Nature-Based Solutions for Mitigating Urban Heat Island: Opportunities for Implementation in Zwolle, the Netherlands

NOELLE MWENDE KAMWELE[1], HELLEN WAFULA[2]
[1, 2]*School of Planning and Architecture, Maseno University*

Abstract- Nature-Based Solutions (NBS) offer sustainable and effective strategies for mitigating Urban Heat Island (UHI) effects. This study evaluates the suitability of various NBS in addressing UHI in Zwolle and explores their implementation potential. Through GIS-based spatial analysis and stakeholder engagement, we assess green roofs, urban forests, and water-based cooling solutions. The study identifies key factors influencing NBS selection, including spatial feasibility, cost-effectiveness, and ecological benefits. The findings provide a decision-support framework for policymakers to integrate NBS into urban planning to enhance climate resilience.

I. INTRODUCTION

When the temperatures in urban areas rise higher than the temperatures in the nearby rural areas, the city is said to experience a phenomenon known as "Urban Heat Island" (UHI) (Nwakaire et al., 2020). Furthermore, some regions of a city are frequently hotter than others. These neighborhood-level heat islands are referred to as "Intra-Urban" Heat Islands (EPA, 2022). The uneven, inequitable distribution of landcovers in the urban landscape results in more heat-absorbing structures and pavements and less cool places with trees and greenery, resulting in Intra-urban Heat Islands (EPA, 2022).

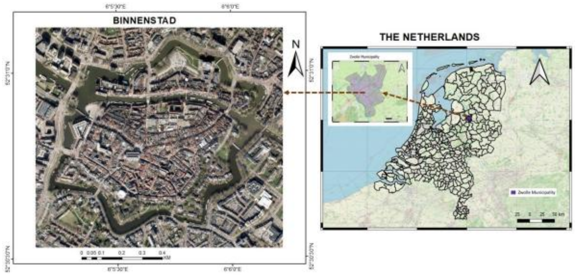
UHI is brought on by differences in the radiative and thermal characteristics of urban infrastructure, as well as by the influence that buildings may have on the local microclimate (Hove et al., 2011). For instance, towering structures may reduce the pace at which cities cool down at night. The UHI effect will worsen the effects of urban warming, raising summer temperatures in urban areas relative to remote rural locations. UHIs may become more intense due to anticipated increases in solar radiation and decreased wind velocity (Hove et al., 2011).

Several Urban Heat Island mitigation strategies have been designed to reduce the amount of heat that is absorbed and retained in urban areas (O'Malley et al., 2015). These strategies include green, grey, and blue infrastructure as well as urban design. One recommended solution is Nature-Based solutions (NBS), which are solutions that are motivated by, supported by, or replicated from nature and exploit its features and complex system processes to achieve desired results while enhancing and sustaining the natural systems (European Commission, 2016).

To create environmentally friendly urban development and to adapt and mitigate the effects Urban Heat Island in cities, as well as promote human health and well-being, planners must take into account ecological planning methods (Augusto et al., 2020). It is recommended to use Nature-Based solutions that are well-designed to manage heat-related risks and concerns sustainably (Albert et al., 2019). This is because they preserve the ecosystem and biological diversity in the present and future and they positively affect people. (Albert et al., 2019).

II. METHODOLOGIES

2.1 Study Area
Zwolle, a medium-sized Dutch city experiencing urbanization challenges. (See Figure 1)
Figure 1 Zwolle City Centre (Binnenstad)



2.2 Data Collection

2.2.1 Literature Review

2.2.1.1 Analysis of global NBS applications in UHI mitigation.
literature review and desk research on the role of NBS in mitigating Urban Heat Islands have been done. A qualitative and exploratory approach was used. A review of literature and desk research on the role of NBS in mitigating Urban Heat Islands was investigated. The Review assesses the findings of numerous published and unpublished research articles. The literature review was compiled using databases from the University of Twente online library, such as Web of Science, Sage Journals and Google Scholar, as well as websites. Preparing a list of key search words is one of the criteria for selecting research articles. The search terms were chosen for their relevance to the topic as shown in Table 1 All sources examined in the literature review were subjected to a credibility check, including the author's credentials, the year of publication, and the website's credibility. The majority of the research publications are from the last decade (2013), with a handful from earlier decades included to offer foundational support for the notions. The results were filtered based on the year of publication, the highly cited papers, and the document type. This Literature Review is necessary to understand how various Nature-Based Solutions influence the outcome of Urban Heat Island (UHI). The literature review also provides relevant information on which Nature-Based Solutions can be used to reduce the UHI effect in general and in the study area, such as, street trees, parks, green roofs, and green walls.

Table 1 Keywords and Results

Keywords	Google scholar	Web of science	Sage Journals
Nature-Based Solutions	42,200	63,283	292
Nature-Based Solutions + Urban	70,800	198	292
Nature-Based Solutions + Urban Heat Island	17,000	120	78
Water + UHI	1,550	24	214
Street trees + UHI	723	7	84
Green roofs + UHI	856	10	60
Green facades + UHI	305	2	22

2.2.3 GIS and Spatial Analysis

2.2.3.1 Identifying high-risk UHI zones and evaluating NBS placement feasibility.
To assess the Intra-Urban Heat Island in the study area, UHI maps of 2017 was obtained to analyze the distribution of UHI in the study area (Table 2). The image was obtained from the National Institute for Public Health and the Environment (RIVM), covering the entire Netherlands. A GIS based methodology was used to generate the summer-average daily maximal 2017 UHI map for the entire Netherlands at a spatial resolution of 10m. The methodology combines population density map of a spatial resolution of 1 km, and the climatological mean 10 m wind speed map of a spatial resolution of 50 m (Lauwaet et al., 2018). The final UHI map is created by combining land use and soil sealing maps at a resolution of 10 meters (Lauwaet et al., 2018).

Table 2 UHI Data

Image	Source	Acquisition Year	Projection
LST/UHI 2017	National Institute for Public Health and the Environment (RIVM)	2017	EPSG:28992 - Amersfoort / RD New

2.2.3.2 Land Cover Classification for spatial Comparison
Remote sensing and GIS methods were used for Land cover Classification. The aerial orthophoto images used in the classification were acquired from PDOK

which is a public Geo web service that has the most recent geospatial data sets of The Netherlands from the government (Publieke Dienstverlening Op de Kaart (PDOK), 2023b). The Geo web service provides access to downloads of the following datasets: the Luchtfoto 2017 Ortho 25cm infrared and the Luchtfoto 2017 Ortho 25cm RGB. Table 3 below summarizes the data properties.

Table 3 Orthophoto Data Properties

Image	Source	Acquisition Year	Projection
Luchtfoto 2017 Ortho 25cm infrared	PDOK	2017	EPSG:28992 - Amersfoort / RD New
Luchtfoto 2017 Ortho 25cm RGB	PDOK	2017	EPSG:28992 - Amersfoort / RD New

III. RESULTS

3.1 The role of Nature-Based Solutions in mitigating Urban Heat Island

Nature-Based Solutions (NBS) are broadly defined as solutions to societal problems that are inspired and supported by nature (Raymond et al., 2017). NBS comprise both naturally occurring green and blue spaces in cities as well as constructed systems that incorporate these features, like infiltration swales, man-made ponds, and plant-based treatment systems (Simperler et al., 2020). The systems make use of organic processes and aim to introduce nature into urban areas (Simperler et al., 2020). NBS are favored because of their adaptability and capacity for multifunctioning. The impact of Urban Heat Islands (UHI) can be lessened using Nature-Based solutions (Gopalakrishnan et al., 2019). NBS provides numerous co-benefits in addition to temperature regulation, such as reducing air pollution, reducing greenhouse gas emissions, lowering carbon dioxide concentrations in the atmosphere, enhancing beauty, improving health and quality of life, and creating green employment (Raymond et al., 2017), (Su et al., 2022). Green infrastructure is also an effective stormwater management solution for storing water during high rainfall events, reducing the flow of water over land, and preventing soil erosion and loading of nutrients. Green infrastructure can also improve biodiversity and provide ecological habitat (Su et al., 2022).

Nature-Based Solutions can address the problem of UHI and heat waves by providing cooling services (Su et al., 2022). Green and blue components of the environment, such as parks, green gardens, and bodies of water, can help to reduce evaporation (Kennisportaal Klimaatadaptatie, 2022a). Evaporation, in general, improves a city's heat resistance (Kennisportaal Klimaatadaptatie, 2022a). Combining NBS and technological engineering in urban development can achieve optimal socio-ecological benefits such as heat mitigation (Su et al., 2022). Table 4 and 5 below summarizes the Nature-Based Solutions that can be used to mitigate Urban Heat Island according to the NBS Technical Handbook by (Eisenberg & Polcher, 2019).

Table 4 NBS For Heat Stress- Technical Handbook (Eisenberg & Polcher, 2019)

NBS	NBS for heat stress	Brief description
Street trees	Single line trees	The trees are located on one side of the roadway, bicycle paths, and sidewalks. Trees have a variety of effects on the local microclimate, they provide shade for both people and structures. The air-cooling impact is one of the most important positive effects for human well-being during hot weather. The impact of street trees in general is determined by a variety of variables, including tree size, canopy coverage, planting density, tree species, tree health, location, availability of root water, and leaf area index.
	Boulevards	Commonly placed along streets, bike paths, and sidewalks, and if possible, on both sides of the path. The canopy of opposing plants frequently forms an almost closed canopy. In the process, the street is protected, shaded, and the air temperature is reduced.

	Group of trees (Arboretum)	In an urban environment, a group of trees mimicking the overall look of a forest. They could be used to create shaded squares and areas, in contrast to densely built-up areas, or as an outdoor area design element. In the summer, the group of trees creates a shaded environment similar to a small area of forest or the edge area of bigger forests.
Public Green Space	Residential Park	Residential Parks form a component of a city's Green Infrastructure (GI) and function as the closest primary entry point for Nature-Based recreation. District parks are larger spatial components of GI that frequently provide more functions and combine multiple uses e.g., sports. Smaller green areas are frequently used as playgrounds or to link green strips of land.
	Green Corridors	Derelict infrastructure, such as railway lines, which are converted into linear parks, serve an important role in urban green infrastructure systems, and serve to re-nature cities. Also, restoration along waterways and rivers frequently results in linear connected parks.

Table 5 NBS For Heat Stress- Technical Handbook (Eisenberg & Polcher, 2019)- Continuation

NBS	NBS for heat stress	Brief description
Green Roof	Intensive green roof	Intensive green vegetation is frequently developed on roofs that are accessible for public or recreational purposes. Humans frequently visit the extensive green roof type: Intensive green roofs are allocated for a variety of activities such as gardening, relaxing, and socializing.
	Extensive green roof	Extensive green roofs are simple, light-weight systems that require little upkeep and management (irrigation and fertilization) after installation.
	Smart roof	Smart roofs are a subset of extensive green roofs that provide a variety of services to safeguard urban ecosystems: they include a drainage mechanism beneath the vegetation layer. Storm water is retained by the drainage stratum.
	Constructed wet roof	Precultured mats with evergreen vegetation are placed on buildings to create constructed wet roofs. To keep the top layer moist, the plants are irrigated with stormwater and wastewater. Water impurities are filtered and incorporated as plant nutrients as they pass through the vegetation layer. Roofs must have a modest to steep slope

		gradient to allow for water runoff. The treated water is used for irrigation, disposal into receiving water, and bathroom flushing. Aside from the effluent, the rooftop is kept green.
Vertical greening	Facade-bound greening	Green facades are planted walls with regulated cultivation. There are two kinds of green facade. The facade-bound greening, which is a component of the exterior or uses it to attach panels and containers. The ground-based facade greening is the second variety.
	Ground-based greening	Climbing plants are used to create ground-based green facades. Climber plants are planted in the ground and grow immediately on the wall, or they climb on a frame attached to the wall and maintain a distance from it. Water and nutrients are extracted from the earth by the plants.
	Noise barrier as ground-based greening	Green barriers to noise are efficient noise-reduction measures along heavily trafficked roads. They are frequently built as walls with ground-level greening. The structure is typically made of concrete, brick, or wood and is covered with a layer of vertical plants. Ground-based green barriers are a popular type of noise barrier along roads, particularly in areas where earth walls are not feasible.
	Free standing living wall	Vertical green spaces are an effective method for increasing green surfaces that provide numerous ecological benefits in urban areas. Freestanding living walls are used to combat the metropolitan heat island effect. They also create spaces with high aesthetic value and possibly high biodiversity, as well as decrease noise emissions. They are ideal for reusing run-off water and have a high evapotranspiration rate.

	Mobile vertical greening / Mobile Green Living Room	The mobile Green Living Room is made up of green wall components that are attached to a hook lift container platform. The vegetation cover is very diverse in order to demonstrate the great potential of living walls to enhance amenity value and stimulate biodiversity. Shade is provided by a light open roof construction that is partially covered by vegetation. The Green Living Room offers instant services for clean air, cooling, and shading, as well as a habitat for urban biodiversity.
	Moss wall-City tree	Mosses have a larger bio-active surface than other plants, they transpire more, and they actively decrease some pollutants.

3.2 The extent that Nature-Based Solutions helps mitigate UHI.

Various studies of cities with different climatic conditions that assess how different types of land cover, such as trees, grass and waterbodies provide cooling have shown that, in comparison to grass and trees, waterbodies have a more noticeable cooling impact (Amani-Beni et al., 2019). A critical component of the cooling impact is the size of the green space (Amani-Beni et al., 2019). Planting vegetation around a building can change the energy balance and provide cooling effect on the building, whereas planting green spaces throughout the city (for example, in the form of urban parks or natural reserves) can change the energy balance of the entire city by adding more evaporating surfaces (Augusto et al., 2020). For example, Lee, (2013), discovered temperature differences of up to 18 degrees Celsius between building-shaded and sun-exposed areas.

A tree can be seen as a solution to many urban problems including UHI, because it provides shade, reduces runoff, and raises the aesthetic value of public spaces. Although a single tree provides these ecological services; they lack the neighboring effects of other trees, single trees are frequently subjected to greater stress (Eisenberg & Polcher, 2019). Only groupings of trees, lines of trees, or boulevards are classified as NBS in the context of the NBS technical guide (Eisenberg & Polcher, 2019). Thom, (2016) found that street trees can reduce a building's transmittance of heat by up to 26.5 K on average; the presence of larger trees will cast more shadow and thus increase the size of the mean radiant temperature drop. It is feasible to identify the contribution of the NBSs to the increase of thermal comfort by analyzing both air temperature and surface temperature (Epelde et al., 2022). Although trees can provide many benefits to cities, they also have drawbacks. Tree roots can be detrimental to building foundations and cause harm to roadways and other infrastructure (Kennisportaal, 2022). Trees can topple over in storms, attract wild species that might be a nuisance, be the source of allergy flare-ups and demand a lot of upkeep (Kennisportaal, 2022). For all these reasons, city green structure design is critical; selecting the best sort of vegetation and planting sites can maximize the benefits while avoiding some of the drawbacks (Kennisportaal, 2022).

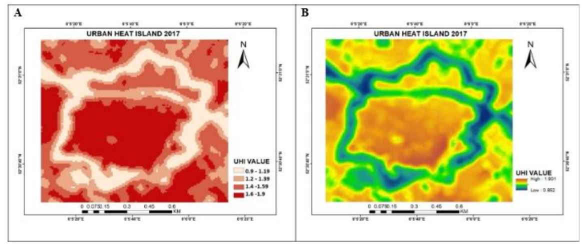
According to a study by Anderson et al, (2022) on evaluating Nature-Based Solutions to increase heat equity in Toronto, Canada, the use of green infrastructure as NBS has a positive impact on the urban climate, resulting in measurable reductions in the air and land surface temperatures. The reduction in maximum monthly average near-surface air temperature ranged between 0.3°C and 1.3°C across sites (Anderson et al., 2022). The average temperature reduction of 0.3°C was observed in urban forestry and vegetation systems, while the average temperature reduction of 1°C was observed in urban agriculture systems (Anderson et al., 2022). Green infrastructure is a long-term solution for improving urban climate, reducing heat, increasing green space equity, and increasing resilience (Anderson et al., 2022).

The scale of environmental effects from NBS depends on a variety of factors, including the physical dynamics operating at the micro (street/neighborhood) or even urban level (Eisenberg & Polcher, 2019). For instance, increased evapotranspiration and increased shading depends on the size of the NBS applied as well as heat fluxes determined by the morphology of the roadway or urban area (Eisenberg & Polcher, 2019). While micro-scale measures like those taken by the NBS may be significant at the level of individual projects, the amount of heat captured by vegetation may be insignificant in relation to the quantity of heat at the urban level. In many cases, measuring impacts may not be reasonable or even feasible at an urban scale because a change caused by a single measure is too small. The same is true for water quality and other issues related to environmental sustainability. Individual NBS projects with spatially limited affects may have very minor effects but taken together they can have a significant influence on an area's health (Eisenberg & Polcher, 2019).

3.3 Urban Heat Island Analysis

X analyzed for June, July and August by the National Institute for Public Health and the Environment (RIVM), as seen in Figure 2(A) and (B); where (A) is classified into 4 classes, and (B) the values are stretched, shows the spatial manifestation of the Intra-Urban Heat Island effect in the study area in a 10m resolution map (rivm, 2023). The maps show that parts of the study area experience warmer temperatures than others. The core of the study area in particular experiences a higher temperature compared to the outskirts of the study area.

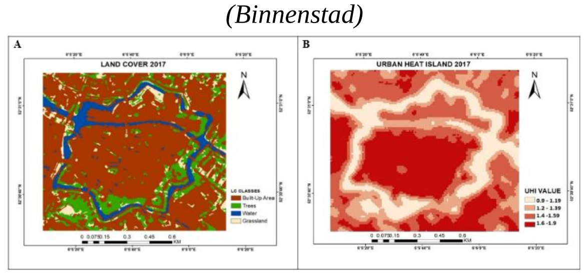
Figure 2 Intra-Urban Heat Island 2017 (rivm, 2023)



3.4 Spatial pattern comparison

When comparing the spatial pattern between the Land Cover (Figure 3A) and Urban Heat Island (Figure 3B), the spatial pattern indicates that the core area of the study area, which comprises of majorly Built-up land cover class, with features like buildings, roads and pavements experiences a higher Urban Heat Island compared to the outskirts of the study area where the canal passes, and has a healthy vegetation combination of trees and grassland. According to research, the existence of vegetation may reduce the intensity of UHI. Tall mature trees provide shade while also lowering the temperature in dense built-up areas. This is because vegetation converts solar energy into latent thermal energy through water evaporation (Hove et al., 2011). The presence of a canal has a cooling impact on the surrounding area through the process of evaporation and heat absorption. The cooling effect of water bodies may also be because water bodies provide a free wind path. (ventilation zone) (Hove et al., 2011). The lowest temperatures are distributed along the water land cover. It can also be noted that the park and pockets of trees within the built-up area have a lower UHI influence on the surrounding built-up area.

Figure 3 Land Cover and Zwolle City Centre (Binnenstad)



IV. FINDINGS

4.1 Nature-Based Solutions selected for the study area

4.1.1 Street trees

Street trees are usually located on one side of the roadway, bicycle paths, and sidewalks. Trees have a variety of effects on the local microclimate in urban environments: they provide shade for both people and structures, they improve the air quality by absorbing pollutants such as carbon dioxide, nitrogen dioxide, and particulate matter, they enhance aesthetics, trees provide wildlife habitat, absorb stormwater and increase property value (Eisenberg & Polcher, 2019). The air-cooling impact is one of the most important positive effects for human well-being during hot weather. Through evapotranspiration and shade production, trees reduce surface and air temperatures (EPA, 2022). For instance, the peak temperatures of shaded materials may be 11–25°C lower than those unshaded (EPA, 2022). When combined with shading or used alone, evapotranspiration can assist lower high summertime temperatures by 1 to 5 degrees Celsius (EPA, 2022). The impact of street trees in general is determined by a variety of variables, including tree size, canopy coverage, planting density, tree species, tree health, location, availability of root water, and leaf area index (Eisenberg & Polcher, 2019).

When planting street trees, it is important to consider several parameters to ensure that the trees thrive and provide maximum benefits to the community. Some of the key factors to consider include:

4.1.1.1 Site conditions

It is essential to evaluate the site conditions, including factors such as street size, soil type, sun exposure, and wind exposure, before planting a tree (EPA, 2022). The ideal places to put trees as a mitigation approach for Urban Heat Island are around buildings or along the streets to shade parking lots and street pavements (EPA, 2022). The space required is mostly determined by the tree's mature size and estimated lifespan given the degree of stress to be sustained by the tree (ACES, 2022). Most of the streets in *Area of Interest A* are pedestrian zones which are paved by impervious materials such as interlocking bricks, concrete and granite. Planting the appropriate street trees along pedestrian walkways can help cool the surface temperature and air temperature and elevate the aesthetic value of these streets.

4.1.1.2 Tree species selection

Choosing the right tree species is crucial to the long-term health and viability of the tree (Barradas et al., 2022). Factors to consider include the tree's growth habits, ultimate size, pest and disease resistance, and environmental requirements. Zwolle municipality has already planted street trees, the majority being tilia platyphyllos species (Gemeente Zwolle, 2022). According to Barradas et al., (2022), tree species with high transpiration and stomatal conductance, like L. styraciflua and Q. rugosa, could aid in reducing the impacts of the UHI. Therefore, when planning and designing the study area, these species might be regarded as good plant selections to lower local air temperature.

4.1.1.3 Tree placement and spacing

Ten street locations (A to J) have been identified around *Area of interest A* (See Figure 19), for possible consideration for the placement of street trees. The locations have been selected based on the streets in the 3D model that have no trees, and cross checked in Google earth. All the tree data used to build the 3D model (Polygons and Points) show that there are no trees in these Street trees should be placed and spaced appropriately to allow for healthy growth and to avoid conflicts with overhead utility lines, sidewalks, and other infrastructure. The ideal tree spacing along main streets is every 4 to 9 meters and every 4 to 14 meters along a street that is largely residential (Mouzon Steve, 2016). The trees should be planted every 6 meters if they are quite large (more than 9 meters wide) (Mouzon Steve, 2016). Since the area is a commercial center, trees should not be placed in front of shops and businesses. The street tree distance from other infrastructures should also be considered in tree placement as shown in Table 6.

Table 6 Street tree distances from other infrastructure (BSS, 2021)

Infrastructure	Street tree distances from other infrastructure in Meters
Water Meter / Vaults	2
Catch Basins	2

Gas Meters	2.5
Driveway Aprons	2.5
Fire Hydrants	3
Pedestrian Lights	4.5
Streetlights	6
Electrical Power Poles	6
Alley Entrances	6
Intersections	14

4.1.1.4 Tree maintenance

Regular tree maintenance is essential to ensure the health and longevity of the trees. This may include pruning, watering, fertilizing, and pest management. During the first and second growing seasons, water is critical. Irrigation should be considered early on (ACES, 2022). If the soil has been correctly prepared and fertilized as shown by the soil test, fertilizer is not necessary for the first year. The standard advice for fertilizer shade trees in an unlimited area for maximum growth is 2 to 4 pounds of nitrogen per 1,000 square feet (ACES, 2022). Pruning must be done at the appropriate time of year and with a particular goal in mind for it to be helpful. All trimming and shaping should be completed at the nursery for initial planting and establishing. However, if pruning is necessary, it should be done after the first season. Pruning, according to research, hinders root growth (ACES, 2022).

4.1.1.5 Local regulations and Community engagement

It is important to involve the community in tree planting process in order to build support and ensure that the trees are valued and cared for over the long term (European Commission, 2023). it is also important to take note of the local regulations, including permits, tree planting guidelines, and any restrictions on tree species or planting locations (European Commission, 2023).

4.1.1.6 Cost

Depending on the maintenance scenario, the lifetime expenses of sustaining a street tree range from 1730 euros to 3260 euros and 35euros to 65 euros each year. The annual maintenance cost of a tree is reduced by 30% when its life span is doubled (Lawry et al., 2009).

4.1.1.7 Drawback

It is important to note that planting street trees has some limitations. Street trees in the study area may reduce the footpath width and reduce accessibility. Street trees damaged by storms such as hurricanes and tornadoes may block emergency access roadways (Virginia Cooperative, 2021). Branches and trees may also bring down power lines and are frequently to blame for power outages. In the fall season, tree leaves can clog storm drains and cause annoyance for business owners (Virginia Cooperative, 2021). Berry-producing trees positioned incorrectly can harm buildings, vehicles, and commercial establishments. Birds and other creatures find habitat in trees, where they may then drop droppings (Virginia Cooperative, 2021). In the spring and summer, they are also a key source of pollen for allergy sufferers increasing the prevalence of asthma (Pataki et al., 2021).

4.1.2 Extensive green roofs

According to research, green roofs and vertical greenery systems, which incorporate natural green elements into building design, stand out as the most potential building-scale thermal solutions (Coma et al., 2020). With the use of green roofs, buildings can be passively cooled by preventing solar radiation from reaching the structure below (Drozd, 2019). According to a study by (Liu & Jensen, 2018), the effect on reducing temperature is greatest during peak Urban Heat Island (UHI) periods, regardless of the season or time of day. Although parks and street trees have been found to be more effective for thermal regulation than green infrastructure such as green roofs and green walls, some studies concluded that they may play a significant role when installed in dense urban environments (where space is limited) and strategically placed to serve populations at risk for heat exhaustion. While air temperature above the roof can only differ by one degree or lower, green roofs can reduce peak surface temperatures by up to 25 C in comparison to conventional roofs (Cook & Larsen, 2021).

Extensive green roofs are a common choice for homeowners since they are lightweight, low-maintenance, and don't require extra watering unless there is a severe drought (Permagard, 2023). They are appropriate for both new and old roof decks (Permagard, 2023). A low covering of vegetation, often between 80 and 100 mm high and made up of grass, moss, sedum, or small flowers, is typical of extensive green roofs (Permagard, 2023). Sedum green roofs are the most popular kind because of the plant's resilience and low maintenance needs. Although it can be relatively shallow, you will need some additional growing medium if you are using sedum blankets (Permagard, 2023). When installing green roofs and green walls, there are several factors to consider, including:

4.1.2.1 Roof type

Flat roofs are the ideal shape for green roofs as they provide a level surface for the green roof to be installed. Any angle less than 10° is regarded as a flat roof (Perini & Rosasco, 2013). This implies that green roofs installation on sheds, log cabins, and garages are all highly popular options (Perini & Rosasco, 2013). However, any outdoor building or garden structure with a flat roof is a viable option, including bike storage facilities. When dealing with a sloped green roof with a gradient of more than 10°, a design solution is required for holding water and keeping the substrate in place (Permagard, 2023). Based on the building footprint data used to build the 3D model, there are three main roof types in the study area: Gable, hip and flat. The flat roofs in the entire study area are 377 (Table 17), while the flat roofs in *Area of Interest A*, are 30 (Table 18). The flat roofs in *Area of Interest A*, are highlighted and visualized in Figure 20. These are the potential roofs (Buildings) that can be used for the installation of green roofs.

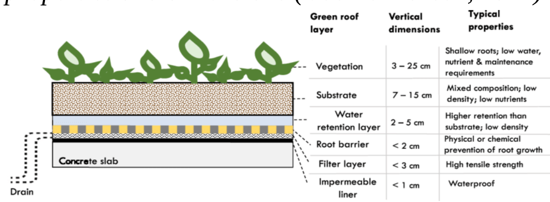
4.1.2.2 Building height

The few studies that were done revealed that adding green roofs on higher buildings had little to no impact on the thermal comfort of pedestrian levels, whereas doing so on lower-rise buildings has an impact on pedestrian levels (Coma et al., 2020). The cooling effects of green roofs demonstrated a pattern of decreasing with the increasing of building height. Tall buildings are more exposed to winds, which can increase moisture loss from the green roof, and dry them out reducing the heat reduction capacity of the green roof (Coma et al., 2020). Taller buildings also receive more direct sunlight, which can increase the surface temperature of the green roof and lead to higher evapotranspiration rates and a higher cooling potential, but it also causes the green roof to dry out more quickly, reducing its ability to retain moisture. The average building height is 20.199 meters, which is about 4 to 5 stories. This is classified as low rise by (Diesel, 2020), making green roofs an ideal NBS intervention for mitigating UHI in the study area.

4.1.2.3 Structural Consideration:

One of the primary factors to consider is the structural integrity of the building or structure on which the green roof or green wall will be installed. This includes factors such as load-bearing capacity, waterproofing, and drainage systems. Most extensive green roof designs made of sedum and other easy, light plants weigh between 60 and 150 kilograms per square meter (Permagard, 2023). Importantly, any weight calculations for green roofs must consider the weight of rain and snow when the substrate is saturated, in addition to the weight of the system's various parts (Permagard, 2023). Figure 4 below illustrates a green roof model with typical properties and dimensions.

Figure 4 Green roof conceptual model with typical properties and dimensions (Cook & Larsen, 2021)



4.1.2.4 The type of vegetation

Sedum, Sempervivum, and moss mat-forming species are suitable plants for extensive green roofs. For dry, shady circumstances, ferns like Polypodium vulgare and Asplenium trichomanes are ideal (Permagard, 2023).

4.1.2.5 Drainage

Green roofs require proper drainage to avoid waterlogging and maintain healthy vegetation (Permagard, 2023). Taller buildings may require more complex drainage systems to manage the increased volume of rainwater runoff, which can affect the efficiency of the green roof in reducing heat (Permagard, 2023).

4.1.2.6 Maintenance

Proper maintenance is critical to ensure the health and longevity of green roofs. The installation of an irrigation system, monitoring of soil moisture levels, and regular inspections are all important factors to be considered (Permagard, 2023).

4.1.2.7 Cost

According to a commercial green roof construction company website in the Netherlands, a sedum roof costs between €40 and €75 per meter square (Nature Green, 2023). This consists of sedum mats, cassettes, or trays, as well as all components such as gravel, foil, and manure (Nature Green, 2023). Construction costs are between 20 and 30 euros per m2 (Nature Green, 2023). Municipalities in the Netherlands may provide a subsidy for the construction of a sedum roof (Nature Green, 2023). Each municipality establishes its own requirements and provides a different amount as subsidy (Nature Green, 2023).

4.1.2.8 Drawback

The major drawback of green roofs is their high price, which is far higher than the price of conventional roofs (Drozd, 2019). This is as a result of their unique design. It has a much greater number of layers than a typical roof (Drozd, 2019). The weight of a green roof is another drawback. It is considerably higher than a typical roof. Because of this, the structure's load capacity must be raised, adding to the structure's weight (Drozd, 2019). Additionally, leaks, water condensation in the thermal insulation layer, and surface mold are also alleged drawbacks of green roofs (Drozd, 2019). Another drawback is that a number of flat roofs in the study area are installed with solar panels. Combining the two technologies to make bio-solar roofs can be costly and requires extensive stakeholder engagement.

4.1.3 Green facades

Green façades can be a sustainable solution for new building construction as well as retrofitting existing structures in order to mitigate Urban Heat Islands, minimize the energy needs of cooling systems, and improve building thermal energy performance. Green façades can provide physical shading for buildings and encourage evapotranspiration in the summer (Vox et al., 2018). Studies on green walls and facades have shown that they have a minimal effect on the temperature of the nearby outside air, occurring mostly during peak solar hours (Coma et al., 2020). However, they show a greater effect on the temperature of the wall surface. The findings from (Bakhshoodeh et al., 2022) showed that on hot, sunny days, the external wall temperatures behind the green façade were up to 7°C cooler than those behind the shade sail. Furthermore, the temperatures behind the green façade and shade sail were consistently colder than the surrounding air, by up to 11 and 6.8°C, respectively, showing that the evapotranspiration cooling effect contributed to 25-35% of the overall cooling caused by the green façades (Bakhshoodeh et al., 2022).

Green facades can be utilized within the study area to cover bare walls and heighten the feeling of coziness in compact areas. According to (Ana & Manso, 2016), empty walls show an unplanned urban development, giving the location an unfavorable impression. This problem can be solved by introducing nature into the city through the use of living walls, which are considered to be a part of public areas and therefore make them more interesting for users. Some factors that should be considered when designing and installing green facades include:

4.1.3.4 Structural support

Building materials such as sandstone and old bricks typically cannot support too much weight (Tensile, 2023). Additionally, most structures are not made to withstand the pulling forces of frames and wires. This means that it will be crucial to design the facade in a way that the structure can handle, especially with an older building (Tensile, 2023). After construction of green facades, the total weight of all the parts (the dead load) must be calculated (Tensile, 2023). This comprises the weight of the chosen plants, which varies from one species to another, as well as the weight of the frame. Once completely saturated with water green facades can weigh anywhere between 25 and 40 pounds per square foot (Anderson McRae, 2008). Structural engineers should be consulted to verify the wall's load-bearing capability of the building (Anderson McRae, 2008). Most buildings in the study area are old and constructed with bricks thus require extensive structural investigation from experts.

4*.1.3.1 Plant selection*

The choice of plants is important when designing a green facade. Plant species that are well-suited for vertical growth and can tolerate the specific conditions of the facade, such as wind exposure and limited soil depth are ideal (Hiemstra et al., 2008). Factors like growth rate, root systems, aesthetics, and maintenance needs should be considered to achieve a visually appealing and sustainable green façade. Plants that are native to the region are often the best choice because they are adapted to the local climate and require less maintenance (Hiemstra et al., 2008). Plants that are drought-resistant and pest-resistant can also be good choices. Ivy (Hedera helix) is used to cover bare street walls in an effort to absorb particles and cool buildings (Hiemstra et al., 2008). Per square meter of wall, ivy plants can grow 3 to 8 square meters of leaves. In addition, this plant maintains its green color throughout the entire year. Ivy is a fantastic way to increase the cooling of surface on bare walls (Hiemstra et al., 2008). Additionally, covering bare walls with vegetation significantly enhances a city's appearance (Hiemstra et al., 2008).

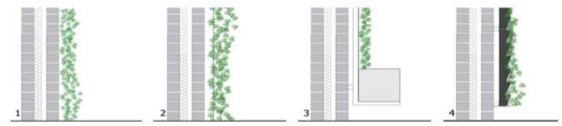
4.1.3.2 Irrigation and Water Management:

A reliable irrigation system needs to be developed to provide water to the plants. Water source availability, irrigation technology, and maintenance requirements should be considered (Tensile, 2023). Water-efficient practices such as rainwater harvesting, and recycled water usage should also be implemented to minimize water consumption (Tensile, 2023).

4.1.3.3 Cost

The cost of green facades varies according to the surface of the façade, the height of the façade, as well as its location and connections. It costs about 30 to 45 Euros/m2 to grow climbing plants at the base of the façade (direct greening system) (Perini & Rosasco, 2013) (Wesołowska & Laska, 2019). The price range for an indirect greening system (grown climbing plants and supporting material) is 40 to 75 Euros/m2 (Perini & Rosasco, 2013) (Wesołowska & Laska, 2019). When planter boxes are used in conjunction with supporting systems, the price varies greatly depending on the type of material (from 100 to 150 Euros/m2 for a plastic system to up to 800 Euros/m2 for a zinc-coated steel system). Costs can also greatly vary when using a living wall system (pre-vegetated panels), ranging from 400 to 1200 Euros/m2, depending on how the system was designed and the materials used (Perini & Rosasco, 2013) (Wesołowska & Laska, 2019). Figure 5 illustrates the different green wall types.

Figure 5 Green walls typology; 1-Direct green wall, 2-Indirect green wall, 3-Indirect green wall incorporating planter boxes, 4-Living wall system (Wesołowska & Laska, 2019)



4.1.3.5 Maintenance and Accessibility

The accessibility of the green façade should be determined for routine maintenance tasks such as pruning, watering, and replanting. Easy access points should be planned for and considered in the maintenance costs associated with the system, such as plant care, cleaning, and repairs.

4.1.3.6 Drawback

Green facades have some drawbacks. The risks of using climbing plants on green facades are mainly related to drying during the winter, damage to the building envelope brought on by choosing resilient species with branch thickness of greater than 15 cm, deformations of the supporting structure caused by a faulty assessment of the weight of the green layer, and problems caused by the difficulty of carrying out maintenance measures on the walls. In order to avoid maintenance problems and damage, the use of live material necessitates careful consideration of a variety of criteria when selecting the appropriate plant species and supporting system for each green façade (Perini & Rosasco, 2013).

4.2 Summary of selected NBS

Depending on the size, and location of the selected NBS, they have shown to have a cooling effect at either the building or local scale, due to the increase in green and blue areas. When designing and installingthe selected NBS, some factors should be considered to ensure effectiveness and longevity. These factors are summarized in Table 7 below.

Table 7 Summary of NBS factors to consider and the cost.

NBS	Factors to consider	Cost

Street trees	Site conditions Tree species Tree placement and spacing Tree maintenance Local regulations and community engagement Cost Drawbacks	35 to 65 Euros per m2 (Installation and maintenance per year)
Green roofs	Roof type Building height Structural consideration Vegetation type Drainage Maintenance Cost Drawbacks	40 to 75 Euros (Installation)
Green facade	Structural support Plant selection Irrigation and water management Maintenance and accessibility Cost Drawbacks	30 to 1200 Euros per m2 (Installation)

CONCLUSION

Nature-Based Solutions play a crucial role in mitigating UHI and enhancing urban climate resilience. This study provides a framework for integrating NBS into Zwolle's urban planning initiatives. Future research should explore hybrid approaches combining NBS with technological solutions like Digital Twins for real-time urban climate monitoring and decision-making.

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