostering a sense of ownership and stewardship. The property owner and municipality would play a facilitating role by ensuring structural safety and basic infrastructure.

Figure 6.8. Images created with KREA.ai from the prompt "project description & aerial imagery Google Earth 2023", 2026).

Spatial outlines*

The spatial and structural organisation of this pilot would in the beginning likely prioritize cheap, lightweight, modular, and reversible interventions. Similar to the project in Heerlen, raised planting beds constructed from recycled materials such as palettes or crates could be built in collaboration with future user groups. Since the roof is accessible by motorized traffic, it would be relatively straightforward to get materials and tools on deck, substrate would likely have to be lifted in via crane.

Standardised planter typologies could enable controlled soil depth and weight distribution over the parking deck. A garden coordinator or association board would likely decide over how the different cultivation beds are arranged, allowing for a safe and equitable spatial organisation (See Figure 6.8). In terms of ecological performance, creating a gradient from highly active to more passive and biodiverse roof zones could be introduced, with for instance peripheral zones reserved for more ecologically driven functions.

Irrigation would preferably happen primarily through harvested rainwater from the parking deck itself, or from close-by blue-green roofs (see pilot project 04).

Vegetation could range from productive crops to flowering species enhancing biodiversity and seasonal variation. In the first years the pilot could be set-up as a temporary installation, if the concept proves successful, it could potentially lead to a more permanent transformation. According to the final TCC scenario, I would have to convert 5-6 similar sized parking decks or courtyards in Tensta to reach about 1.81ha of intensive green roof coverage.

Figure 6.9-10. Image converted with KREA.ai from the prompt "project description & aerial imagery Google Earth 2023", 2026).

Analytical Framework*

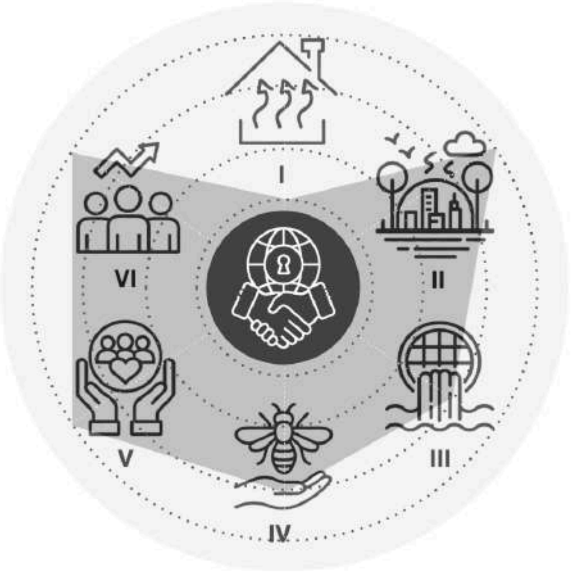


Diagram & Table 6.2.
Spider diagram evaluating the opportunities and limitations of pilot 01.

Parameter	Evaluation
I. Thermal Performance	/
II. Climate Adaptation	High
III. Water Management	Medium
IV. Biodiversity Support	Medium
V. Human Well-being	High
VI. Socio-economic Value	High
Governance Model	Negotiated public-private approach

This pilot performs strongest in relation to climate adaptation, human well-being, and socio-economic values as it demonstrates how underutilised active roof surfaces can become multifunctional spaces that support local food production, recreation, stewardship, and environmental awareness. It's success of implementation will depend strongly on a negotiated public-private governance model, requiring cooperation and agreements between private property owners, public actors, and local associations/user groups.

PILOT 02: “Vattenvägg” - Living Wall Systems on Blank Façades

In Tensta I measured a total of 9.93ha of “inert facade surface”, or approximately 14 international football fields. In many cases these “blank” façades are positioned at the outer ends of the many prefabricated slab blocks, lamella houses, and loft-access buildings (See Figure 6.11-12). As the naming of the category already suggests, most of these surfaces have currently little to no function and a rather grim aesthetic. Instead of treating them as passive elements to be insulated and refinished, as it’s mostly done in the current renovation agenda, this pilot proposes their transformation into active environmental surfaces.

In my final TCC target scenario, inert façades are paired with living walls for high-impact retrofitting. However, as I learned in my system analysis, living wall systems are among the more expensive and technically complex NBS, and need multi-targeted implementation strategies in order for them to be viable for property owners. The argument must therefore extend beyond their high ecological value (0,7 CE) and engage directly with functional and financial feasibility. The key question rises: why invest in living systems instead of conventional façade renovation strategies?

A possible approach could be to focus on living walls capable of decentralized water management at building or neighbourhood scale. With approximately 19.000 residents in Tensta, the cumulative impact of water reuse and on-site treatment could be substantial and an important argument. In order to valuate the technical capability of living walls in regards to water saving and treatment, I interviewed Teun Depreeuw. He started the company ‘Muurtuin BVBA’ about 15 years ago, a Belgian SME which supplies high-end living wall systems that allow for grey water purification and circular water use.

Figure 6.11-12. Tensta’s “blank” facades positioned at the outer ends of the many residential developments, April 2026.

Figure 6.13-15. ‘Total Value Wall’ system (Muurtuin 2022).

Learning from Others: ‘Total Value Wall’, BE*

Teun Depreeuw and his company approach vertical greenery and living walls not as separate systems or a purely aesthetic feature, but rather as an inclusive and indispensable part of a building’s envelope and technical functioning. A living wall constitutes for them the replacement of less sustainable traditional materials (metal, brick, concrete, etc.) while simultaneously providing additional benefits; such as filtering wastewater, catching particulate matter, oxygen production, sound insulation, improved fire safety, and reducing the urban heat island effect.

Over the years, Muurtuin has developed a fully-functioning ‘Total Value Wall’ system in collaboration with Flanders Circular, Vlakwa, and Ghent University. This modular system offering an adaptive greening solution to both new and existing buildings of different scales, was extensively tested with two full-scale pilot set-ups in Lier and Ghent (BE). The total value wall has proven that living walls can be used for the purification of grey water and enable circular water usage with water conservation up to 30% in each household (TotalValueWall 2019).

Their system is composed of a metal support frame that holds a growing medium, which is slightly offset against the structure of the building, creating a ventilated cavity which protects the facade from moisture and contributes to thermal regulation. At the core of the system we find a vegetated substrate layer, which basically functions as a vertical bio-reactor. A pocketed textile-based growing mat holds a variety of mostly evergreen plants (See Figure 6.13-15).

Domestic shower water, laundry water, and dish-washing water are distributed across the top of the system via a pumping system. From there, it flows downward by gravity. During this process, contaminants are biologically broken down, solid particles are filtered out, and nutrients are absorbed by plant roots.

This mechanism closely resembles that of a constructed wetland, but reconfigured into a vertical format. The treated water is collected at the base of the wall and reused for non-potable purposes such as toilet flushing or irrigation. In addition to water treatment, the system has proven to help with capturing airborne PM, supporting urban biodiversity, and reducing heat gain through shading and evapotranspiration. The added façade thickness improves thermal and acoustic insulation, while also protecting the underlying building structure from weather exposure (Ibid.).

> “ *According to my interview with Teun Depreeuw (April 24, 2026), their system is technically scalable to a Nordic and larger urban context. In a configuration where multiple adjacent buildings could be fitted with their solution, the system could even evolve from decentralised façade units, to a more centralised infrastructure with shared tanks, pumps and filtration installations. This could significantly reduce construction and operational costs per square metre. Maintenance routines (typically around three interventions per year) involving vegetation pruning, removal of dead biomass, and cleaning of filtration components also would become more efficient due to consolidated servicing routes and shared technical infrastructure.*
>
> *According to Depreeuw, it is also advisable to integrate the cost of this maintenance with other recurring building fees. This ensures that maintenance is not treated as an optional or irregular expense, but as a continuous, professionally managed service embedded in the long-term operation of the building system.*
>
> *Climatic conditions in Stockholm, particularly winter frost and extended cold periods, he does not consider a fundamental limitation, as system resilience primarily depends on appropriate plant selection and already integrated frost-protection strategies. One example is the use of black textile substrate mats, which increase solar heat absorption, alongside the system’s inherent capacity to regulate moisture and temperature through its layered structure and constant grey water injection.* ”

District Water Management*

The average water usage in Sweden is about 140 litres per person per day (Svenskt Vatten AB 2022). Although, in older housing developments like in Tensta, water consumption might be even higher due to aging circulation systems, inefficient fixtures, toilets with large flush volumes, and the general absence of rainwater reuse systems. Furthermore, in a study on the chemical and organic composition of Swedish domestic water, an average of 98 litres per person per day of grey water is reported, representing approximately 70-75% of total household wastewater (which averages 135 litres per day) (Almqvist & Hanæus 2006).

An average grey water production of 60-200 litres per capita is common in developed countries, for which grey water reuse could theoretically entail a water savings potential of 50-80% (Noutsopoulos et al. 2018).

Following the results from the Belgian pilot projects, the total value wall system can process up to 10 litres of grey water per m2 of façade per day, of which 3-4 litres are retained within the system through irrigation and evapotranspiration during the summer months; with this figure decreasing by roughly 20-30% in winter.

If all these figures are considered together with 9.93 hectares of available inert façade surface identified in Tensta, several conclusions can be drawn:

> With approximately 19.000 inhabitants, and by using the Swedish average of 98 litres of grey water per person per day, Tensta theoretically generates 1.862.000 litres (=1.862 m3) of grey water per day. If the identified 9.93 hectares (= 99.300 m2) of inert façade surface would be fully equipped with the total value wall system, and each square meter could process up to 10 litres of grey water per day, the façades could theoretically treat 993 m3/day, which is more than 50% of Tensta's daily grey water production. Of course it needs to be noted that an implementation rate of 100% would be highly unlikely.
>
> If I were to follow the final TCC target scenario (= greening 22.9% or 2.28 ha of inert facade surface), we could recover and recirculate approximately 8-12% of Tensta's total daily grey water production, depending on season and operational conditions. This could be a valuable argument towards actors like the city of Stockholm and Stockholm Vatten och Avfall to co-invest or support living wall systems, as they reduce wastewater loads and generally support climate resilience.

Figure 6.16-17. Image converted with KREA.ai from the prompt "project description & aerial imagery Google Earth 2023", 2026.

Figure 6.18-20. Images converted with KREA.ai from the prompt "project description & personal imagery", 2026.

If I were to apply the concept on a more local scale, for instance by targeting home-owner associations like BRF Päronet in the north of Tensta (See Figure 6.16-20); we could calculate the water saving capacity and financial return for this specific association and its residents. In the VCM model, I measured approximately 1.35 ha of inert façade surface for the association's 20 residential buildings with 676 apartments, which accommodate approximately 1500 residents.

Therefore, a total value wall system could theoretically process about 87.700 litres of grey water per day for this BRF (corresponding to roughly 59 litres per person per day). This would translate into an annual recovery potential of roughly 32.000 m3 of water, with an estimated monetary value of around 1.3-2.0 million SEK per year; This based on a generalised water and wastewater tariff of 40-60 SEK/m3 (Stockholm Vatten och Avfall 2025).

If the system installation is assumed to cost between 5.500-11.000 SEK/m2, the total investment would be in the order of 74-148 million SEK, resulting in a payback period of roughly 40-70 years when based solely on water savings. This makes it economically weak as a standalone water-based intervention. Therefore I conclude that this solution only becomes financially viable when framed as an integrated renovation strategy, which combines already necessary facade upgrades together with other functional and ecological benefits.

The total value wall should thus be seen as a multi-functional infrastructure layer that combines water management, thermal improvement, biodiversity enhancement, and climate adaptation within a single intervention, with value distributed across multiple stakeholders.

Analytical Framework*

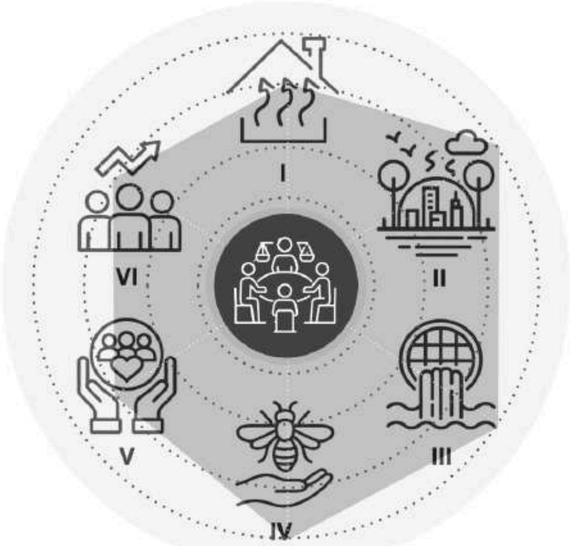


Diagram & Table 6.3.
Spider diagram evaluating the opportunities and limitations of pilot 02.

Parameter		Evaluation
I.	Thermal Performance	Medium
II.	Climate Adaptation	High
III.	Water Management	High
IV.	Biodiversity Support	High
V.	Human Well-being	Medium
VI.	Socio-economic Value	Medium
	Governance Model	Hybrid approach

This pilot achieves the strongest ecological performance of all four pilots, particularly in relation to climate adaptation, water management, and biodiversity support. At the same time, it is also among the most technically and economically demanding interventions with specialised systems, irrigation, maintenance, and long-term management. The project demonstrates that high ecological performance alone does not guarantee implementation. Instead, realisation depends on governance arrangements capable of aligning public, private, and community-based benefits and investment.

PILOT 03: "Vinterträdgård-Sommarhud" - Seasonal Envelopes for "Glazed" Façades

In my VCM model, I calculated that approximately 47% (36.05 ha) of the total potential greening surface in Tensta can be assigned to the "active façade surface" category, which refers to façades with openings, balconies or windows. In the final TCC scenario I paired these surfaces with climbing systems (0.5 CE) and calculated that I have to "activate" 8.26 ha of this surface category in order to reach my goal. As I learned in my greening system analysis, green façades (GF's) are among the easiest and most affordable vertical greening systems. In many cases the rough textured concrete panels which make up the cladding of the buildings in Tensta, could be suitable hosts for climbers with adhesive rootlets or pads.


Figure 6.21. Competition "tegelwippen", Eindhoven NL, 2019.

Learning from Others: 'Tegelwippen' NL*

An important advantage of direct climbers is that they can be implemented incrementally and at low cost through community participation and small-scale municipal interventions. Examples of such initiatives can also be found in the Netherlands, where "tegelwippen" (literally "tile flipping"), demonstrates how removing paved surfaces and replacing them with vegetation can be both a practical climate adaptation strategy, and a public campaign encouraging residents to participate in urban greening (See Figure 6.21). In this initiative, local Dutch governments encourage residents to dig up narrow planting strips along their own façades in order to support ground-based or climbing vegetation.

When applied in Tensta, these sorts of strategies could involve direct planting or selectively removing sections of asphalt or paving adjacent to suitable facade surfaces. It is however important that safety concerns, vulnerable construction details, and maintenance protocols would be taken into account. Vegetated façades directly adjacent to walking paths could for instance be a cause of falling ice in winter; some sorts of vegetation might increase fire-safety issues such as flash-overs, and some self-supporting climbers might damage porous facade materials or expand construction seams.

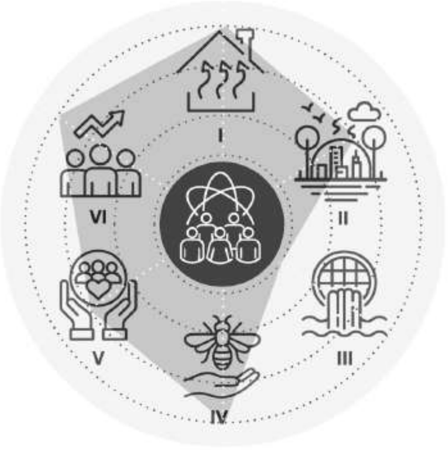
Lower three-story façades built with durable, dense materials, simple facade detailing, and set back several meters from public walkways are therefore likely the most suitable candidates for this type of intervention (See Figure 6.22-23). For higher buildings, direct climbers may be less suitable, as maintenance becomes increasingly complex and safety concerns become more significant at greater heights.


Figure 6.22-23. Image converted with KREA.ai from the prompt "project description & personal imagery", 2026.

Diagram & Table 6.4.
Spider diagram evaluating the opportunities and limitations of pilot 03a.

Parameter		Evaluation
I.	**Thermal Performance**	High
II.	**Climate Adaptation**	Medium
III.	**Water Management**	/
IV.	**Biodiversity Support**	High
V.	**Human Well-being**	Medium
VI.	**Socio-economic Value**	High
	Governance Model	Bottom-up approach

This case-study demonstrates how VUE can be implemented through low-cost, incremental interventions. While its ecological impact is more modest than the larger retrofit strategies, the proposal performs strongly in terms of biodiversity support, thermal buffering, and socio-economic value. Its main strength lies in its suitability for bottom-up implementation through resident participation and local stewardship.



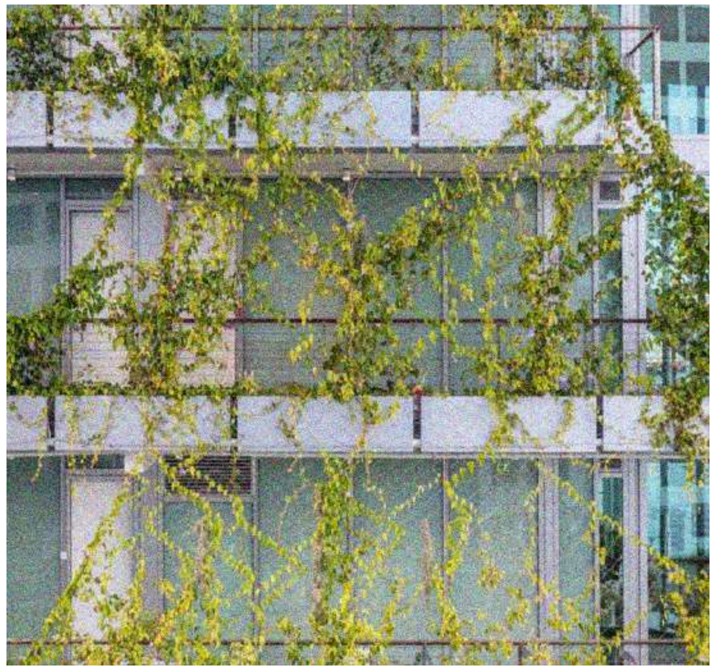


Figure 6.24. Indirect greening system where climbing vegetation is supported by cables, Barcelona, 2021.


Figure 6.25. Reconversion of Cité du Grand Parc, adapted from Ruault, via (EU Mies 2019).

Since many of the taller façades in Tensta are highly exposed to solar radiation during the summer months, which contributes to internal overheating as well as the UHI-effect, a more integrated green façade strategy may be required. A viable approach might be the application of indirect greening systems, where climbing vegetation is supported by cables, trellises, or mesh structures (See Figure 6.24). Such systems allow vegetation to form a climatic buffer layer, effectively transforming otherwise passive façades into adaptive environmental infrastructure. The use of deciduous climbing species could further enhance seasonal performance.

During summer, dense foliage can partially shield glazed façades and balconies from excessive solar exposure, reducing cooling demands and improving thermal comfort. In winter, however, leaf loss allows increased solar penetration, enabling passive solar heat gains and daylight access when they are most beneficial.

As I learned in my greening system analysis, the cost and sustainability of indirect facade greening is mainly related to the materials used for the support structure, and the maintenance required to keep the often fast growing climbers under control. Large firms such as 'Jakob Rope Systems' have brought several certified products to the market which make it possible to realize large scale indirect green façades. Their systems primarily consist of lightweight stainless components such as webbing and tension cables or integrated planters, and have proven their durability, strength and adaptability in a multitude of projects across the globe.

Applying such systems to existing million housing façades might be technically possible, but the question remains why building owners would opt for these more expensive and maintenance intensive solutions above their current, often more basic facade renovation strategies? In Sweden the financial benefits in regards to thermal regulation in summer are for instance much less convincing than in more southern climates. The question rises: How can we convince property owners to apply this sort of NBS to their façades?

Learning from Others: 'Cité du Grand Parc', FR*

In response, I found inspiration in the retrofit strategies of the French architecture office Lacaton & Vassal. The specific project I am referring to consists of the transformation of three buildings of the 'Cité du Grand Parc' in Bordeaux. Built in the early 60s, these social housing buildings with approximately 530 dwellings, reached a point of urgent renovation around the 2010's. After the question of their demolition was ruled out, Lacaton & Vassal developed a clever retrofit strategy based on transforming the existing building without doing important interventions on the existing: the structure, the stairs or the floors and of proceeding by facade additions and internal spatial reorganisation.

By adding a new layer of winter-garden-like balcony structures to the existing façades (See Figure 6.25), the spatial-and experiential quality of the buildings was drastically improved. The former deteriorated, enclosed facade surfaces with little outdoor space were now opened up to a new balcony structure, creating the opportunity for each apartment to enjoy more space, more natural light, more mobility of use and more views. In this project, a social housing estate became an example of how relevant and economically viable transformation strategies can generate generous, pleasant, and high-performing dwellings from an existing building stock perceived as lacking quality and associated with negative imagery.

The building-typology and neighbourhood characteristics of the project in Bordeaux, closely resemble the situation in Tensta. Lacaton & Vassal's intervention might not have much to do with NBS, but it does project a blueprint where building owners can be convinced of more integrated green facade typologies in return for development agreements, more spatial quality, improved neighbourhood desirability, and accordingly higher property valuation. It needs to be acknowledged that this type of pilot might play into processes of gentrification, where lower-income residents risk displacement. However, with strong community-led planning and governance, and paired with adequate social housing protection, it could become a valuable strategy for transforming Tensta into a more socially mixed, attractive, and environmentally resilient urban area.

Vinterträdgård- Sommarhud*

In translation of the French example, I introduce: “Vinterträdgård- Sommarhud”; a retrofit proposal which reinterprets the popular Nordic tradition of the winter garden. Within this pilot I propose the addition of a lightweight inhabitable climatic layer around existing housing blocks. The intervention consists of a new structural extension attached to the exterior of the buildings, enlarging the apartments through winter gardens and balconies while introducing a second outer layer of deciduous climbing vegetation.

Supported by lightweight glazed balcony structures, this vegetated skin acts as a seasonal climatic membrane. In summer, dense foliage shades the façade, filters sunlight, and cools the building through evapotranspiration. In winter, the vegetation sheds its leaves, allowing low-angle sunlight to penetrate deep into the winter gardens and adjacent apartments, contributing to passive solar heating.

Rather than functioning solely as a decorative green façade, this new skin transforms existing building envelopes into a thickened ecological interface between architecture, climate, and domestic life.

In Tensta, primarily the large southeast oriented façades, such as those in the central ‘Kullinge’ and ‘Risinge’ developments, would likely benefit most from this type of intervention as it would also have a positive influence on their adjacent courtyards (See Figure 6.26-27).

Figure 6.26-27. Image converted with KREA.ai from the prompt ”project description & aerial imagery Google Earth 2023”, 2026.

Figure 6.28-29. Pilot 03 applied to the south-west oriented façade of ‘Vissinge’ Image converted with KREA.ai from the prompt ”project description & personal imagery”, 2026.

Analytical Framework*

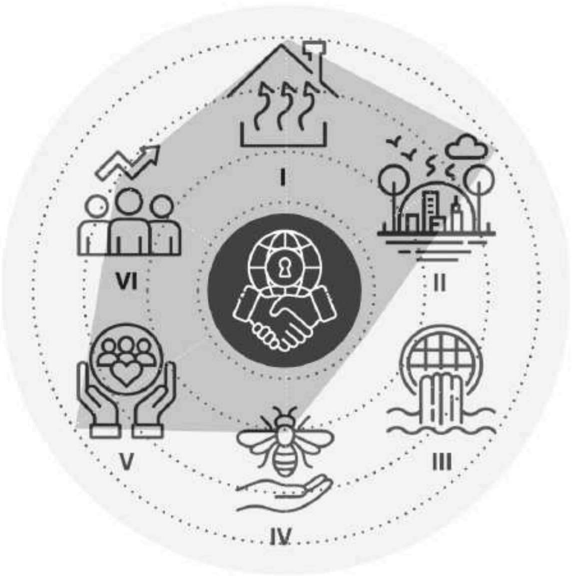


*Diagram & Table 6.5.
Spider diagram evaluating the opportunities and limitations of pilot 03b.*

Parameter		Evaluation
I.	Thermal Performance	High
II.	Climate Adaptation	High
III.	Water Management	/
IV.	Biodiversity Support	Low
V.	Human Well-being	High
VI.	Socio-economic Value	Medium
	Governance Model	Negotiated public-private approach

This pilot performs strongest in relation to thermal performance, climate adaptation, and human well-being. Its main challenge lies in the substantial investment and coordination required between property owners, residents, and public actors. While such improvements may also increase property values and neighbourhood attractiveness, they raise important questions regarding affordability and the risk of renovation-driven displacement. Consequently, the social benefits of the intervention depend not only on its physical design, but also on governance arrangements capable of safeguarding housing accessibility for existing residents.

PILOT 04: "Tenstas Blågröna Matta" - Extensive Blue-green Roof Retrofits

As calculated in my VCM model, approximately 30% (22.78 ha) of the total potential greening surface in Tensta can be assigned to the "inert roof surface", referring to horizontal or slightly inclined surfaces that are inaccessible and primarily technical in function.

These include conventional rooftops with potential for future activation, such as green roofs, water retention, or energy systems. Inert roofs hold the second biggest untapped reserve in regards to potential greening surface on building envelopes in Tensta.

In the final TCC scenario I paired these surfaces with extensive green roofs (0.5 CE) and calculated that I have to cover 5.22 ha (= 7-8 international football fields) in order to reach my goal.

When flying over Tensta, it however becomes clear that this might become challenging, as the application of green roofs is today very limited. Currently, only two newer developments in central Tensta (the town houses along Järingegränd and three residential building blocks adjacent to Tensta plan) show some sort of green coverage. Apart from these developments, most roofs are covered with metal (usually zinc) or asphalt roofing (See Figure 6.30-32).

As I learned in my literature study, green roofs are among the most extensively researched and widely implemented NBS for buildings; particularly in relation to energy performance, ecological value, and storm water management. They generally require relatively low capital investment, maintenance, and irrigation, making them both efficient and feasible interventions.

However, when looking at recent renovations in Tensta, their implementation appears to remain absent. For instance, in the renovation of the apartment building Kv Åvinge (owned by Einar Mattsson and renovated between 2017 and 2021) the website of the architects describes the installation of a new fan system with heat recovery through a rooftop extension equipped with solar cells, yet greening measures are not addressed (Ahlqvist & Almqvist Arkitekter 2021). Also other recent renovations such as the 'Krällinge' property owned by Familjebostäder, focus primarily on façade upgrades, while green roofs again appear to be absent from the renovation strategy (Redaktionen 2025).

From my VUE perspective, I could state that these are missed opportunities. Instead of viewing roofs solely as technical surfaces, they could be understood as climate infrastructures. Particularly within the MHP renovation agenda, roof retrofits might present a unique opportunity to embed ecological systems directly into the urban fabric without requiring additional land consumption. By attaching ecological requirements to moments when roofs are already being replaced, the City of Stockholm could significantly reduce implementation costs and normalize green roofs as part of standard building practice.

In searching for strategies that use the renovation cycle as an implementation mechanism for GR's, I peeked towards Basel (Switzerland), which is often referred to as the "world capital of green roofs".

Figure 6.30-32. Currently, only two newer developments in central Tensta (the town houses along Järingegränd and three residential building blocks adjacent to Tensta plan) show some sort of green coverage (Google Earth 2023).

Figure 6.33. World Green Roof & Green Façades (Congress Basel 2025).

Learning from Others: 'Basel', CH*

The Swiss city Basel, with approximately 50% of its flat roofs covered in vegetation, is one of the highest green roof areas per capita worldwide. This achievement is the product of decades of coordinated policy, financial incentives, legal mandates, scientific collaboration, and public awareness campaigns. Last year, even the 'World Green Roof & Green Façades Congress' was hosted by the city (See Figure 6.33), organized by the Urban Ecology Research Group at the Zurich University of Applied Sciences (ZHAW 2025).

One of the most important lessons to learn from Basel is that green roofs are integrated into existing renovation and construction cycles, rather than treated as optional additions. Over several decades, the city gradually introduced regulations requiring green roofs on new flat roofs and later expanded these requirements to renovated roofs as well. This policy mechanism can be compared with Europe's current renovation wave, where millions of aging housing units are scheduled for energy retrofits and roof replacements in the coming decades (Ibid).

Basel therefore demonstrates the importance of combining legal obligations with financial incentives. In the early 1990's the City implemented a law to support energy saving measures. According to this law, 5% of all customers' energy bills are put into an 'Energy Saving Fund', which is then used to fund energy saving campaigns and measures. The national Department of Environment and Energy decided to pursue and promote green roofs using this source of funds for the 1996-1997 program (up to 20 CHF per m2). A second funding program was implemented in 2005-2007 (up to 30-40 CHF per m2 for retrofitting existing buildings) (Brenneisen & Baumann 2016).
In 2002, an amendment to the City of Basel's Building and Construction Law was passed which reads that all new and renovated flat roofs must be greened and also stipulates associated design guidelines.

Ultimately, Basel demonstrates that urban greening only becomes truly transformative when it shifts from being perceived as an architectural luxury to being treated as an essential public utility.

Tenstas Blågröna Matta*

Interestingly, Stockholm may actually be well-positioned to move beyond Basel as it has a much larger portfolio of municipal housing, strong public planning traditions and a strong climate adaptation agenda. However, the city and its policies still lack Basel's retrofit-scale implementation and political incentives to push through citywide retrofit mandates and universal renovation-linked ecological requirements.

Since many roofs in Tensta and other MHP areas will require replacement or upgrading in the coming decades, it would be the right moment to start thinking about policies and incentives to implement green roofs without requiring additional land consumption, large-scale spatial transformation or high construction costs.

A municipal led pilot combining legal requirements, subsidies, ecological standards, and public communication might therefore be needed to normalize green roofs as an accepted and routine part of Swedish construction/ renovation practice.

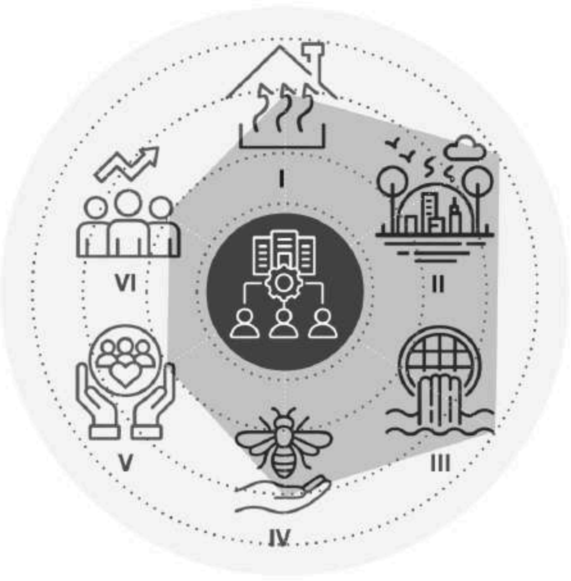
In December last year, it was decided that the municipal housing company Familjebostäder would purchase Hjulstahem AB, a subsidiary of the Einar Mattsson Group. The acquisition includes 14 properties containing approximately 1.200 rental apartments in the west of Tensta. This re-acquisition is the result of a political shift in power. In 2008, the centre-right government sold this housing stock to the Einar Mattsson Group, while the current red-green administration has sought to bring it back into public ownership. According to Deniz Butros: “As the public housing sector grows, we can work more long-term with maintenance, well-being, and social sustainability. This is about taking responsibility for the city’s future and for people’s everyday lives” (Hagström 2025).

If we were to convince Familjebostäder to apply all these roofs with a greening solution (apart from the fact that some buildings might be structurally unsuitable), I could potentially reach 60% of the required extensive green roof area to fulfil our final TCC scenario.

Spatially this also demonstrates how a relatively limited number housing blocks can contribute substantially toward district-scale climate adaptation goals (See Figure 6.34-35).

Figure 6.34-35. Image converted with KREA.ai from the prompt ”project description & aerial imagery Google Earth 2023”, 2026.

Analytical Framework*



Parameter	Evaluation
I. Thermal Performance	Medium
II. Climate Adaptation	High
III. Water Management	High
IV. Biodiversity Support	Medium
V. Human Well-being	Low
VI. Socio-economic Value	Low
Governance Model	Top-down municipal approach

This pilot performs strongest in relation to climate adaptation and water management. By retrofitting existing roof surfaces with extensive blue-green systems, the proposal contributes to water retention, urban cooling, and increased environmental resilience at a district scale. Compared to the other pilots, its social and experiential benefits are less direct, as most interventions occur outside residents’ everyday view, use and perception.

The evaluation suggests that one of the greatest strengths of this proposal lies in its scalability. Because large roof areas can be upgraded through coordinated renovation and maintenance programmes, implementation is well suited for a top-down municipal or public-housing-led governance approach.

Diagram & Table 6.6.
Spider diagram evaluating the opportunities and limitations of pilot 04.

6.5 Synthesis of the Pilot Projects

Pilot	Primary Governance Model	Strongest Parameters	Main Constraints	Main Lesson
Pilot 01: Takterrängen	Public-private	Climate adaptation, well-being, socio-economic value	Ownership coordination	Social value depends on collaborative governance
Pilot 02: Vattenvägg	Hybrid	Biodiversity, water management, climate adaptation	Technical complexity, maintenance & cost	High ecological performance often comes at the cost of greater technical and financial complexity
Pilot 03a: Direct Climbers	Bottom-up	Biodiversity, socio-economic value	Maintenance & technical issues	Replicability and stewardship may compensate for smaller scale
Pilot 03b: Vinterträdgård-Sommarhud	Public-private	Thermal performance, well-being	Investment cost & possibly higher rental prices	Ecological retrofitting is most realistic when embedded in renovation cycles
Pilot 04: Tenstas Blågröna Matta	Top-down municipal	Climate adaptation, water management	Limited resident engagement	Large-scale environmental gains can be achieved through municipal infrastructural approaches

Table 6.7.
Matrix synthesis of the pilot projects.

When bringing the pilot projects together in one matrix (See Table 6.7), it reveals that each pilot rests on different NBS benefits and implementation pathways which highlights how ownership structures, governance arrangements, investment capacity, and maintenance requirements shape the applicability of VUE in practice.
This synthesis therefore suggests that the principal challenge for implementing VUE is not the identification of suitable surfaces, but rather the development of governance structures capable of aligning ecological ambitions with long-term stewardship and financial feasibility

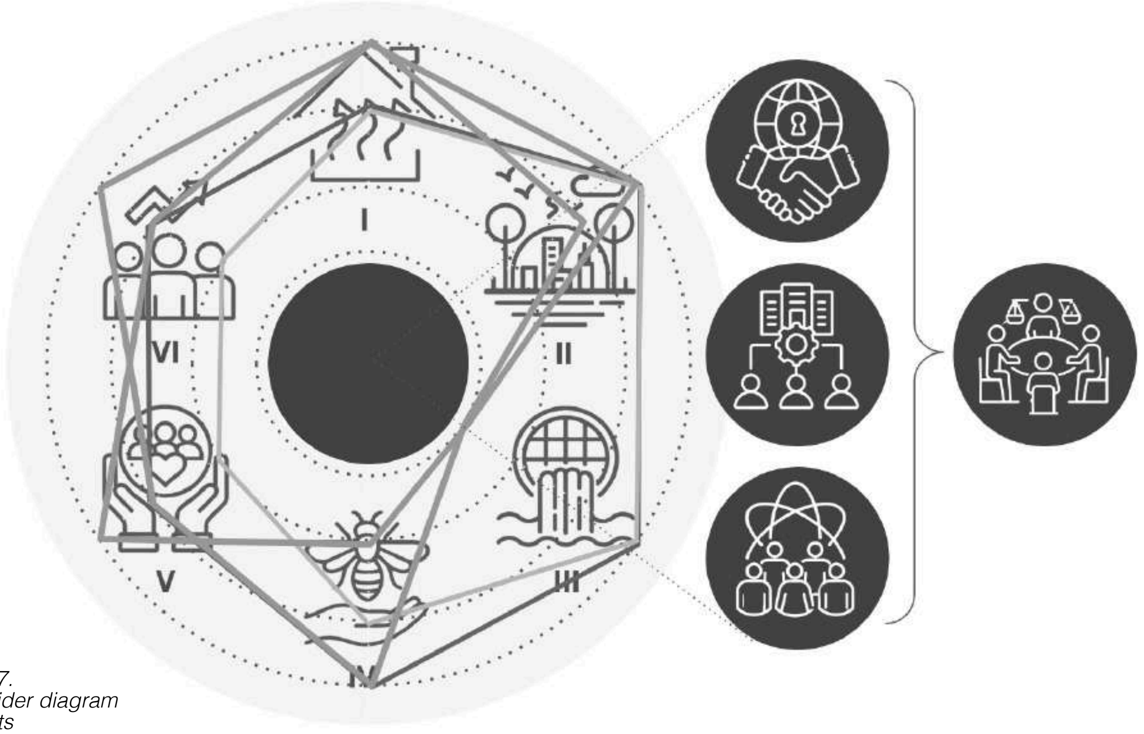


Diagram 6.7.
Overlay Spider diagram
Pilot projects

When overlaying the parameter profiles of the individual pilots. The resulting diagram (See Diagram 6.7) illustrates that while the projects differ considerably in focus, they collectively cover the full spectrum of possible NBS benefits. The strength of VUE lies therefore not in identifying an optimal solution, but in its capacity to activate multiple interventions that collectively address climate adaptation, biodiversity enhancement, water management, thermal performance, human well-being, and socio-economic values on a district scale.

6.6

MOCK-UP: “Vägg av liv” - An Educational Testing Model

Most of the previous pilots are oriented towards large institutional actors and will need significant financial investment. While such projects demonstrate what might be possible at larger scale, they remain largely speculative scenarios and may also project the impression that building-integrated NBS can only be realised through high investment and institutional incentives.

The mock-up was developed to complement these investigations by testing VUE at the scale of individual components, materials, and maintenance practices, while simultaneously exploring how VUE might also emerge through incremental, educational, and community-based initiatives. In this sense, the prototype functions not only as a technical experiment but also as a governance experiment.

While a single prototype cannot generate measurable ecological impact at district scale, it can contribute to awareness, stewardship, tangible learning, and public engagement. This perspective is particularly relevant in the context of Tensta and other MHP areas, where successful implementation is strongly dependant on cooperation between municipalities, housing companies, local organisations, and residents.

Schools for instance play important roles in educating future generations about the importance of climate adaptation and biodiversity. The Education Committee of Stockholm has already been running a school yard project since 2015, where a total of 33 school yards have been “greened” so far (Wilén et al. 2026). Elinsborgsskolan in Tensta is for example one of five schools whose school yard is currently being rebuilt with asphalt replaced by trees, play bushes and climbing frames (Stockholms stad 2024).

Building insect hotels, hanging bird- and bat houses, and low-tech growing initiatives have become part of the general educational program. ‘Green Camp with George and Fahyma’ was for instance an initiative by Tensta Konsthall, where local kids (6-12 years) learn about farming, from irrigation to soil and harvest (Tensta konsthall 2023).

Introducing the concept of VUE, and specifically teaching children and local actors how vertical greening systems work and what their advantages are, could be a valuable addition to these initiatives. The mock-up is therefore aimed to serve as a bridge between the strategic ambitions of VUE and the everyday practices through which ecological transformation is realised. It is meant to demonstrate that implementation can also emerge through experimentation, participation, and local initiative.

Figure 6.36-37. Mock-up in Knivsta on May 11, 2026.

Following these insights, I built a 1/1 low-tech living wall mock-up at the beginning of April 2026; To my regret, the climatic conditions and condensed timeframe of this thesis did not allow me to construct the prototype together with local actors in Tensta, although the methods and materials were deliberately selected so that the system could be easily replicated by residents or local associations as a potential bottom-up initiative.

Constructed primarily from second-hand and locally sourced natural materials, the prototype culminated in a 2×2m green wall consisting of four modules, each representing a different ecological perspective.

Building the mock-up with my own hands further enabled me to directly experiment with construction methods, material selection, planting strategies, maintenance requirements, and biodiversity support. It therefore generated a form of practical and experiential knowledge that could not be obtained through theoretical research, policy analysis, or digital design proposals alone. A good example is the challenge of working with gravitational forces and substrate weight when filling and plating the modules. The construction process also revealed the importance of details such drainage, irrigation, accessibility for maintenance, material durability, etc. which are invisible in the more conceptual proposals.

In this sense, the prototype transformed development and implementation of VUE from an abstract planning discussion into a personal tangible learning process.

Figure 6.38-40. Construction images of the wooden framework for the base-modules, April 2026.

Overall Specifications*

Each separate module of the wall measures approximately 1x1x0,20m, and is made-up of a wooden framework. Impregnated terrace planks with (95x22mm cross-section) were reused from a former terrace structure, and composed in such a way that they form a stable framework that can hold substrate, habitat aids and vegetation.

The planks were painted with ‘Falu rödfärg’, the natural red iron oxide paint obtained as a byproduct of the Falun copper mine in central Sweden; this in order to protect the wood, but also to create a visually recognizable framework for a rather “exotic” greening solution (See Figure 6.38-40).

The four modules were each developed using a distinct material and vegetation concept in order to provide a diverse range of habitat aids for insects, arthropods, and birds (See Figure 6.36-37).

Since many living wall systems currently on the market are primarily composed of inert and less sustainable materials such as steel, plastic, and concrete, the intention behind the materialisation of this mock-up was to rely as much as possible on natural materials with a low carbon footprint that also offer ecological value.

Overall, the materialisation of the concept proved successful. The only compromise involved the use of HDPE planters and waterproof backing foil, which were necessary to maintain adequate moisture levels within the panels.

In addition, special attention was given to substrate composition, moisture management, and plant selection for each module, partly inspired by the mock-up presented in the German field study by Krause et al. (2023).

Specifications of each module*

Module 01: “Woolen Loom” (Top Left)

The upper left module combines a rigid rebar structure with soft wool, jute, and dry grass creating a layered habitat inspired by farm environments. The varied textures and sheltered crevices provide nesting and overwintering opportunities for spiders, lacewings, and other arthropods, while flowering species such as *Salvia nemorosa* and *Campanula carpatica* offer valuable nectar resources for pollinators throughout the season.

Structure: +-3cm metal rebar grid with wool fabric pockets.
Substrate: +-10cm - 50/30/20 - Leca/soil/hay
Insulation layer: +-7cm jute/ dry grass mattress
Back foil: HDPE moisture barrier

Vegetation:
Stachys byzantina
Sesleria heufleriana
Campanula carpatica Djupedal
Veronicastrum virginicum album
Salvia nemorosa

Figure 6.41-44. Construction images module 01, April 2026.

Module 02: “Solar Terrace” (Top Right)

This module was designed as a dry, heat-retaining habitat inspired by Mediterranean roof landscapes. The stacked ceramic plateaus and nutrient-poor substrate create warm and well-drained conditions that favour drought-tolerant species such as Sedum, Sempervivum, and Thymus. Meanwhile the open sand and rock layers provide potential nesting and basking spaces for solitary bees and other thermophilic insects. The flowering thyme and *Armeria maritima* act as high-nectar resources, attracting pollinators.

Structure: Open structure with ceramic (roof tile) plateaus
Substrate: +-5-10cm - 60/30/10 - sand/rocks/ceramic

Vegetation:
Armeria maritima
Sedum mexicanum Britton
Sedum dasyphyllum L.
Phedimus spurius
Sempervivum globiferum L.
Thymus serpyllum Albus
Thymus longicaulis odoratus
Cerastium tomentosum (x2)

Figure 6.45-48. Construction images module 02, April 2026.

Module 03: “Forest Floor” (Bottom Left)

This module recreates the sheltered and moisture-rich conditions of a woodland edge through a braided branch framework, organic substrate, and layered vegetation. The combination of jute, wood chips, and leafy under-story plants such as *Geranium cantabrigiense, Carex morrowii*, and *Alchemilla mollis* creates cool and humid microclimates that provide refuge for beneficial insects, spiders, and potentially amphibians during warmer periods.

Structure: Braided branch framework with jute backing
Substrate: +-10cm - 40/40/20 - Leca/soil/wood chips
Insulation layer: +-6cm Rockwool
Back foil: HDPE moisture barrier

Vegetation:
Geranium cantabrigiense Biokovo
Carex morrowii
Heuchera (x2 - red and green varieties).
Alchemilla mollis

Figure 6.49-52. Construction images module 03, April 2026.

Module 04: “Marshy Meadow” (Bottom Right)

Bound reed bundles and a dense clay-soil substrate mimic wet meadow and marsh conditions, while moisture-loving species such as *Astilbe, Alchemilla epipsila*, and *Geranium nodosum* form shelter for insects and other small fauna. The pooling water within the lower planter creates a constantly damp micro-climate that contrasts with the drier modules and increases the overall ecological diversity of the wall. Pockets of panicle/plume provide soft nesting material for birds.

Structure: Bound reed bundles
Substrate: Dense soil-heavy mixture +-10cm - 50/50 - clay/soil
Insulation layer: +-7cm jute/ reed leaves mattress
Back foil: HDPE moisture barrier

Vegetation:
Astilbe arendsii Fanal
Astilbe simplicifolia
Alchemilla epipsila
Geranium nodosum (x2)

Figure 6.53-56. Construction images module 04, April 2026.

Figure 6.57. Mock-up in Knivsta on May 11, 2026.

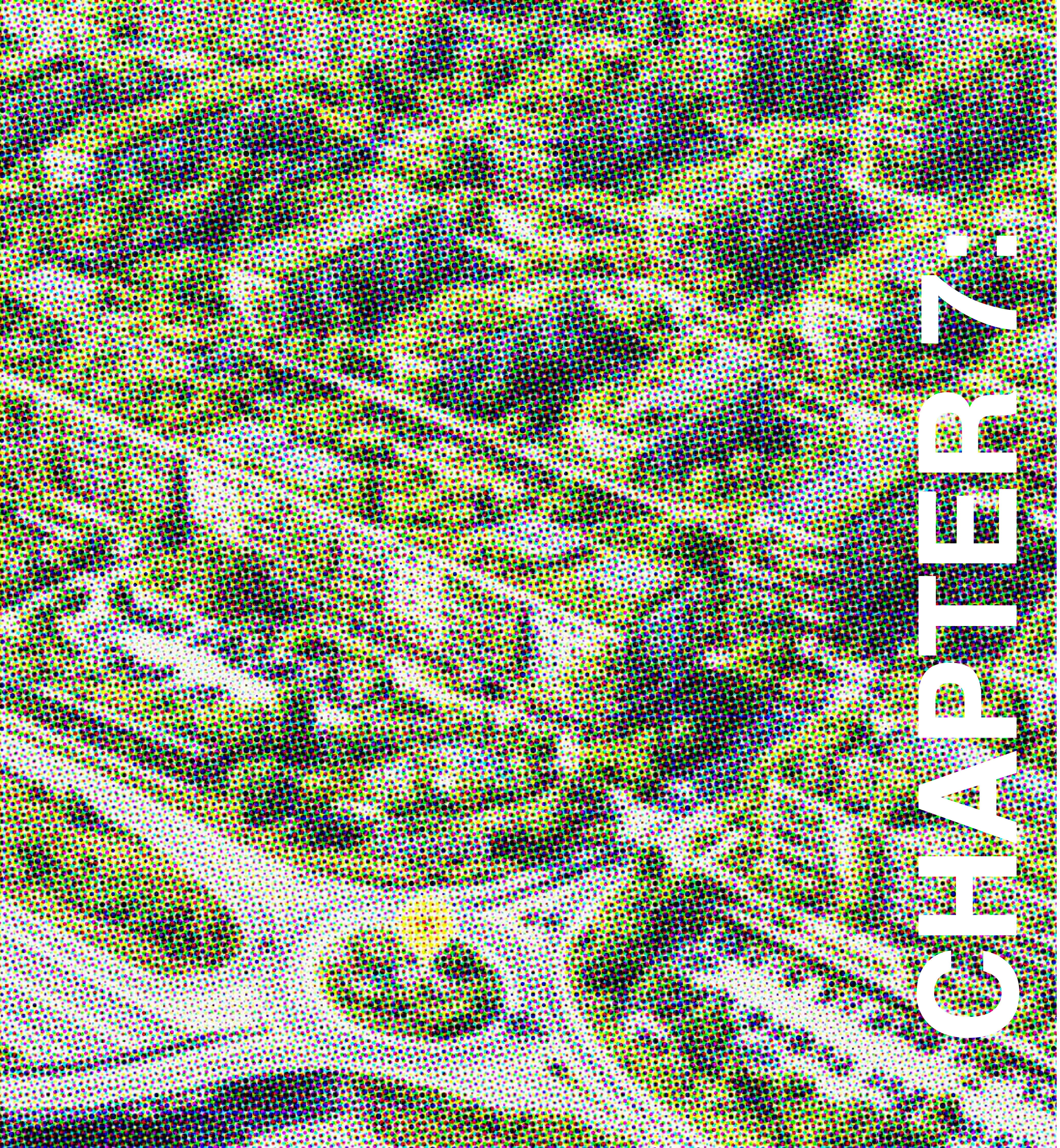
Figure 6.58. Newly constructed & planted mock-up, April 15, 2026.

Figure 6.59. Mock-up on May 28, 2026.

After about one months of growth, we can observe that all plants have established well (See Figure 6.58-59), and that the moisture levels within the panels stay surprisingly stable. In front of the mock-up, a pile of garden waste, rocks, and soil has been deposited. This with the idea to attract all sorts of non-human guests. During occasional observations common blackbirds, green finches, common chaffinches, European Robins, squirrels and all sorts of insects have been observed both in front, and on the mock-up. Birds like to use the branches and wool as nesting material, bumblebees have been spotted crawling into the reed, little spiders are crawling in the shady area created by the braided branches, and ants have occupied some of the sandy areas of the solar terraces. One week before my final presentation a couple of blackbirds even started a nest in the upper right module (See Figure 6.60).

Even though it is too early to draw real conclusions; the mock-up proves successful so far, and shows that with a cost of about 600 SEK/ module, one can already achieve a low-tech living wall system. The coming winter and summer will however be the real test, as extreme temperatures might challenge some of the plant species and the organic nature of many of the materials used.

Figure 6.60. The nest of a blackbird in the upper right module.



CHAPTER 7:

Discussion & Conclusion

The final chapter reflects on the findings, limitations, and implications of the research. It discusses what Vertical Urban Ecology may contribute, the challenges that remain, and the questions that future research will need to address.

7.1 Multi-scalar Synthesis Matrix Across Policy, Planning, Design and Material Engineering

Scale	Focus	Main Finding	Main Limitation	Contribution to VUE
Policy	NBS frameworks, planning instruments, legislation	Strong political support for NBS and climate adaptation	Limited ability to require interventions on existing private property	Establishes the institutional conditions for implementation
Planning	Stockholm, MHP areas, Tensta	Existing building stock contains substantial ecological potential	Ownership fragmentation and competing priorities	Identifies where VUE can be strategically applied
Design	Pilot projects	Different interventions address different objectives	No single pilot maximises all parameters	Demonstrates multiple implementation pathways
Material Experiment	Full-scale mock-up	Ecological retrofitting is technically feasible using accessible materials	Maintenance, durability and stewardship remain critical	Tests implementation realities at component scale

Table 7.1. Multi-scalar synthesis matrix thesis.

The research in this thesis has operated across multiple scales, ranging from policy frameworks and regional planning strategies, to site-specific design interventions and material experimentation.

While each of these scales addresses different questions, a multi-scalar synthesis (See Table 7.1) suggests that successful application of VUE depends on the ability to connect these scales:

Policy vs Planning

Policy ambitions identify the need for climate adaptation and biodiversity enhancement, while the planning analysis reveals where these ambitions could realistically be implemented. The thesis demonstrates that Stockholm's MHP areas provide one such opportunity because ecological retrofitting can be integrated into ongoing renovation processes.

Planning vs Design

The VCM, system-surface design matrix and ownership analysis translate regional ambitions into specific and measurable spatial opportunities. Rather than treating the built environment as a passive object, design investigations demonstrate how different surface categories can support different social, ecological, technical and economic functions.

Design vs Material Experiment

While the pilot projects explore strategic implementation scenarios at neighbourhood scale, the mock-up reveals the practical realities of construction, maintenance, and stewardship. This demonstrates that ecological ambition must ultimately always be reconciled with material feasibility and resident interaction.

Following these insights, VUE should not be understood as a singular design intervention or ideological fantasy. Rather, it represents a multi-scalar planning approach that links policy, planning, design, and material experimentation in order to embed ecological functions within the urban built environment.

7.2 Summary of Findings

My initial literature review in chapter one confirmed that the urban built environment might represent a large underutilized domain for implementing NBS. Green Roofs (GR's) and Vertical Green Structures (VGS) demonstrate considerable potential to transform building envelopes into more active components.

These findings form the conceptual and theoretical basis for what can be described as Vertical Urban Ecology (VUE): a planning approach that recognizes buildings and other infrastructure, not merely as functional and architectural objects, but as potential habitats, climate regulators, and infrastructural components within a broader urban ecosystem.

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In the second chapter I concluded that the value of studying VUE in a Nordic context lies not only in its local environmental impact, but also in its ability to test how building-integrated NBS perform under climatic, institutional, and governance conditions that differ significantly from the contexts in which many existing precedents have emerged. After studying the legal frameworks, I concluded that from a planning perspective, the autonomous organisational structure of Nordic municipalities would make it challenging to implement nationwide NBS in these countries. I therefore decided to narrow the scope of this thesis to my nearest metropolitan region: Stockholm County.

While most successful examples of NBS in the Stockholm primarily operate at the level of public space (parks, corridors, and green-blue infrastructure), the ecological potential of the built environment, and especially of the existing building stock, remains largely underutilized. This primarily because Swedish municipalities do not have the legal means to impose specific NBS on existing private properties. This creates a need for more innovative urban development processes that can't focus solely on spatial, social and ecological qualities, but also need to generate other benefits for different sorts of actors.

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In chapter three I questioned the potential of the pressing renovation agenda of the Million Housing Program (MHP) building stock as a strategic window for implementing VUE. Within the trends of increasing inner-city expansion, densification, fragmentation of green areas and declining biodiversity; it was assumed that especially large scale peri-urban MHP areas could play a crucial role in enhancing ecological connectivity. Simultaneously many MHP neighbourhoods have become central to contemporary debates surrounding urgent renovation needs, segregation, socio-economic inequality, and urban regeneration.

Re-imagining façades, roofs, terraces, and courtyards in these districts as ecological infrastructure may create opportunities to renegotiate the structural, ecological, and social conditions of these suburban areas, and the larger ecological functioning of Stockholm itself.

In chapter four and five I focused on the Jarva region in Stock to accordingly further zoom in on Tensta. The analysis of Tensta's urban structure and municipal park plans revealed that its built environment and surrounding greenery constitute a large share of residents' everyday life, yet offers considerable potential for ecological and social improvement.

A series of 2D and 3D analyses were developed to quantify, qualify, and classify existing green structures in relation to the potential vertical greening surface. This resulted in a Vertical Capacity Model (VCM), a simplified volumetric representation of Tensta's urban building geometry designed to map, classify, and evaluate the three-dimensional surface potential of Tensta's urban built environment.

The model demonstrated that different building typologies and surface categories offer distinct opportunities for implementing NBS. By shifting the analysis from horizontal land cover towards three-dimensional surface potential, the VCM demonstrated that façades and roofs represent a significant yet largely overlooked resource for climate adaptation, biodiversity enhancement, and ecological retrofitting. These findings provided the foundation for the development of several implementation scenarios.

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In chapter six, I shifted my focus to the development of an analytical framework for pilot evaluation and identified possible governance pathways for vertical greening strategies; this resulted in four pilot projects demonstrating the possible ecological, economic, and social potential of VUE on multiple scales. Each of these pilots is meant to inspire both policy makers, residents, designers and developers of the potential benefits of integrating NBS on their buildings.

In addition, a full-scale low-tech living wall mock-up was developed. The prototype was conceived as a practical and educational template that could be replicated in participatory and community-based environments using accessible materials and construction methods. Beyond its demonstrative value, the mock-up provided an opportunity to test questions of constructibility, materiality, maintenance, and biodiversity support that could not be fully explored through concepts and digital models alone.

The culmination my findings across all chapters suggest that the primary challenge for implementing VUE in Sweden, and particularly in Stockholm, is not the lack of spatial potential within the built environment, or the technical potential of NBS, but rather the ability to translate this potential into feasible planning, governance, and implementation strategies.

This work further demonstrates that Sweden's existing building stock and its related challenges contain substantial opportunities for the wider implementation of NBS on buildings. However, its success will primarily hinge on ownership structures, financing mechanisms, maintenance responsibilities, resident acceptance, and institutional support.

7.3 From Potential to Implementation: Recommendations for Existing and Future Urban Development

The following recommendations respond directly to the structural challenges identified throughout this thesis and consider how VUE might be implemented within both existing building stock and future urban development projects.

1. Expand Planning Tools Beyond the Ground Plane

Current planning practices continue to focus primarily on horizontal land cover, canopy coverage, and public green space. Future planning tools should increasingly recognise the vertical character of cities by mapping façades, roofs, and other building-envelope surfaces as potential ecological infrastructure. Such approaches would enable to better identify opportunities for ecological retrofitting within existing urban environments and support a more systematic and dispersed integration of NBS into climate adaptation, biodiversity, and urban regeneration strategies.

3. Target Strategic Retrofit Areas

Rather than treating building-integrated NBS as additions solely for newly developed buildings and urban areas, ecological interventions should be promoted and introduced into façade upgrades, roof replacements, energy retrofits and climate-adaptation measures within Sweden's existing building stock. The Tensta case-study serves as an example of how ecological retrofitting can be aligned with investments that are already required, reducing implementation costs while enhancing biodiversity, climate adaptation, and environmental quality.

4. Develop Strategic Pilot Projects & Partnerships

The ownership analysis of Tensta and the parameter analysis of the pilot projects suggests that no single actor is capable of implementing VUE at district scale. Future efforts should therefore focus on creating partnerships between municipalities, housing companies, private property owners, and resident cooperatives. Demonstration projects or pilots can act as shared learning platforms through which ecological, technical, financial, and organisational challenges are explored before larger-scale implementation is pursued. By reducing uncertainty and generating visible examples of success, such projects will help build the trust, acceptance, and institutional capacity required for the wider adoption of VUE.

2. Develop Incentives for Existing Buildings and their Actors

Current legal planning frameworks provide limited mechanisms for requiring NBS on private property in Sweden. Consequently, the implementation of VUE is likely to depend on subsidies, ecological performance standards, climate-adaptation grants, tax incentives, and other policy instruments that encourage voluntary participation. Future VUE planning efforts should therefore focus not solely on establishing ecological goals, but also on creating economic and institutional conditions that make ecological retrofitting more attractive for property owners, housing companies, and residents.

5. Embed Ecological Infrastructure Early in the Urban Development Process

While this thesis primarily focuses on ecological retrofitting, future urban developments represent an equally important opportunity for implementation. We learned that through land-allocation agreements, development contracts, and sustainability requirements, municipalities possess significantly greater influence over ecological outcomes in newly developed districts than within existing neighbourhoods. Future planning can therefore be more ambitious and should demand and integrate NBS from the earliest design stages. Especially in high-density new urban areas, VUE could be relevant as open green space and the built environment are in constant negotiation.

6. Ethical Considerations

Although NBS have become a mainstream climate mitigation and adaptation concept, the critical review of Anguelovski & Corbera (2023) points out that it's capacity to deliver benefits, especially in regards to human well-being and socio-economic parameters remains uncertain. They argue that in it's current myriad forms and applications, NBS can become a key enabler for nature-based dispossession, as private investors might try to capitalize upon the global call to put nature at the centre of climate action.

Especially the fragmented private-public ownership structure of the rental housing stock in Sweden and its urgent renovation agenda, might lead to negative impacts such as higher rental prices after renovation, short term-only mitigation, and dynamics of gentrification, as the ability of vulnerable social groups to remain in place becomes jeopardized by regeneration practices initiated by NBS-based concepts such as VUE.

The choice for Tensta as a case-study in this thesis is strongly connected to these considerations as besides its spatial characteristics, the neighbourhood brings up discussions surrounding socio-spatial inequality and territorial stigma. Stockholm's planning documents might recognize the differences in living conditions in the Jarva region compared to other parts of Stockholm, but the continued disparities within many MHP neighbourhoods, suggest that ecological improvements alone cannot be equated with social progress.

Therefore, the implementation of VUE must be accompanied by governance structures that actively safeguard affordability, participation, and long-term social inclusion. While large-scale implementation may be most feasible through municipal actors, housing companies, and public-private partnerships, this thesis suggest that resident participation and community stewardship are equally essential for ensuring that ecological transformation remains locally grounded and socially meaningful.

To avoid VUE becoming a vehicle for socio-environmental dispossession, greenwashing, or speculative forms of ecological redevelopment, its implementation should be guided by principles and legal frameworks that place social justice alongside ecological performance. Drawing on Anguelovski and Corbera (2023), four of their principles form particularly relevant lessons to the future development of VUE:

*
Residents should not merely be consulted, but actively involved in shaping, implementing, and maintaining ecological interventions.
*
The benefits of NBS should first prioritise neighbourhoods and groups that have historically experienced lower environmental quality and reduced access to urban nature.
*
Ecological retrofitting should strengthen everyday interactions between residents and urban ecosystems rather than simply producing technical benefits or visual "greening".
*
Ecological interventions should primarily be evaluated according to their social and environmental outcomes rather than their marketing value or ability to attract investment.

From this perspective, the success of VUE should not only be measured by the amount of vegetation that can be added to buildings, but by the extent to which ecological improvements remain accessible to existing residents and contribute to more equitable forms of urban transformation.

7.4 Possible Discussions

This thesis opens up several broader discussions concerning the future role of the built environment within urban ecological systems. In this paragraph I will shortly address some prominent discussion points:

1. Should cities prioritise retrofitting the existing building stock over new developments?

The “greenest” building may not be a newly constructed building, but rather the building that you don’t have to build. While cities like Stockholm focus heavily on the ecological values of newly developed districts, these developments also require lots of material resources and space.

This raises the question whether sustainable urbanisation should be focussing first on retrofitting and activating what is already there, before relying on the creation of completely new “green” developments. This thesis therefore brings up discussions related to the principles of adaptive reuse.

2. To what extent should municipalities be able to intervene in private property for environmental purposes?

As environmental challenges become increasingly urgent, the role of governments in demanding environmental performance standards within privately owned urban environments is likely to become an important area of future debate. At the same time, research has shown that municipalities already play a complex and sometimes contradictory role because of their often dual position as both planning authorities, landowners, and development facilitators.

This thesis could therefore raise broader questions regarding the appropriate balance between private property rights, public environmental objectives, and democratic accountability.

3. Do European cities need a more unified framework for measuring ecological performance, especially in cities?

Current planning frameworks continue to rely heavily on horizontal indicators such as land cover, TCC, and large-scale ecological structures such as Stockholm’s green wedges. Through the development of the VCM, this thesis attempted to explore alternative ways of identifying and evaluating the ecological potential embedded within the vertically built environment.

The analysis of existing three-dimensional ecological valuation systems such as the GnPR, BAF, and GSF demonstrated that a wide range of approaches already exist. However, these frameworks employ different parameters, scales, weighting systems, and ecological assumptions, making direct comparison difficult. This could raise the question whether a more unified international framework for assessing the ecological health of cities may be necessary in relation to the collective European goals.

4. Could vertical urban ecology undermine the provision of open green space?

In this thesis, several scenarios explored how canopy deficits could partly be addressed through a canopy-equivalent framework. If building-integrated NBS would be seen as substitutes for conventional green space, there might be a risk that they could be used to justify higher densities, reduced open-space provision, or the loss of existing urban vegetation. In such a scenario, VUE would no longer complement urban green infrastructure but potentially compete with it.

This raises the question of whether building-integrated greening should be understood as an addition to, rather than a replacement for. Future planning frameworks may therefore need to ensure that canopy-equivalent or volumetric valuation systems strengthen rather than weaken the protection of open green space within cities.

7.5 Future Research

Topics remaining open for future investigation:

1. Future research could explore how VUE planning principles can also be integrated into newly developed urban districts, possibly by including existing green space planning tools such as Stockholm’s Green Space Factor (GSF) tool.

2. The ecological performance of many building-integrated NBS remains insufficiently documented over longer time periods and in especially in Nordic contexts. Future research should therefore focus on the long-term biodiversity outcomes, maintenance requirements, and the actual sustainability of the different systems.

3. While many studies highlight potential benefits such as energy savings, local water management, and increased environmental quality, the long-term costs and benefits of implementation, maintenance, and management remain difficult to assess. The economic feasibility of VUE therefore requires more detailed interdisciplinary investigation.

4. More research is needed into the social dimensions of VUE. This thesis identified human well-being, stewardship, and participation as important benefits of building-integrated NBS, yet resident perceptions and experiences are underexplored and difficult to measure. Future field studies could investigate how different user groups perceive ecological retrofitting, how stewardship practices develop over time, and how VUE influences everyday relationships between residents and urban nature.

5. The ownership analysis and pilot projects demonstrated that governance arrangements are often more decisive than the spatial potential alone. Further work is therefore needed to explore how municipalities, housing companies, private property owners, housing cooperatives, and residents can collaborate to implement VUE across different planning contexts.

7.6 Conclusion & Personal Reflection

In the beginning of this thesis, one of the main questions asked was to what degree the Swedish built environment could contribute more actively to urban ecological functioning. Through a broad literature review on building-integrated NBS, regional policy analysis, local spatial investigation, and site-specific design explorations; I can finally conclude that the ecological potential of the built environment in Sweden is considerably greater than is currently recognised.

My mixed qualitative research demonstrated that especially Stockholm’s MHP neighbourhoods can form strategic opportunities for ecological retrofitting due to their extensive building stock, ongoing renovation needs, and important role within broader processes of urban transformation. Through the development of a Vertical Capacity Model (VCM) and subsequent pilot projects, the thesis makes an attempt at how building-envelope surfaces can be identified, evaluated, and re-imagined as ecological infrastructure. At the same time, the work concludes that the principal barriers to implementation are not necessarily spatial or technical. Rather, they are institutional, economic, and social.

Perhaps the most important insight gained through this work is that the presented VUE concept, should not be understood as a singular intervention or planning doctrine. Instead, it should be viewed as a lens through which the existing city can be reconsidered. Rather than treating buildings as static objects that merely consume resources, VUE invites us to see them as active components within larger ecological systems. As Hillier (2025) reminds us, planning concepts often risk becoming ideological fantasies when their promises are accepted uncritically. Throughout the thesis I therefore attempted not to present VUE as a universal solution, but rather as an exploratory framework through which new spatial opportunities and tensions become visible.

On a personal level, this thesis has been both a joy and a challenge in repositioning my previous architectural disciplinary perspective. What initially began as an interest in finding the relationship between architecture and landscape architecture, gradually evolved into a broader reflection on the hidden ecological capacities of the built environment and the complex governance structures that shape their implementation.

Walking through Tensta, mapping ownership patterns, developing pilot projects, and constructing the living wall prototype revealed that ecological transformation is rarely limited by a lack of ideas or spatial opportunity. More often, it is constrained by the ways in which cities are organised, managed, financed, and governed. Throughout this work, my perspective therefore shifted from viewing Nature-Based Solutions as design interventions, towards understanding them as long-term urban transformation processes.

Ultimately, this thesis should not be understood as a definitive statement on Vertical Urban Ecology, but as an invitation to continue exploring the ecological possibilities embedded within the urban landscape. If sustainable urbanisation is to address the intertwined challenges of climate change, biodiversity loss, and social inequality, then the built environment may need to become more than a backdrop to ecological processes. It may need to become part of the ecosystem itself.

Figure 7.1. Collecting material for the Mock-up together with friends.

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BIBLIOGRAPHY

Abhijith, K.V., Kumar, P., Gallagher, J., McNabola, A., Baldauf, R., Pilla, F., Broderick, B., Di Sabatino, S. & Pulvirenti, B. (2017). Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. Atmospheric Environment, 162, 71–86. https://doi.org/10.1016/j.atmosenv.2017.05.014

Abualfaraj, N., Cataldo, J., Elborolosy, Y., Fagan, D., Woerdeman, S., Carson, T. & Montalto, F.A. (2018). Monitoring and Modeling the Long-Term Rainfall-Runoff Response of the Jacob K. Javits Center Green Roof. Water, 10 (11), 1494. https://doi.org/10.3390/w10111494

Agonafir, C., Lakhankar, T., Khanbilvardi, R., Krakauer, N., Radell, D. & Devineni, N. (2023). A review of recent advances in urban flood research. Water Security, 19, 100141. https://doi.org/10.1016/j.wasec.2023.100141

Ahlqvist & Almqvist Arkitekter (2021). Awinge. https://www.ahlqvist-almqvist.se/projekt/avinge/ [2026-05-12]

Amca, Y., Yorucu, V. & Kırıkkaleli, D. (2025). Construction Cost Index: Political, Economic, and Financial Risk Indices Within the European Continent. Sustainability, 17 (3), 917. https://doi.org/10.3390/su17030917

Andersson, E., Barthel, S., Borgström, S., Colding, J., Elmqvist, T., Folke, C. & Gren, Å. (2014). Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services. AMBIO, 43 (4), 445–453. https://doi.org/10.1007/s13280-014-0506-y

Andersson, R., Turner, L. & Holmqvist, E. (2011). Contextualising ethnic residential segregation in Sweden: welfare, housing and migration-related policies.

Astell-Burt, T., Hartig, T., Putra, I.G.N.E., Walsan, R., Dendup, T. & Feng, X. (2022). Green space and loneliness: A systematic review with theoretical and methodological guidance for future research. Science of The Total Environment, 847, 157521. https://doi.org/10.1016/j.scitotenv.2022.157521

Awais Piracha & Marotullio, P. (2003). Urban Ecosystem Analysis: Identifying Tools and Methods. Unpublished. https://doi.org/10.13140/RG.2.1.5055.4963

Azaria, G. (2022). selvatico transforms car park rooftop into lively urban garden in the heart of heerlen. designboom | architecture & design magazine. https://www.designboom.com/architecture/selvatico-car-park-rooftop-urban-garden-heerlen-10-27-2022/ [2026-05-12]

Barmparesos, N., Assimakopoulos, M., Assimakopoulos, V., Loumos, N., Sotiriou, M.A. & Koukoumtzis, A. (2018). Indoor Air Quality and Thermal Conditions in a Primary School with a Green Roof System. Atmosphere, 9 (2), 75. https://doi.org/10.3390/atmos9020075

Baró, F., Langemeyer, J., Łaszkiewicz, E. & Kabisch, N. (2021). Editorial to the special issue "Advancing urban ecosystem service implementation and assessment considering different dimensions of environmental justice". Environmental Science & Policy, 115, 43–46. https://doi.org/10.1016/j.envsci.2020.10.008

Barwise, Y. & Kumar, P. (2020). Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection. npj Climate and Atmospheric Science, 3 (1), 12. https://doi.org/10.1038/s41612-020-0115-3

Basu, R. (2009). High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environmental Health, 8 (1), 40. https://doi.org/10.1186/1476-069X-8-40

Becker Giseke Mohren Richard Landscape Architects (1990). The Biotope Area Factor as an Ecological Parameter. https://share.google/NJM32zf2ksH12gULj

Berto, R., Barbiero, G., Barbiero, P. & Senes, G. (2018). An Individual's Connection to Nature Can Affect Perceived Restorativeness of Natural Environments. Some Observations about Biophilia. Behavioral Sciences, 8 (3), 34. https://doi.org/10.3390/bs8030034

Bhui, K., Newbury, J.B., Latham, R.M., Ucci, M., Nasir, Z.A., Turner, B., O'Leary, C., Fisher, H.L., Marczylo, E., Douglas, P., Stansfeld, S., Jackson, S.K., Tyrrel, S., Rzhetsky, A., Kinnersley, R., Kumar, P., Duchaine, C. & Coulon, F. (2023). Air quality and mental health: evidence, challenges and future directions. BJPsych Open, 9 (4), e120. https://doi.org/10.1192/bjo.2023.507

den Boer, E. & Schroten, A. (2007). Traffic noise reduction in Europe: Health effects, social costs and technical and policy options to reduce road and rail traffic noise. https://www.transportenvironment.org/uploads/files/2008-02_traffic_noise_ce_delft_report.pdf [2026-02-27]

Boverket (2021). Uppdrag att utvärdera stödet för renovering och energieffektivisering samt att analysera ägarförhållanden på hyresbostadsmarknaden. Boverket. https://www.boverket.se/sv/om-boverket/publikationer/2021/uppdrag-att-utvardera-stodet-for-renovering-och-energieffektivisering-samt-att-analysera-agarforhallanden-pa-hyresbostadsmarknaden/ [2026-03-16]

Bratman, G.N., Anderson, C.B., Berman, M.G., Cochran, B., De Vries, S., Flanders, J., Folke, C., Frumkin, H., Gross, J.J., Hartig, T., Kahn, P.H., Kuo, M., Lawler, J.J., Levin, P.S., Lindahl, T., Meyer-Lindenberg, A., Mitchell, R., Ouyang, Z., Roe, J., Scarlett, L., Smith, J.R., Van Den Bosch, M., Wheeler, B.W., White, M.P., Zheng, H. & Daily, G.C. (2019). Nature and mental health: An ecosystem service perspective. Science Advances, 5 (7), eaax0903. https://doi.org/10.1126/sciadv.aax0903

Bråvander, L.-G. & Jacobson, R. (2003). Skötselplan för Nationalstadsparken i Stockholm. https://www.ekoparken.org/Medlemssidor/kdf/splan%20NSP%203%20nov%20del%20I.pdf [2026-03-18]

Brenneisen, S. & Baumann, N. (2016). Green roofs in Basel, Switzerland: combining mitigation and adaptation measures. https://climate-adapt.eea.europa.eu/en/metadata/case-studies/green-roofs-in-basel-switzerland-combining-mitigation-and-adaptation-measures-1 [2026-05-12]

Brokking, P., Liedholm Johnson, E. & Paulsson, J. (2020). Implementation Strategies for Sustainable Urban Development : Examples from Swedish practice. vdf Hochschulverlag AG an der ETH Zürich. 223–234. https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-283966 [2026-03-13]

Brokking, P., Mörtberg, U. & Balfors, B. (2021). Municipal Practices for Integrated Planning of Nature-Based Solutions in Urban Development in the Stockholm Region. Sustainability, 13 (18), 10389. https://doi.org/10.3390/su131810389

Bustami, R.A., Rawlings, R., Universiti Malaysia Sarawak, 94300 Kota Samarahan, MALAYSIA, Beecham, S., University of South Australia, Mawson Lakes, 5095, AUSTRALIA, Ward, J., University of South Australia, Mawson Lakes, 5095, AUSTRALIA, Mah, D.Y.S., & Universiti Malaysia Sarawak, 94300 Kota Samarahan, MALAYSIA (2023). Living Walls in The City: Community Values and Expectations. International Journal of Integrated Engineering, 15 (6). https://doi.org/10.30880/ijie.2023.15.06.009

Cascone, S. (2019). Green Roof Design: State of the Art on Technology and Materials. Sustainability, 11 (11), 3020. https://doi.org/10.3390/su11113020

City of Stockholm (2024). Stockholm Royal Seaport. https://vaxer.stockholm/en/areas/city-development-areas/stockholm-royal-seaport/ [2026-03-13]

Cityfied (n.d.). CITYFIED. http://se.cityfied.eu/projektet/om-cityfied.kl [2026-03-16]

Clar, C., Prutsch, A. & Steurer, R. (2013). Barriers and guidelines for public policies on climate change adaptation: A missed opportunity of scientific knowledge-brokerage. Natural Resources Forum, 37 (1), 1–18. https://doi.org/10.1111/1477-8947.12013

Cohen-Shacham, E., Walters, G., Janzen, C. & Maginnis, S. (eds) (2016). Nature-based solutions to address global societal challenges. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Colding, J., Lundberg, J. & Folke, C. (2006). Incorporating Green-area User Groups in Urban Ecosystem Management. AMBIO: A Journal of the Human Environment, 35 (5), 237–244. https://doi.org/10.1579/05-A-098R.1

Colding, J., Marcus, L., Barthel, S., Andersson, E., Jansson, Å. & Borgström, S. (2012). När, vad och hur? Gröna svaga samband i Stockholms gröna kilar. Stockholms Läns Landsting. https://urn.kb.se/resolve?urn=urn:nbn:se:hig:diva-34050 [2026-03-13]

COP 15 | UNFCCC (n.d.). https://unfccc.int/event/cop-15 [2026-03-05]

Crandall, C.G. & González-Alonso, J. (2010). Cardiovascular function in the heat-stressed human. Acta Physiologica, 199 (4), 407–423. https://doi.org/10.1111/j.1748-1716.2010.02119.x

Debucquet, G., Maignant, A., Laroche, A.-L., Widehem, C. & Morel, P. (2022). Bringing nature into private urban housing: Environmental, social and food connections for urban resilience. Cities, 131, 104007. https://doi.org/10.1016/j.cities.2022.104007

Dorst, H., Van Der Jagt, A., Toxopeus, H., Tozer, L., Raven, R. & Runhaar, H. (2022). What's behind the barriers? Uncovering structural conditions working against urban nature-based solutions. Landscape and Urban Planning, 220, 104335. https://doi.org/10.1016/j.landurbplan.2021.104335

Dover, J.W. (2015). Green Infrastructure. 0. ed Routledge. https://doi.org/10.4324/9780203121993

Drotte, F. & von Hofsten, A. (2016). Mer stadskvalitéer till lägre pris. Föreningen för Samhällsplanering. https://www.planering.org/plan-blog/2016/5/17/mer-stadskvaliter-till-lgre-pris [2026-03-13]

Drukker, E.F., Schranz, M.E., Vet, L.E.M., Voeten, J., Fatouros, N.E. & Quist, C.W. (2026). The development of insect diversity and ecosystem complexity on green roofs: A review. Insect Conservation and Diversity, 19 (1), 11–25. https://doi.org/10.1111/icad.70007

Ekologigruppen (2015). Kartläggning av ekosystemtjänster i Upplands Väsby kommun, Underlag till utvecklingsplan för ekosystemtjänster. Upplands Väsby Municipality: Stockholm.

Elmqvist, T., Colding, J., Barthel, S., Borgström, S., Duit, A., Lundberg, J., Andersson, E., AHRNé, K., Ernstson, H., Folke, C. & Bengtsson, J. (2004). The Dynamics of Social-Ecological Systems in Urban Landscapes: Stockholm and the National Urban Park, Sweden. Annals of the New York Academy of Sciences, 1023 (1), 308–322. https://doi.org/10.1196/annals.1319.017

Embleton, T.F.W. (1963). Sound Propagation in Homogeneous Deciduous and Evergreen Woods. The Journal of the Acoustical Society of America, 35 (8), 1119–1125. https://doi.org/10.1121/1.1918662

Faivre, N., Fritz, M., Freitas, T., De Boissezon, B. & Vandewoestijne, S. (2017). Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. Environmental Research, 159, 509–518. https://doi.org/10.1016/j.envres.2017.08.032

Femenías, P., Mjörnell, K. & Thuvander, L. (2018). Rethinking deep renovation: The perspective of rental housing in Sweden. Journal of Cleaner Production, 195, 1457–1467. https://doi.org/10.1016/j.jclepro.2017.12.282

Fleck, R., Gill, R., Pettit, T.J., Torpy, F.R. & Irga, P.J. (2022). Bio-solar green roofs increase solar energy output: The sunny side of integrating sustainable technologies. Building and Environment, 226, 109703. https://doi.org/10.1016/j.buildenv.2022.109703

Furberg, D., Ban, Y. & Mörtberg, U. (2020). Monitoring Urban Green Infrastructure Changes and Impact on Habitat Connectivity Using High-Resolution Satellite Data. Remote Sensing, 12 (18), 3072. https://doi.org/10.3390/rs12183072

Gill, S., Handley, J.F., Ennos, R. & Pauleit, S. (2007). Adapting Cities for Climate Change: The Role of the Green Infrastructure. Built Environment, 33, 115–133. https://doi.org/10.2148/benv.33.1.115

Goddard, M.A., Dougill, A.J. & Benton, T.G. (2010). Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution, 25 (2), 90–98. https://doi.org/10.1016/j.tree.2009.07.016

Gothnier, M., Hjorth, G. & Östergård, S. (1999). Rapport fran ArtArken. Miljöförvaltningen. https://miljobarometern.stockholm.se/content/docs/tema/natur/Rapport%20fr%C3%A5n%20ArtArken1999%20publ.pdf [2026-03-18]

Gover, M. (1938). Mortality during Periods of Excessive Temperature. Public Health Reports (1896-1970), 53 (27), 1122. https://doi.org/10.2307/4582590

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X. & Briggs, J.M. (2008). Global Change and the Ecology of Cities. Science, 319 (5864), 756–760. https://doi.org/10.1126/science.1150195

Hagström, E. (2025). Hjulstaaffären är godkänd. Mitt i - Nyheter Stockholm. https://www.mitti.se/nyheter/hjulstaaffaren-ar-godkand-6.3.335805.d618281151

Hallberg, P. (2006). Kämpingebacken 13 : Stockholms stadsmuseums museilägenhet i Tensta.

Hao, X., Liu, L., Tan, H., Lin, Y., Hu, J. & Wei, Y. (2022). The Impacts of Greenery Systems on Indoor Thermal Environments in Transition Seasons: An Experimental Investigation. Buildings, 506. https://doi.org/10.3390/buildings12050506

Hartig, T., Mitchell, R., De Vries, S. & Frumkin, H. (2014). Nature and Health. Annual Review of Public Health, 35 (1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

He, Y., Yu, H., Dong, N. & Ye, H. (2016). Thermal and energy performance assessment of extensive green roof in summer: A case study of a lightweight building in Shanghai. Energy and Buildings, 127, 762–773. https://doi.org/10.1016/j.enbuild.2016.06.016

He, Y., Yu, H., Ozaki, A., Dong, N. & Zheng, S. (2017). Long-term thermal performance evaluation of green roof system based on two new indexes: A case study in Shanghai area. Building and Environment, 120. https://doi.org/10.1016/j.buildenv.2017.04.001

Hillier, J. (2025). Nature-Based Solutions as Ideological Fantasy. In: Ideological Fantasies in Planning Theories and Practices. Routledge.

Hunter, A.M., Williams, N.S.G., Rayner, J.P., Aye, L., Hes, D. & Livesley, S.J. (2014). Quantifying the thermal performance of green façades: A critical review. Ecological Engineering, 63, 102–113. https://doi.org/10.1016/j.ecoleng.2013.12.021

Interlace Hub (2023). Green Space Factor and Green Points System - Malmö. https://interlace-hub.com/green-space-factor-and-green-points-system-malm%C3%B6 [2026-04-23]

Jacobs, J., Beenaerts, N. & Artois, T. (2023). Green roofs and pollinators, useful green spots for some wild bee species (Hymenoptera: Anthophila), but not so much for hoverflies (Diptera: Syrphidae). Scientific Reports, 13 (1), 1449. https://doi.org/10.1038/s41598-023-28698-7

Johansson, D. (2026). Nedgånget p-hus i Tensta 'ingen säkerhetsrisk'. Nyhetsbyrån Järva. https://www.nyhetsbyranjarva.se/nedganget-p-hus-i-tensta-ingen-sakerhetsrisk/ [2026-05-12]

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K. & Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecology and Society, 21 (2), art39. https://doi.org/10.5751/ES-08373-210239

Kandel, S. & Frantzeskaki, N. (2024). Nature-based solutions and buildings: A review of the literature and an agenda for renaturing our cities one building at a time. Nature-Based Solutions, 5, 100106. https://doi.org/10.1016/j.nbsj.2023.100106

Kauark-Fontes, B., Marchetti, L. & Salbitano, F. (2023). Integration of nature-based solutions (NBS) in local policy and planning toward transformative change. Evidence from Barcelona, Lisbon, and Turin. Ecology and Society, 28 (2), art25. https://doi.org/10.5751/ES-14182-280225

Kew, B., Pennypacker, E. & Echols, S. (2014). Can greenwalls contribute to stormwater management? A study of cistern storage greenwall first flush capture. Journal of Green Building, 9 (3), 85–99. https://doi.org/10.3992/1943-4618-9.3.85

Klaassen, A. & De Block, G. (2025). BEYOND ' BAD DENSITY ' AND TERRITORIAL STIGMA : An Infrastructure Access Lens on Suburban Exclusion. International Journal of Urban and Regional Research, 49 (5), 1063–1081. https://doi.org/10.1111/1468-2427.13329

Klingberg, J., Broberg, M., Strandberg, B., Thorsson, P. & Pleijel, H. (2017). Influence of urban vegetation on air pollution and noise exposure – A case study in Gothenburg, Sweden. Science of The Total Environment, 599–600, 1728–1739. https://doi.org/10.1016/j.scitotenv.2017.05.051

Knapp, S., Schmauck, S. & Zehnsdorf, A. (2019). Biodiversity Impact of Green Roofs and Constructed Wetlands as Progressive Eco-Technologies in Urban Areas. Sustainability, 11 (20), 5846. https://doi.org/10.3390/su11205846

Köhler, M. (2008). Green facades—a view back and some visions. Urban Ecosystems, 11 (4), 423. https://doi.org/10.1007/S11252-008-0063-X

Kontoleon, K.J. & Eumorfopoulou, E.A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. Building and Environment, 45 (5), 1287–1303. https://doi.org/10.1016/j.buildenv.2009.11.013

Krause, P., Meier, L., Leistner, P., Eitle, A., Bender, E., Fischer, L.K. & Müller, H. (2023). Entwicklung und Erprobung eines urbanen Grünfassadensystems für Mensch, Flora und Fauna. Bauphysik, 45 (1), 44–54. https://doi.org/10.1002/bapi.202200039

LAND Arkitektur (2021). Sjödalsparken, Huddinge. LAND Arkitektur. https://landarkitektur.se/projekt/sjodalsparken-huddinge/ [2026-03-15]

Leather, S.R. (2018). "Ecological Armageddon" – more evidence for the drastic decline in insect numbers. Annals of Applied Biology, 172 (1), 1–3. https://doi.org/10.1111/aab.12410

Lehmann, S. (2021). Growing Biodiverse Urban Futures: Renaturalization and Rewilding as Strategies to Strengthen Urban Resilience. Sustainability, 13 (5), 2932. https://doi.org/10.3390/su13052932

Lepp, N.W. (2008). Planting Green Roofs and Living Walls. Journal of Environmental Quality, 37 (6), 2408–2408. https://doi.org/10.2134/jeq2008.0016br

Lindemann-Matthies, P. & Marty, T. (2013). Does ecological gardening increase species richness and aesthetic quality of a garden? Biological Conservation, 159, 37–44. https://doi.org/10.1016/j.biocon.2012.12.011

Ling, T.-Y., Hung, W.-K., Lin, C.-T. & Lu, M. (2020). Dealing with Green Gentrification and Vertical Green-Related Urban Well-Being: A Contextual-Based Design Framework. Sustainability, 12 (23), 10020. https://doi.org/10.3390/su122310020

Litschke, T. & Kuttler, W. (2008). On the reduction of urban particle concentration by vegetation a review. Meteorologische Zeitschrift, 17 (3), 229–240. https://doi.org/10.1127/0941-2948/2008/0284

Littke, H. (2015). Planning the Green Walkable City: Conceptualizing Values and Conflicts for Urban Green Space Strategies in Stockholm. Sustainability, 7 (8), 11306–11320. https://doi.org/10.3390/su70811306

Liu, K.K.Y. & Bass, B. (2005). Performance of green roof systems. 1–18

Liu, L., Cao, J., Ali, M., Zhang, J. & Wang, Z. (2021). Impact of green roof plant species on domestic wastewater treatment. Environmental Advances, 4, 100059. https://doi.org/10.1016/j.envadv.2021.100059

Löfvenhaft, K., Björn, C. & Ihse, M. (2002). Biotope patterns in urban areas: a conceptual model integrating biodiversity issues in spatial planning. Landscape and Urban Planning, 58 (2–4), 223–240. https://doi.org/10.1016/S0169-2046(01)00223-7

Lovell, S.T. & Taylor, J.R. (2013). Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landscape Ecology, 28 (8), 1447–1463. https://doi.org/10.1007/s10980-013-9912-y

Lundholm, J., MacIvor, J.S., MacDougall, Z. & Ranalli, M. (2010). Plant Species and Functional Group Combinations Affect Green Roof Ecosystem Functions. Bruun, H.H. (ed.) (Bruun, H. H., ed.) PLoS ONE, 5 (3), e9677. https://doi.org/10.1371/journal.pone.0009677

Lundholm, J.T., Weddle, B.M. & MacIvor, J.S. (2014). Snow depth and vegetation type affect green roof thermal performance in winter. Energy and Buildings, 84, 299–307. https://doi.org/10.1016/j.enbuild.2014.07.093

Lupp, G., Zingraff-Hamed, A., Huang, J.J., Oen, A. & Pauleit, S. (2020). Living Labs—A Concept for Co-Designing Nature-Based Solutions. Sustainability, 13 (1), 188. https://doi.org/10.3390/su13010188

Malmheden, S. (2020). The 'Million' programme is being updated to accommodate both the climate and tenants. Swedish Environmental Research Institute. [text]. https://www.ivl.se/english/ivl/press/press-releases/2019-02-26-the-million-programme-is-being-updated-to-accommodate-both-the-climate-and-tenants.html [2026-03-15]

Martens, M.J.M. & Michelsen, A. (1981). Absorption of acoustic energy by plant leaves. The Journal of the Acoustical Society of America, 69 (1), 303–306. https://doi.org/10.1121/1.385313

Mazzali, U., Peron, F. & Scarpa, M. (2012). Thermo-physical performances of living walls via field measurements and numerical analysis. Proceedings of ECO-ARCHITECTURE 2012, Kos, Greece, September 5 2012. 251–259. https://doi.org/10.2495/ARC120231

McKinney, M.L. (2006). Urbanization as a major cause of biotic homogenization. Biological Conservation, 127 (3), 247–260. https://doi.org/10.1016/j.biocon.2005.09.005

Mentens, J., Raes, D. & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, 77 (3), 217–226. https://doi.org/10.1016/j.landurbplan.2005.02.010

Molari, M., Dominici, L., Manso, M., Silva, C.M. & Comino, E. (2024). A socio-ecological approach to investigate the perception of green walls in cities: A comparative analysis of case studies in Turin and Lisbon. Nature-Based Solutions, 6, 100175. https://doi.org/10.1016/j.nbsj.2024.100175

Molina, I. (1997). Stadens rasifiering : Etnisk boendesegregation i folkhemmet : [ethnic residential segregation in the Swedish Folkhem]. https://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-20 [2026-06-05]

Mumaw, L. & Bekessy, S. (2017). Wildlife gardening for collaborative public–private biodiversity conservation. Australasian Journal of Environmental Management, 24 (3), 242–260. https://doi.org/10.1080/14486563.2017.1309695

Muntean, D.M., Ungureanu, V., Petran, I. & Georgescu, M. (2017). Large Prefabricated Concrete Panels Collective Dwellings from the 1970s: Context and Improvements. IOP Conference Series: Materials Science and Engineering, 245, 052050. https://doi.org/10.1088/1757-899X/245/5/052050

Næss, Ø., Piro, F.N., Nafstad, P., Smith, G.D. & Leyland, A.H. (2007). Air Pollution, Social Deprivation, and Mortality: A Multilevel Cohort Study. Epidemiology, 18 (6), 686–694. https://doi.org/10.1097/EDE.0b013e3181567d14

Nagle, L., Echols, S. & Tamminga, K. (2017). Food production on a living wall: Pilot Study. Journal of Green Building, 12 (3), 23–38. https://doi.org/10.3992/1943-4618.12.3.23

Ng, E., Chen, L., Wang, Y. & Yuan, C. (2012). A study on the cooling effects of greening in a high-density city: An experience from Hong Kong. Building and Environment, 47, 256–271. https://doi.org/10.1016/j.buildenv.2011.07.014

Nizamani, A.G. & Torgersen, G. (2025). Climate as the Primary Moderator: Towards Context-Driven Design and Implementation of Vertical Greenery Systems for Stormwater Management. Civil and Environmental Engineering. https://doi.org/10.31223/X5QB3H

Nordregio, Aguiar Borges, L., Rohrer, L. & Nilsson, K. (2024). Green and healthy Nordic cities: How to plan, design, and manage health-promoting urban green space. Nordregio. https://doi.org/10.6027/R2024:11403-2503

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M. & Williams, N.S.G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, 134, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018

Noutsopoulos, C., Andreadakis, A., Kouris, N., Charchousi, D., Mendrinou, P., Galani, A., Mantziaras, I. & Koumaki, E. (2018). Greywater characterization and loadings – Physicochemical treatment to promote onsite reuse. Journal of Environmental Management, 216, 337–346. https://doi.org/10.1016/j.jenvman.2017.05.094

Ode Sang, Å., Thorpert, P. & Fransson, A.-M. (2022). Planning, Designing, and Managing Green Roofs and Green Walls for Public Health – An Ecosystem Services Approach. Frontiers in Ecology and Evolution, 10, 804500. https://doi.org/10.3389/fevo.2022.804500

Oke, T.R. (1982). The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society, 108 (455), 1–24. https://doi.org/10.1002/qj.49710845502

Oliveira, F.L.D. (2017). Green Wedge Urbanism: History, Theory and Contemporary Practice. 1. ed Bloomsbury Publishing Plc. https://doi.org/10.5040/9781474229227

Oloś, G. (2024). Green facades support biodiversity in urban environment – A case study from Poland. Journal of Water and Land Development, 257–266. https://doi.org/10.24425/jwld.2023.148450

Olsson, L. (2018). The Neoliberalization of Municipal Land Policy in Sweden. International Journal of Urban and Regional Research, 42 (4), 633–650. https://doi.org/10.1111/1468-2427.12651

Ottelé, M., Perini, K., Fraaij, A.L.A., Haas, E.M. & Raiteri, R. (2011). Comparative life cycle analysis for green façades and living wall systems. Energy and Buildings, 43 (12), 3419–3429. https://doi.org/10.1016/j.enbuild.2011.09.010

Pasquini, L. & Cowling, R.M. (2015). Opportunities and challenges for mainstreaming ecosystem-based adaptation in local government: evidence from the Western Cape, South Africa. Environment, Development and Sustainability, 17 (5), 1121–1140. https://doi.org/10.1007/s10668-014-9594-x

Patel, R. & Boning (2016). Acoustics. In Cities Alive Green Building Envelope. In: Cities Alive: Green Building Envelope. Arup Deutschland. https://www.arup.com/insights/cities-alive-green-building-envelope/ [2026-02-26]

Paull, N., Krix, D., Torpy, F. & Irga, P. (2020). Can Green Walls Reduce Outdoor Ambient Particulate Matter, Noise Pollution and Temperature? International Journal of Environmental Research and Public Health, 17 (14), 5084. https://doi.org/10.3390/ijerph17145084

Perales-Momparler, S., Andrés-Doménech, I., Hernández-Crespo, C., Vallés-Morán, F., Martín, M., Escuder-Bueno, I. & Andreu, J. (2017). The role of monitoring sustainable drainage systems for promoting transition towards regenerative urban built environments: a case study in the Valencian region, Spain. Journal of Cleaner Production, 163, S113–S124. https://doi.org/10.1016/j.jclepro.2016.05.153

Pérez-Urrestarazu, L., Blasco-Romero, A. & Fernández-Cañero, R. (2017). Media and social impact valuation of a living wall: The case study of the Sagrado Corazon hospital in Seville (Spain). Urban Forestry & Urban Greening, 24, 141–148. https://doi.org/10.1016/j.ufug.2017.04.002

Perini, K., Ottelé, M., Haas, E.M. & Raiteri, R. (2011). Greening the building envelope, facade greening and living wall systems. Open Journal of Ecology, 01 (01), 1–8. https://doi.org/10.4236/oje.2011.11001

Perini, K. & Rosasco, P. (2013). Cost–benefit analysis for green façades and living wall systems. Building and Environment, 70, 110–121. https://doi.org/10.1016/j.buildenv.2013.08.012

Piracha, A. & Chaudhary, M.T. (2022). Urban Air Pollution, Urban Heat Island and Human Health: A Review of the Literature. Sustainability, 14 (15), 9234. https://doi.org/10.3390/su14159234

Pirouz, B., Turco, M. & Palermo, S.A. (2020). A Novel Idea for Improving the Efficiency of Green Walls in Urban Environment (an Innovative Design and Technique). Water, 12 (12), 3524. https://doi.org/10.3390/w12123524

Pucher, B., Zluwa, I., Spörl, P., Pitha, U. & Langergraber, G. (2022). Evaluation of the multifunctionality of a vertical greening system using different irrigation strategies on cooling, plant development and greywater use. Science of The Total Environment, 849, 157842. https://doi.org/10.1016/j.scitotenv.2022.157842

Randrup, T. & Jansson, M. (2020). Strategic management of urban open spaces. https://res.slu.se/id/publ/105833 [2026-03-10]

Randrup, T.B., Buijs, A., Konijnendijk, C.C. & Wild, T. (2020). Moving beyond the nature-based solutions discourse: introducing nature-based thinking. Urban Ecosystems, 23 (4), 919–926. https://doi.org/10.1007/s11252-020-00964-w

Randrup, T.B. & Persson, B. (2009). Public green spaces in the Nordic countries: Development of a new strategic management regime. Urban Forestry & Urban Greening, 8 (1), 31–40. https://doi.org/10.1016/j.ufug.2008.08.004

Rasidi, M.H., Jamirsah, N. & Said, I. (2018). Development of Urban Green Space Affects Neighbourhood Community Social Interaction. Asian Journal of Environment-Behaviour Studies, 3 (8), 79–88. https://doi.org/10.21834/aje-bs.v3i8.281

Rayner, J.P., Raynor, K.J. & Williams, N.S.G. (2010). Façade greening: A case study from melbourne, Australia. Acta Horticulturae, (881), 709–713. https://doi.org/10.17660/ActaHortic.2010.881.116

Redaktionen (2025). Tensta, Stockholm: Omfattande renoveringsprojekt genomförs av Interoc Fasad. Nya Projekt. https://www.nyaprojekt.se/2025/01/17/tensta-stockholm-omfattande-renoveringsprojekt-genomfors-av-interoc-fasad/ [2026-05-12]

Reid, W., Mooney, H., Cropper, A., Capistrano, D., Carpenter, S. & Chopra, K. (2005). Millennium Ecosystem Assessment. Ecosystems and human well-being: synthesis.

Santamouris, M. & Osmond, P. (2020). Increasing Green Infrastructure in Cities: Impact on Ambient Temperature, Air Quality and Heat-Related Mortality and Morbidity. Buildings, 10 (12), 233. https://doi.org/10.3390/buildings10120233

Sayadi, S., Hayati, A. & Salmanzadeh, M. (2021). Optimization of Window-to-Wall Ratio for Buildings Located in Different Climates: An IDA-Indoor Climate and Energy Simulation Study. Energies, 14 (7), 1974. https://doi.org/10.3390/en14071974

SCB (2023). Fewer children in almost all counties and municipalities by 2040. Statistikmyndigheten SCB. https://www.scb.se/en/finding-statistics/statistics-by-subject-area/population-and-living-conditions/population-composition-and-development/population-projections/pong/statistical-news/the-future-population-in-counties-and-municipalities-of-sweden-2024-2040/ [2026-03-13]

Schindler, B.Y., Vasl, A., Blaustein, L., Gurevich, D., Kadas, G.J. & Seifan, M. (2019). Fine-scale substrate heterogeneity does not affect arthropod communities on green roofs. PeerJ, 7, e6445. https://doi.org/10.7717/peerj.6445

Scott, M., Lennon, M., Haase, D., Kazmierczak, A., Clabby, G. & Beatley, T. (2016). Nature-based solutions for the contemporary city/Re-naturing the city/Reflections on urban landscapes, ecosystems services and nature-based solutions in cities/Multifunctional green infrastructure and climate change adaptation: brownfield greening as an adaptation strategy for vulnerable communities?/Delivering green infrastructure through planning: insights from practice in Fingal, Ireland/Planning for biophilic cities: from theory to practice. Planning Theory & Practice, 17 (2), 267–300. https://doi.org/10.1080/14649357.2016.1158907

Shanahan, D., Astell–Burt, T., Barber, E., Brymer, E., Cox, D., Dean, J., Depledge, M., Fuller, R., Hartig, T., Irvine, K., Jones, A., Kikillus, H., Lovell, R., Mitchell, R., Niemelä, J., Nieuwenhuijsen, M., Pretty, J., Townsend, M., Van Heezik, Y., Warber, S. & Gaston, K. (2019). Nature–Based Interventions for Improving Health and Wellbeing: The Purpose, the People and the Outcomes. Sports, 7 (6), 141. https://doi.org/10.3390/sports7060141

Shattuck, G.C. & Hilferty, M.M. (1933). Causes of Deaths from Heat in Massachusetts. New England Journal of Medicine, 209 (7), 319–329. https://doi.org/10.1056/NEJM193308172090701

Singh, G.G., Cottrell, R.S., Eddy, T.D. & Cisneros-Montemayor, A.M. (2021). Governing the Land-Sea Interface to Achieve Sustainable Coastal Development. Frontiers in Marine Science, 8, 709947. https://doi.org/10.3389/fmars.2021.709947

Stella, P. & Personne, E. (2021). Effects of conventional, extensive and semi-intensive green roofs on building conductive heat fluxes and surface temperatures in winter in Paris. Building and Environment, 205, 108202. https://doi.org/10.1016/j.buildenv.2021.108202

Stenberg, E. (2013). Structural Systems of the Million Program Era. Issuu. https://issuu.com/kth-arkitekturskolan/docs/structuralsystems [2026-03-15]

Stockholm County Administrative Board (2019). Grön infrastruktur - Regional handlingsplan för Stockholms län. Länsstyrelsen Stockholm. https://www.lansstyrelsen.se/stockholm/om-oss/vara-tjanster/publikationer/2019/gron-infrastruktur---regional-handlingsplan-for-stockholms-lan.html [2026-03-13]

Stockholm County Council (2025a). Ny regional utvecklingsplan - granskningsyttrande. Region Stockholm. https://www.regionstockholm.se/regional-utveckling/ny-regional-utvecklingsplan---granskningsyttrande/ [2026-03-13]

Stockholm County Council (2025b). Ny regional utvecklingsplan för Stockholmsregionen. Region Stockholm. https://www.regionstockholm.se/regional-utveckling/regional-utvecklingsplanering/ny-regional-utvecklingsplan-for-stockholmsregionen/ [2026-03-13]

Stockholm County Council. (2025). RUFS 2050 - regional utvecklingsplan för Stockholmsregionen. Region Stockholm. https://www.regionstockholm.se/regional-utveckling/strategier-och-planer/rufs-2050---regional-utvecklingsplan-for-stockholmsregionen/ [2026-03-13]

Stockholm Vatten och Avfall (2025). Taxor och avgifter för VA. https://www.stockholmvattenochavfall.se/kunskap/regler-riktlinjer-och-forskning/taxor-och-avgifter-for-va/ [2026-05-12]

Stockholms län Landstinget Regionplane- och trafikkontoret (1991). Regionplan 1991 för Stockholms län. Regionplane- och trafikkontoret, Stockholms läns landsting.

Stockholms stad (2015). GYF - grönytefaktor för kvartersmark. https://tillstand.stockholm/globalassets/foretag-och-organisationer/tillstand-och-regler/tillstand-regler-och-tillsyn/lokal-och-fastigheter/hallbarhetskrav-vid-byggnation/gyf---gronytefaktor-for-kvartersmark.pdf

Stockholms stad (2021). Parkplan Spånga-Tensta Del 1

Stockholms stad (2023). Tensta - Stockholms stad. https://vaxer.stockholm/omraden/jarva-stadsdelsomrade/tensta/ [2026-04-14]

Stockholms stad (2024). A greener schoolyard. https://vaxer.stockholm/siteassets/stockholm-vaxer/projekt/jarva-sdo/tensta/mer-gronska-pa-elinsborgsskolans-skolgard/elinsborgsskolan.pdf [2026-05-11]

Stockholms stad (2025a). Befolkning kvartersvis Årsrapport 2025. https://start.stockholm/globalassets/start/om-stockholms-stad/utredningar-statistik-och-fakta/statistik/befolkning/kvarterslistan-2025.pdf

Stockholms stad (2025b). Fokus Järva. https://vaxer.stockholm/omraden/stadsutvecklingsomraden/fokus-jarva/ [2026-04-14]

Stovin, V. (2010). The potential of green roofs to manage Urban Stormwater: The potential of green roofs to manage Urban Stormwater. Water and Environment Journal, 24 (3), 192–199. https://doi.org/10.1111/j.1747-6593.2009.00174.x

Svenska Bostäder (n.d.). The Järva Lift | Swedish Housing. https://www.svenskabostader.se/var-historia/artiklar/jarvalyftet/ [2026-03-17]

Svenskt Vatten AB (2022). Analys – Hushållens vattenkonsumtion. https://vattenbokhandeln.svensktvatten.se/wp-content/uploads/2022/05/M151_Analys-hushallens-vattenkonsumtion.pdf

Sveriges Radio (2007). Husbybor protesterade mot Järvalyftet - P4 Stockholm. https://www.sverigesradio.se/artikel/1748537 [2026-03-17]

Swedish National Board for Housing, Building and Planning (2010). Legislation - Planning and Building Act (2010:900) - Planning and Building Ordinance (2011:338).

Swedish National Board for Housing, Building and Planning (2021). Säkerställ ekosystemtjänster i detaljplan. Boverket. https://www.boverket.se/sv/PBL-kunskapsbanken/teman/ekosystemtjanster/metod_planering/dp/sakerstall-dp/ [2026-03-13]

Täby Municipality (2019). Täby Stadskärna 2050 Fördjupning av Översiktsplan (Antagen KS 2019-11-04). https://www.taby.se/stadsplanering-och-trafik/stadsplanering-och-utbyggnad/oversiktlig-planering/fordjupad-oversiktsplan-for-taby-stadskarna-2050/ [2026-03-13]

Tang, S.H., Ong, P.P. & Woon, H.S. (1986). Monte Carlo simulation of sound propagation through leafy foliage using experimentally obtained leaf resonance parameters. The Journal of the Acoustical Society of America, 80 (6), 1740–1744. https://doi.org/10.1121/1.394287

Tensta konsthall (2023). Tensta konsthall | Green Camp with George and Fahyma. https://www.tenstakonsthall.se/en/hander-pa-konsthallen/gront-kollo-med-george-och-fahyma [2026-05-11]

Teotónio, I., Silva, C.M. & Cruz, C.O. (2021). Economics of green roofs and green walls: A literature review. Sustainable Cities and Society, 69, 102781. https://doi.org/10.1016/j.scs.2021.102781

Tiago, P., Leal, A.I. & Silva, C.M. (2024). Assessing Ecological Gains: A Review of How Arthropods, Bats and Birds Benefit from Green Roofs and Walls. Environments, 11 (4), 76. https://doi.org/10.3390/environments11040076

Timboe, I. & Pharr, K. (2021). Nature-based solutions in international policy instruments. In: Nature-based Solutions and Water Security. Elsevier. 125–147. https://doi.org/10.1016/B978-0-12-819871-1.00015-4

Tiwary, A., Godsmark, K. & Smethurst, J. (2018). Field evaluation of precipitation interception potential of green façades. Ecological Engineering, 122, 69–75. https://doi.org/10.1016/j.ecoleng.2018.07.026

TotalValueWall (2019). TotalValueWall - A sustainable wall for your building. https://www.totalvaluewall.com/en/ [2026-05-12]

Tunström, M. & Wang, S. (2019). The segregated city. Nordic Council of Ministers. https://doi.org/10.6027/Nord2019-007

URA (2017). Updates to the Landscaping for Urban Spaces and High-Rises (LUSH) Programme: LUSH 3.0. https://www.ura.gov.sg/Corporate/Guidelines/Circulars/dc17-06 [2026-04-06]

Vedung, E. (1993). Statens markpolitik, kommunerna och historiens ironi. 1. uppl. SNS Förlag.

Victoriahem (2022). Här finns alla husen. Vi lyfter miljonprogrammet. https://www.victoriahem.se/se-alla-artiklar/har-finns-alla-husen/ [2026-03-16]

Wang, L., Wang, H., Wang, Y., Che, Y., Ge, Z. & Mao, L. (2022). The relationship between green roofs and urban biodiversity: a systematic review. Biodiversity and Conservation, 31 (7), 1771–1796. https://doi.org/10.1007/s10531-022-02436-3

Warner, E., Giuliani, L.M., Campbell, G.A., Smith, P., Seddon, N., Seddon, D. & Smith, A.C. (2025). Integrated above- and below-ground ecological monitoring for nature-based solutions. Ecological Solutions and Evidence, 6 (2), e70043. https://doi.org/10.1002/2688-8319.70043

Wilén, C., Ahlqvist, V.H., Migueles, J.H., Campos-Garzón, P., Dahlén, M., Kosidou, K., Rådholm, K., Henriksson, P. & Berglind, D. (2026). Reconstructing schoolyards with greenery to increase schoolchildren's physical activity and mitigate climate changes in urban areas: study protocol for a stepped-wedge trial. BMC Public Health, 26, 708. https://doi.org/10.1186/s12889-026-26609-9

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

Wong, N.H., Kwang Tan, A.Y., Chen, Y., Sekar, K., Tan, P.Y., Chan, D., Chiang, K. & Wong, N.C. (2010). Thermal evaluation of vertical greenery systems for building walls. Building and Environment, 45 (3), 663–672. https://doi.org/10.1016/j.buildenv.2009.08.005

Yuliani, S., Hardiman, G., Setyowati, E., Setyaningsih, W. & Winarto, Y. (2021). Thermal behaviour of concrete and corrugated zinc green roofs on low-rise housing in the humid tropics. Architectural Science Review, 64 (3), 247–261. https://doi.org/10.1080/00038628.2020.1751054

ZHAW (2025). World green roof & green facades congres. https://www.ideassonline.org/public/pdf/GreenRoofsCongressBasel-ENG.pdf [2026-12-11]

Zheng, J., Li, Z. & Zheng, B. (2024). A Study on the Effect of Green Plot Ratio (GPR) on Urban Heat Island Intensity and Outdoor Thermal Comfort in Residential Areas. Forests, 15 (3), 518. https://doi.org/10.3390/f15030518

Ziter, C.D., Pedersen, E.J., Kucharik, C.J. & Turner, M.G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proceedings of the National Academy of Sciences, 116 (15), 7575–7580. https://doi.org/10.1073/pnas.1817561116

APPENDIX

*Reflections on the use of Generative AI for Visual Representation

Visualisations played an important role throughout this thesis, serving both as analytical and communicative tools. Mappings, diagrams, three-dimensional modelling, photography, prototyping and AI-generated visualisations were used to explore the potential of Vertical Urban Ecology across the multiple scales.

My intention throughout this work, was to rely as much as possible on visual material that I produced myself. However, for a limited number of images, primarily within the pilot project chapter, generative AI was used as a conceptual visualisation tool. This appendix briefly reflects on the process, prompts, limitations, and considerations that informed the use of AI-software.

Traditionally, the visualisation of planning and design proposals has mostly relied on time- and labour intensive processes of physical models, drawings, three-dimensional modelling, rendering software, and post-production editing. The rise of Generative AI, which is currently being implemented in almost every digital layer of society and in many software programs, is however challenging these processes, as it allows to create images at a fraction of the time it would have taken before.

Without a doubt, this evolution, comes at an environmental, societal, and creative cost. But one can question, if in the coming years, planning and design professions will be able to compete without using AI-tools; as these inevitably will change and speed-up work processes. It is in this regard, I believe it was valuable to personally explore to what degree I want to make use of this technology, and how it can be used in a responsible, and ethical way.

Within this thesis, AI was not used to generate design proposals or analytical findings, but rather to quickly visualize concepts that had already been developed through literature review, policy analysis, spatial investigation, and design exploration.

The AI-generated images in this work were used to help illustrate the spatial atmosphere of the pilot projects, particularly for actors or readers who may find it difficult to imagine speculative scenarios through descriptions and case-studies alone. Consequently, these images should be understood as exploratory representations rather than accurate predictions of future conditions.

For the creation of the eleven AI-generated images included in this thesis, I used KREA AI, a generative image platform that allows users to generate and edit visual content through image references and text prompts. In all cases either Google earth aerial imagery or personal site photographs from Tensta were used as input material, after which details project descriptions were used as prompts.

One of the principal limitations I experienced when using generative AI software for image production was its tendency to produce generic and idealised representations that do not necessarily reflect real-world implementation. In most images, green structures are portrayed as continuous and perfectly vegetated surfaces, whereas in reality they would likely exhibit seasonal variation, irregular growth patterns, maintenance issues, and periods of reduced visual quality, particularly during the winter months. Similarly, many architectural and ecological details are either simplified, omitted, or blended into visually convincing yet technically ambiguous elements.

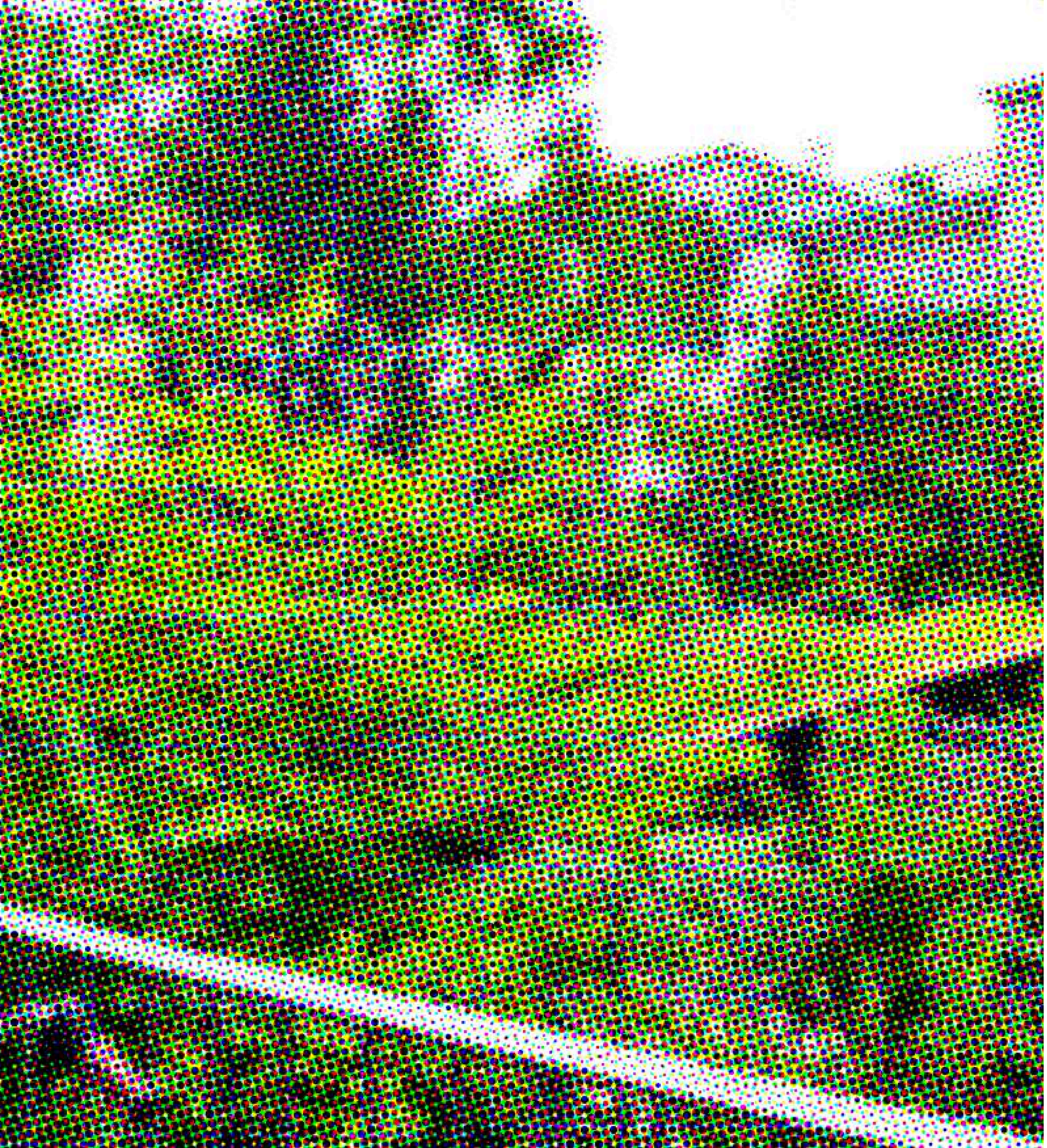
For these reasons, the images in this work were never used as analytical evidence or detailed design-drawings, but solely as inspiring communicative devices, supporting the broader design narrative of VUE.

*Work-flow

1. Selection of site-specific aerial imagery or photographs.
2. Development of project-specific prompts based on the pilot descriptions.
3. Generation of visual outputs using KREA AI.
4. Post-production editing in Adobe Photoshop (+20% brightness, +20% contrast, +10 grain bits).

*Project Specific Prompts

Figures	Source Material Base Image	Detailed Prompt
Fig. 4.14-15	Google Earth aerial imagery (2023)	***Visualize the following project description on the attached location image:*** *Vertical Urban Ecology explores the stacked relationships and potential between the city's ground level, canopy cover, and built (architectural) form. Through this perspective, the city can be understood as a layered ecological system in which architectural elements such as façades, roofs, terraces, and other infrastructural surfaces could be re-designed and activated in support of urban ecological, economical and social functioning.*
Fig. 6.8-10	Google Earth aerial imagery (2023)	***Visualize the following project description on the attached location image.*** ***+ Visualize how the upper deck would look like in three different variants:*** *A temporary, and potentially permanent, intensive green roof project on the Tensta Centrum parking deck could offer significant social, ecological, and economic benefits. Bringing opportunities for gardening and food production closer to the dense urban centre would likely be well received by local residents and would contribute to increased biodiversity and improved public health. In that sense, the Heerlen Rooftop Project (https://www.designboom.com/architecture/selvatico-car-park-rooftop-urban-garden-heerlen-10-27-2022/) forms an inspiring blueprint for a socio-ecological awareness-pilot.* *The spatial and structural organisation would in the beginning likely prioritize cheap, lightweight, modular, and reversible interventions. Similar to the project in Heerlen, raised planting beds constructed from recycled materials such as palettes or crates, could be built in collaboration with future user groups. Standardised planter typologies could enable controlled soil depth and weight distribution over the parking deck. A garden coordinator or association board would likely decide over how the different cultivation beds are arranged, allowing for a safe and equitable spatial organisation. In terms of ecological performance, creating a gradient from highly active to more passive and biodiverse roof zones could be introduced, with, for instance, peripheral zones reserved for more ecologically driven functions.*
Fig. 6.16-20	Google Earth aerial imagery (2023) & Personal site photograph, Tensta (April 2026)	***Visualize the following project description on the attached location image:*** *Blank building outends can be paired with living walls for high-impact retrofitting. A possible approach could be to focus on living walls capable of decentralized water management at building or neighbourhood scale based on the Total value wall system (https://www.totalvaluewall.com/en/). This modular green wall system offers an adaptive greening solution to both new and existing buildings of different scales and can be used for the purification of grey water.* *Domestic shower water, laundry water, and dish-washing water are distributed across the top of the system via a pumping system. From there, it flows downward by gravity. During this process, contaminants are biologically broken down, solid particles are filtered out, and nutrients are absorbed by plant roots. The treated water is captured in tanks and can be reused for toilet flushing, leading to household water savings up to 30%. *Visualize the distribution system on them image.*
Fig. 6.22-23	Personal site photographs, Tensta (April 2026)	***Visualize the following project description on the attached location image:*** *I calculated that approximately 47% (36.05 ha) of the total potential greening surface in Tensta can be assigned to façades with openings, balconies or windows. In the final TCC scenario I paired these surfaces with climbing systems. As I learned in my greening system analysis, green façades (GF's) are among the easiest and most affordable vertical greening systems. In many cases the rough-textured concrete panels that make up the cladding of the buildings in Tensta, could be suitable hosts for climbers with adhesive rootlets or pads.* *Lower three-story façades built with durable, dense materials, simple facade detailing, and set back several meters from public walkways are therefore likely the most suitable candidates for this type of intervention.*
Fig. 6.26-29	Google Earth aerial imagery (2023) & Personal site photograph, Tensta (April 2026)	***Visualize the following project description on the attached location image:*** *In translation of the following project (https://eumiesawards.com/heritageobject/transformation-of-530-dwellings---grand-parc-bordeaux/), I want to introduce: "Vinterträdgård- Sommarhud"; a retrofit proposal which reinterprets the popular Nordic tradition of the winter garden. Within this pilot I propose the addition of a lightweight inhabitable climatic layer around existing housing blocks. The intervention consists of a new structural extension attached to the exterior of the buildings, enlarging the apartments through winter gardens and balconies while introducing a second outer layer of deciduous climbing vegetation. Supported by lightweight glazed balcony structures, this vegetated skin acts as a seasonal climatic membrane. In summer, dense foliage shades the façade, filters sunlight, and cools the building through evapotranspiration. In winter, the vegetation sheds its leaves, allowing low-angle sunlight to penetrate deep into the winter gardens and adjacent apartments, contributing to passive solar heating. Rather than functioning solely as a decorative green façade, this new skin transforms existing building envelopes into a thickened ecological interface between architecture, climate, and domestic life. In Tensta, primarily the large southeast oriented façades would likely benefit most from this type of intervention as it would also have a positive influence on their adjacent courtyards.*
Fig. 6.34-35	Google Earth aerial imagery (2023)	***Convert all marked (red dot) roofs in the image to green roofs.***



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