INTEGRATING NATURE-BASED SOLUTIONS EFFECTIVELY IN A RESIDENTIAL NEIGHBORHOOD RENOVATION

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ABSTRACT

Boerhaavewijk needs to be renovated to meet national carbon neutral goals and improve the public space. Nature-based solutions are effective tools to tackle its urban challenges. Renovation projects rarely incorporate NBs due to their added complexity. To effectively apply NBs in the context we ask what building-integrated greenery should be used to respond to conditions and challenges? We use literature to categorize the roles NBs have in a neighborhood and the parameters that influence decisions. Boerhaavewijk is then used to put it into a context. The results show that many nature- based functions have opposite parameter preferences and neighborhood characteristics can influence the decision on the building.

KEYWORDS: *Nature-Based Solutions, Residential Renovation, Neighborhood Improvement, Vertical Green, Green Roofs*

I. INTRODUCTION

In the post-war period, a large demand for affordable housing led to neighborhoods that were mass-produced using new industrial methods and prefabrication within a new modern urban structure of function segregation hinting towards 'air, light, and space'. Building methods prioritized efficiency and quantity. Therefore building quality is reduced and the resulting public space has questionable quality. Boerhaavewijk, a neighborhood in Haarlem's Schaalkwijk, is one such example. Technical building performance is low, and the urban structure leads to a socially unengaging outdoor environment with virtually no connection with green. Energy use is high and summer-time comfort are unsatisfactory and unequipped for future climate challenges. The characterized future weather will increase cooling demand to maintain indoor conditions similar to when the buildings were first constructed, potentially worsening the problem. Hamdy et al. (2017) simulated future scenarios of overheating in common housing archetypes and found that post-war housing has more resilience compared to better and low ventilated buildings. This resilience is possibly a result from their poorer performance in the winter. At the neighborhood scale, Haarlem is considered particularly un-green when compared to other cities of its kind, but it does still have great greenery present surrounding it (Municipality of Haarlem, 2017). The hardened urban surfaces and extreme rain patterns cause droughts and floods (Kluck et al., 2017). Furthermore, the urban heat island effect is increased with hardened surfaces. Children and the elderly (>75) are at higher risk for heat stress caused by increased extreme heat days exaggerated by UHI (Gronlund et al., 2014, Uejio et al., 2011). The lack of neighborhood greenery does not encourage outdoor activity causing people to spend more time indoors, increasing the building energy demand, increasing loneliness, and reducing physical activity (Reijneveld et al., 2023, Cohen-Cline et al., 2015, Richardson et al., 2013). On a national scale, carbon neutrality of the built environment has been set as a goal for 2050 (Ministerie van Infrastructuur en Waterstaat, n.d.). Reducing built environment energy usage will tackle an estimated 40% of the total energy use. Keeping post-war neighborhoods like Boerhaavewijk in their current state will hold the Netherlands back from reaching energy neutrality. Haarlem is striving to improve residents' well-being and to reach a sustainable balance between urban development and natural green spaces. This involves qualitative changes to public spaces, adding more space for people outdoors, integrating more blue-green infrastructure, more space for people outdoors, and retrofitting buildings towards future-proof energy-neutral and comfortable housing. Nature-based solutions (NBs) can facilitate these changes. The International Union for the Conservation of Nature (IUCN) classifies NBs as actions that effectively address societal challenges, promote human well-being, and contribute to biodiversity conservation (Cohen-Shacham et al., 2016). They are recognized as essential tools in reaching the Sustainable Development Goals (SDGs), thanks to the NBs' ability to address various interconnected urban problems as a system with self-correction and resilience (Adams et al., 2023, Bush & Doyon, 2019, Jennings & Bamkole, 2019). By protecting, managing, and restoring ecosystems, NBs contribute to the delivery of essential ecosystem services in urban areas (Adams et al., 2023). This inclusive approach gains added significance in low socio-economic neighborhoods, where the positive impact of natural elements on residents' health is more pronounced than in higher socio-economic status neighborhoods (Snep et al., 2023, Rigolon et al., 2021). The integration of NBs reaches beyond mere environmental strategy for economic gain; it becomes a catalyst for social equity, community resilience, and the redefinition of people-nature relationships in urban environments. However, the application of NBs is largely limited to new buildings where the integration is planned early in the design stages to reap cost-effective benefits. In the context of renovating millions of houses and buildings towards energy neutrality, the renovation focus is geared toward cost and time efficiency to increase productivity and encourage participation from private owners. The process of renovating an existing building is complicated enough without adding this additional green layer. During renovation, many design choices are baked into the existing structure, and many additional constraints exist. The objective of this research is to avoid unnecessary renovation complexity and increase the ecosystem services' effectivity. What building-integrated greenery should be used to respond to conditions and challenges? What NBs functions should be prioritized and what are their parameters? The benefits, referred to as functions, we will be exploring are biodiversity conservation and restoration, promoting coexistence between urban environments and nature, stormwater management, water re-use, microclimate regulation, urban air pollution, noise attenuation, decreased energy consumption (especially in the summer), and increased energy production.

II. METHOD

There are 2 levels of detail in this research question, the neighborhood and the building. Both benefit from using an NBs approach. The NBs that are applied in the public space and the NBs that are applied as part of the building renovation will affect the buildings' performance and the neighborhood's potential. Many of the solutions that take place on the building scale are noted as valuable in urban areas with limited space. The Boerhaavewijk does not have limited space, though other externalities do exist and an efficient use of the space is still desirable. Many of NBs functions that are applicable on the building scale can then be allocated to the public space. Understanding the challenges the neighborhood faces, the externalities, and the spatial distribution of NBs functions better inform the smart application of NBs in the renovation. To answer which NBs function the building should adopt from a spatial perspective, a literature review is carried out on the larger scale effects of NBs. To apply this to the building, the most influential parameters of the various functions are identified are put side by side and compared. The table is then applied to a block in the boerhaavewijk.

2.1. NBs literature review

When looking through the literature the topics discussed that were the social impact of green exposure or green access, indoor comfort, outdoor comfort, noise mitigation, air quality, stormwater management, water re-use, and biodiversity. A main contributing factor to the success of NBs and one of its many strengths is that it works as an interconnected system (Adams et al., 2023, Bush & Doyon, 2019, Jennings & Bamkole, 2019). Single elements of the system (i.e green roofs, community gardens, constructed wetlands) acts in favor towards multiple functions (i.e storwater management) (Cohen-Shacham et al., 2016). Simultaneously, many different elements work in parallel and independently of each other and an inherent resilience is created. However, the application of these elements must be planned with this versatility and resilience from the start. Biodiversity is an emergent property of nature-based solutions. Green infrastructure such as green roofs, green facades, rain gardens, trees, and wadis are urban tools towards green networks. Managing green spaces ecologically is imperative for preserving various plant and animal species, including insects, birds, and amphibians. In general, solutions such as tiny forests, bioswales, and community gardens foster higher biodiversity counts than nearby local nature. The runoff of rainwater is previously mismanaged with the runoff running into the sewage system or into surface water. This runoff often includes accumulated pollution from streets making it a source of water pollution (Kluck et al., 2017). Managing the storm water entails slowing and decreasing the run off, storing some of the water for dry periods, and filtering any pollutants that have been accumulated before discharging it into nature. An additional benefit of decreasing the impervious surfaces is the effect it has on the microclimate, especially in the summer. Depending on what NBs is applied, additional comfortable outdoor spaces are created. Urban green infrastructure that benefit stormwater management are tiny forests, bioswales, green roofs, green walls, constructed wetlands, and community gardens. These utilize the surface area of plants, landscape depressions to collect water, the absorption capability of healthy soil, and soil and roots intercepting pollutants via sedimentation and nitrification-denitrification, which transform dissolved pollutants, organic matter and pathogens. Afforested areas have roughly 10-22% of rainfall intercepted and evaporated, 16% rainfall transpiration, 60% rainfall infiltration, and 10-20% run-off (Rahman et al., 2023). The soil in these areas can have up to 160 mm/h in tests. Bioswales have a designed enhanced infiltration rate with a capacity to handle most heavy rainfalls and pool water if their capacity is reached. They can also be designed to redirect the water to surface water or other more infiltrating regions (BioSwales | Urban Green-Blue Grids, n.d.). Bioswales can also be designed with a purifying component to them reducing the pollution impact from the streets. With enough water-holding capacity, either via substrate or storage, the surfaces of the building can contribute to the infiltration rate of stormwater. Trees above 5 years of age constitute the most effective option to reduce heat stress at the local scale because of evapotranspiration and large shading, 3 degrees for daytime ambient temperatures and 16 degrees for physiological equivalent temperatures at night (Erlwein et al., 2021). The impact of trees is observed more at the street level than the building scale (Priya & Senthil, 2021). The combination of trees, vertical green and green roofs offer a more comfortable open outdoor space. On a neighborhood scale, green roofs regulate the microclimate with evaporative cooling and an improved surface albedo that positively influence the UHI (Erlwein et al., 2021, Alexandri & Jones, 2008, Priya & Senthil, 2021). The impact is influenced by the degree of UHI and the climate. Vertical greening is an option in dense locations where trees have no space. Sun-exposed westward oriented facades get the highest benefit and see 15.5 degrees cooling for surface temperature and 2.3 degrees for mean radiant temperatures. (Alexandri & Jones, 2008). The combining of different green elements produces better performance and temperature control. Trees are more effective in outdoor conditions and green roofs and walls are more influential in indoor conditions. The effect of green walls is more influential than green roofs because there is often more façade than roof space and green walls are in closer proximity to users (Erlwein et al., 2021). However too much vegetation in close proximity to pedestrians might be negative because of reduced wind speeds and increased humidity (Priya & Senthil, 2021). Green roofs are capable of reducing energy demand by 4% and 7% for Amsterdam and London but water management is essential for it to be remotely feasible and a cost-effective solution. (Ascione et al., 2013) Green roofs are not convenient for energy refurbishments. If there is green systems in place to process greywater for reuse the water can be collected and used locally instead of relying on central treatment. By reducing the quantity of water that needs treated and by treating it locally a reduction in emissions can be expected up to 50% (Boano et al., 2020). However using plants to treat water isn't always suitable. A dense neighborhood has too much water demand and use and too little surface area for plants to treat the water. Simultaneously, feasibility is also low with low density. Analyzing Boerhaavewijk, the density and amount of open space does indicate local treatment to be possible. With the intensification of green on the roof, facades and neighborhood the availability of rainwater for the purpose of water re-use might diminish entirely and in dry periods greywater will be used for irrigation. The possibility of building-integrated water treatment to be sufficient for household re-use is dependent on further research beyond the pilot studies. Constructed wetlands (CW) biodegrade or immobilize a range of emerging pollutants including pharmaceuticals and perform better than conventional "grey (non-nature-based)" solutions. CW is considered a sustainable low-cost low-maintenance technology. Horizontal and vertical subsurface flow systems are possible even with low spatial footprints of 1 m2/PE in cold and temperate climates. Free water surface systems have a higher biodiversity. It is suggested to use a disinfection step UV or chlorine to meet strict water re-use standards. (Boano et al., 2020). Outdoor air pollution mitigation is difficult to measure as it is influenced by plant capabilities (Weerakkody et al., 2017) and surrounding conditions such as wind patterns, air volumes, pollution types and concentrations, and distance to source. (Han et al., 2022). Formaldehyde, SO2, NOx, CO, Lead, O3 and particulate matter (PM1, PM2.5, and PM10) are common pollutants measured. Most outdoor pollution studies focus on PMx mitigation. Trees and vertical green systems and green walls show the ability to remove particulate matter (PM) though the variety of plants and their configurations are influential in the effectivity to reduce PM. For example, big trees, small trees, shrubs, and grasses. (Han et al., 2022, Xu et al., 2020) (Xu et al., 2020). There is a potential benefit for vertical green in combination with trees and shrubs to increase the total air quality around a building and thus the air that is brought indoor. The ability of plants to reduce the intensity or presence of noise is well accepted and applied often near sources of loud noises. Plants placed close to the source dampen the sound better. Some application of greenery has sound reduction properties (Perez et al., 2016). Plants add an additional cognitive and environmental noise attenuation benefit, that of nuisance reduction and sound masking. (Palacio et al., 2018). The environment someone is in influences their perception of noise and a green environment and exposure to green gives people the perception of quite. A soundscape of noises perceived as natural masks exterior noise nuisances.

2.2. Green roof

Yearly stormwater retention and can range from 40-80% (Luque & Perini, 2018, Baryla et al., 2023). On a single event retention ranges 12-74.6% (Luque & Perini, 2018). Retention is 100% during precipitation of >5 mm/day using hydraulically active substrates of 150 mm (Baryla et al., 2023). Gong et al. (2019) measured runoff for different sizes of green boxes, substrates of 100 mm retained 12.1-100% with better results from the thicker substrates. Substrate composition and thickness is the key point here. Pitched roofs are disadvantaged for detaining stormwater. Geogrids can be used to keep the soil from eroding to lower elevation and temporarily store stormwater beyond the substrate saturation (Luque & Perini, 2018). These roofs again require a substrate of at least 100mm and a 150 mm build height for the water storage. A flat roof can have 60mm substrate with water crates underneath (Föllmi et al., 2023). These roofs can hold up to 65 l/m^2. (Luque & Perini, 2018). There is disparity on results if green roofs are a source or a sink of nitrogen and heavy metals. Green roofs are sources of runoff phosphorous. Green roofs with high organic matter leach nitrogen and phosphorous, avoiding substrate with fertilizer reduces 60-80% phosphorous (Marín et al., 2023). Nitrogen leachates are still below regulation of 10 mg/l (Marín et al., 2023). Heavy metals fall significantly below the WHO recommended threshold. A lightweight extensive green roof was measured to reduce PM10 concentrations by 7.5-18.4% $PM_{2.5}$ concentrations by 15-28% and PM_1 concentration by 17.5- 31.8% (Kostadinovic et al., 2023). A roof with short grasses is thought to remove SO_2 0.65 $g/m^2/yr$, NO_2 2.33 $g/m^2/yr$, PM_{10} 1.12 $g/m^2/yr$, and O_3 4.49 $g/m^2/yr$ for a total of 8.59 $g/m^2/yr$. For herbaceous plants that is SO_2 0.83 $g/m^2/yr$, NO_2 2.94 $g/m^2/yr$, PM_{10} 1.52 $g/m^2/yr$, and O_3 5.81 $g/m^2/yr$ for a total of 11.10 $g/m^2/yr$ (Yang et al., 2008). 150 mm or more is recommended for herbaceous plants. Beyond pollution, green roofs are capable of carbon sequestration. A study measured a 60 mm sedum roof to remove a net 378 g C/m^2 after 2 years (Luque & Perini, 2018). Sedum is not known to sequester a lot of carbon and larger substrate depths and taller plants sequester more carbon. Plants commonly used on unirrigated roofs undergo crassulacean acid metabolism (CAM) to cope better with drier conditions. These sequester less carbon than those that don't activate this mechanism. A properly irrigated roof is therefore more productive in carbon sequestration. The vegetation on green roofs changes the surface albedo and reflects 5-30% of the solar irradiation. Photosynthesis converts an additional 5-20% into latent heat and evapotranspiration (Koch et al., 2020, Rakotondramiarana et al., 2015) (Raji et al., 2015, Erlwein et al., 2021). The surface area (leaf area index LAI) of the leaves and their orientation (LAD). The higher the LAI and LAD the less solar transmittance there is, down to 5% (Luque & Perini, 2018, Raji et al., 2015). The substrate also has a cooling effect, by evaporating moisture it releases 20-40% of the heat, cooling the air. An irrigated roof will maximize active cooling via evapotranspiration and evaporative cooling. For stormwater mitigation, air pollutant capture, and microclimate regulation a pattern of larger vegetation, thicker substrates, and high moisture content is clear. However, the role of moisture becomes more complicated. Runoff retention and detention is higher when the volumetric water content prior to the rainfall event is low (Palermo et al., 2023). Additionally, the moisture content becomes negative for noise mitigation and winter building energy use. In the summer, the microclimate regulating mechanisms also contribute to reduced energy usage and less heat transfer by reducing outdoor ambient and surface temperatures. For building energy usage, the substrate becomes an additional insulation layer. 100 mm thick substrate reduced energy usage by 31% and 200 mm substrate by 37%. 100 mm substrate reduces heat transfer 59% and 200 mm by 96% (Permpituck & Namprakai, 2012). Moisture conducts heat better and the R value of the substrate is reduced. How detrimental this is depends on the added insulation of the roof. A green roof increases heating demand by 3-9% on insulated roofs (Raji, et al. 2015). Furthermore, roof insulation decreases the effectiveness of benefits in the summer too (Rakotondramiarana et al., 2015, Olivieri et al., 2017). Pitched roof benefits from green roofs transmission losses more than flat roofs due to noise often originating from the ground plane (Luque & Perini, 2018). A 50 mm thick substrate is sufficient for transmission losses of 5 dB, 11 dB, and 25 dB for low, mid and high frequencies (Connelly & Hodgson, 2013). Increasing the thickness increases transmission loss of low frequencies by about 1 dB/25mm and mid frequencies by about 4 dB/25 mm (Connelly & Hodgson, 2013). More sound reduction via a mass-spring-mass arrangement with an added 50 mm sound insulated cavity. A 25 mm thick substrate (15 kg/m^2) reduced sound transmission by 13 dB (Galbrun & Scerri, 2017). Thicker substrates will increase the mass and transmission loss from the mass-spring-mass. 50 mm insulation is still acceptable to still have energy usage reduction. Subjects in the noise shadow (double diffraction) of a roof benefit more from green roofs because of absorption, single diffraction absorption might be decreased by larger vegetation (Van Renterghem & Botteldooren, 2011). Double diffraction is not negatively affected by vegetation. Thicker substrates (up to 180 mm) reduce all frequencies by around 10 dB. Thin substrates (20-30 mm) with vegetation are sufficient for high frequencies with also 10 dB (Van Renterghem & Botteldooren, 2011). Moisture reduces the porosity of soil and creates reflections reducing the sound absorption up to 10 dB (Luque & Perini, 2018, Van Renterghem & Botteldooren, 2014). This occurs mostly between 125 Hz and 1.6 kHz with little effect on higher frequencies. Traffic noise absorption is reduced by 2 dBA (Van Renterghem & Botteldooren, 2014).

2.3. Vertical green

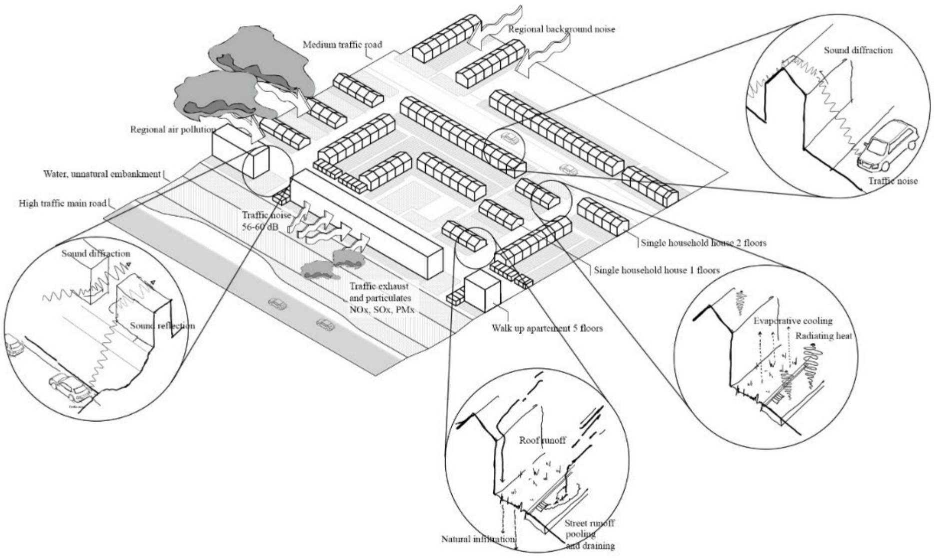
Vertical green is a common strategy for reducing summer energy usage and improving urban outdoor microclimates. Green walls provide more complete shading on underlying surfaces, reducing surface and reducing cooling demand by 53-61%. Additionally, evaporation mechanisms work to actively reduce ambient temperature decreasing the heat flow. Measurements in the Netherlands demonstrated a definite 5-degree Kelvin difference in living walls compared to smaller differences in indirect and direct green walls. Living walls create an insulated air gap between the surface and the substrate. Vertical green Indirect green walls can also have air gaps with reduced windspeeds (Perini et al., 2011). (Ottelé & Perini, 2017) measured the winter R values of a direct green wall (0.18 m^2 K W^{-1}), a modular vertical green wall (0.18 m^2 K W^{-1}), and a mineral wool continuous living wall (0.18 m^2 K W^{-1}). Living walls have additional evaporative cooling directly from the substrate. This was not considered in the calculation of the R-value, though moisture conducts heat better and reduces R values in winter (Föllmi et al., 2023). In simulation evergreen plants increase winter heating 21% and Deciduous less (Raji et al., 2015) due to evaporation and photosynthesis processes. (Tudiwer & Korjenić, 2017) measured the surface and air temperatures behind a complete living wall set up and calculated winter R values between at least 0.31 and 0.68 m^2 K W^{-1}. For outdoor microclimate regulation indirect green walls have an advantage of higher ventilation and thus higher evapotranspiration rates while living walls have the advantage of evaporative cooling from the substrate. Living walls often have higher LAI increasing their effectiveness (Raji et al,. 2015).

Vertical green is also used to mitigate air pollution. There are many factors that go into an effective setup, however, most parameters go into details of plant choice and both direct and modular living walls can be used. Climbing and hanging plants are also useful and can be used in indirect and direct green walls (Perini et al., 2017). The advantage of living walls is the larger diversity of plants in one area. Plants with different leaf micro and macro morphology can share the same space increasing the range of pollutants handled (PM_{10}, $PM_{2.5}$, PM_1, NO_2 SO_2). Some studies on winter building energy use suggest plants that are dormant in the winter, these plants types naturally have a reduced pollutant interception performance in the winter. The same is true for using vegetation to mitigate noise, seasonal plants will reduce performance in dormant seasons. Vegetation in green walls contribute to noise mitigation but have only a partial role. The transmission of noise is reduced more significantly by suitable substrates. However, living wall systems are not designed for acoustics and are not airtight, dramatically sacrificing performance (Luque & Perini, 2018). There are differences between lab tests and in situ measurements. In labs living walls exhibit sound reductions between 5-10-15 dB in middle frequencies and 2-4 dB in high frequencies (Luque & Perini, 2018). An in situ measurement testing both an indirect green wall and a continuous living wall saw that the substrate is responsible for reducing the middle frequencies and the vegetation for the high frequencies. Substrate and vegetation combined have a complete frequency profile (Pérez et al., 2016). The study concludes a 1dB reduction in traffic noises for both systems, a 2 dB pink noise reduction for the indirect green wall, and a 3 dB pink noise reduction in the living wall. The density of the soil, its composition, and the moisture in the soil influence the effects (Attal et al., 2021). Many of the beneficial elements of vertical green, all except thermal and noise insulation performance the substrates, are perform better with irrigation. Green walls can be irrigated with greywater in dry periods to avoid system failure and to increase the diversity of used plants. Households produce well over 100 Liters of greywater a day. Furthermore, pilot projects are being tested to treat household greywater, either partially or fully. Gholami et al. (2023) reviewed the capabilities promoted by these studies. Nitrogen and phosphorous concentrations are the commonly measured nutrients. Living walls can remove up to 93% of nitrogen concentrations and 53% of phosphorous. Modular systems are recommended for their flexibility in case of failure, while continuous are beneficial for increased surface area and aerobic processes. The majority of the systems use substrate compositions designed for this purpose and can work without vegetation. We chose to look at studies that can support vegetation. Sami et al. (2023) used a commercially available modular system (Gro-wall 4.5) to test 5 substrates and 3 hydraulic loading rates (HLR). The most promising was a biochar pumice 3:1 composition. The best results used a higher 214 $l/m^2/d$ HLR. Extrapolating the results makes a 3.6 m^2 façade sufficient for a 5-person household (Van Der Mooren Harm Jan Boonstra, 2022), reducing effluent concentration; Total nitrogen concentration <2mg/l, total phosphorous <0.5 mg/l, BOD <2 mg/l, most ammonia, and all organic nitrogen (Sami et al., 2023). Many other substrates are tested (Gholami et al., 2023) to provide better fits for various scenarios. The removal of pathogens still requires an additional chemical or UV treatment, but that is not necessary for all use cases. The quality of stormwater runoff of green roofs is another source of nutrient pollution, Teemusk & Mander, (2011) measured runoff concentration to reach TN and TP concentrations of 6.4 mg/l and 0.64 mg/l. Stormwater runoff from green roofs and standard green wall substrates can also benefit from this process. Green walls can also be used to manage stormwater without green roof by using the foliage or the substrate. The capacity of a living wall to retain and detain stormwater is underutilized and unaddressed in studies and the same leachate concerns of green roofs apply in living walls with standard substrate too. Palermo et al. (2023) looked at modular system to measure the stormwater capacity and runoff rates. The most influential parameter to determine the retention capacity was the initial volumetric water content (VWC). A 5% VWC resulted in 13% runoff while a 10% VWC resulted in 43% runoff. Incorporating water reuse systems in stormwater management has a small caveat. Stormwater management benefits from longer detention periods which reduces the HLR, which can decrease the treatment effectiveness of some substrates (Gholami et al., 2023). Direct and indirect walls also have stormwater benefits mainly that the foliage intercepts rainwater, detains it momentarily, and evaporates what remains on the leaves and branches. A field measurement determined that fully foliated walls had larger than 50% interception rates, and partially foliated walls had less than 50% interception rates (Tiwary et al., 2018).

2.4. Externalities and challenges of Boerhaavewijk

Illustration 1 gives the spatial arrangement of a block in the Boerhavewijk. The block is adjacent to a main road with high traffic. Another road runs through the block, connecting it with the rest of the neighborhood and more southern neighborhood. The neighborhood, and the block, have an equal division of single-family homes and apartments. The apartements in the block are 4-5 story walk up apartments and the houses are 1-2 stories. The 2 story houses are arranged to enclose private yard, the single story houses are in rows, and the apartments border the neighborhood lines. The orientation of the buildings are mostly facing east or west with some facing south-north. The 2 story houses are the majority and have a few outdoor yard/garden variations. All houses have a back yard and half have a front garden. The street-facing gardens are mostly paved with very minor vegetation, and gardens facing a green space are greener with larger vegetation. The private yards are divided by tall solid wooden fences and partially or very commonly mostly paved. The water that divides the main road has a wide naturally planted slope and an unnatural wood-lined embankment. A few trees grow on the slope. The high traffic road is a perpetual source of noise and air pollutants that are estimated to influence slightly past the row apartment. The road passing through the neighborhood has much less traffic and is not perpetual. The air quality of the neighborhood is worse than recommended by WHO for multiple pollutant types, and the background noise levels are reasonable but not good.

Illustration 1.



III. RESULTS

3.1. Mutual parameters of green systems

From the literature we have identified parameters of building integrated green that influence their performance for particular functions; noise absorption and transmission, particulate matter sedimentation, carbon and pollution sequestration, thermal insulation, temperature and humidity regulation, water retention and detention, rain and greywater treatment, and biodiversity and habitat creation. These are categorized into noise mitigation, pollution capture, building energy use, microclimate, water reuse, stormwater management, and biodiversity. Table 1 shows mutual parameters between the various functions. The functions that rely on these parameters (noted with a +) or are sensitive to a parameter (noted with a -) are highlighted per parameter. The parameters are given abbreviations for use in table 2. Table 2 shows the function and what parameters influence or harm their performance with certain categories of building integrated green.

Table 1. Highlighted parameters and functions that receive advantage or disadvantage effect to performance.

Abbr.	**Parameter**	**Functions positive/negative effect**
I	Insulation	Noise mitigation+, Building energy use -
St	Substrate thickness	Noise mitigation+, Building energy+, Stormwater management+
M	Substrate moisture	Noise mitigation-, Building energy+/-
Sc	Substrate composition	Water reuse+
Si	Solar irradiation	Building energy+, Microclimate+
S	Season	Pollution capture-, Noise mitigation-
V	Vegetation	Pollution capture+, Microclimate+, Building energy+, Water reuse+, Biodiversity +
OM	Substrate organic matter	Noise mitigation+, Stormwater management-, Water reuse-

Substrate organic matter refers to higher organic content in the substrate, substrate moisture refers volumetric water content, substrate composition refers to the necessity for specialized substrates, solar irradiation refers to high solar irradiation being exceptionally influential for performance, season refers to seasonal vegetation affecting performance, vegetation refers to denser vegetation increasing performance, and insulation refers to if the function is influence by construction thermal insulation.

Table 2. Parameter influence on function performance per system type. [X+] parameter is beneficial, [X-] parameter is negative, [X+/-] parameter both positive and negative, [X] parameter is sometimes beneficial.

Functions	**Indirect**	**Modular living wall**	**Continuous living wall**	**Green roof**
Noise mitigation	[V+] [I+]	[OM+] [Sc+] [V+] [I+]	[OM+] [Sc+] [V+] [I+]	[OM+] [M-] [St+] [Sc+] [I+]
Pollution capture	[S-] [V+]	[M] [S-] [V+]	[M] [S-] [V+]	[M] [S-] [V+]
Building energy use	[Si+] [V+] [I-]	[M+/-] [Si+] [S] [V+] [I-]	[M+/-] [Si+] [S] [V+] [I-]	[M+/-] [St+] [Si+] [S] [V+] [I-]
Microclimate	[Si+] [V+]	[M+] [Si+] [V+]	[M+] [Si+] [V+]	[M+] [Si+] [V+]
Water reuse	[V+]	[OM-] [M+] [St+] [Sc+] [V+]	[OM-] [M+] [St+] [Sc+] [S] [V+]	[OM-] [M] [V+]
Stormwater management	[S-] [V+]	[OM-] [M] [St+] [S-] [V+]	[OM-] [M] [St+] [S-] [V+]	[OM-] [M] [St+] [Sc-]

3.2. Externalities and adaption typologies

A neighborhood or a block, like in boerhaavewijk, has various externalities that make some functions more relevant. A renovation project has more externalities that can't be controlled due to much of the design set in stone. To give examples, building typologies, facade structures, roof structures, form factors, proximity with other structures, construction methods, structural capacities, and orientation are much more rigid than new projects. A design that integrates nature-based solutions or nature-enhancing greenery has to contend with a lot more factors. Building integrated greenery should be part of a larger system that works together to stabilize the neighborhood. If the space in the neighborhood is limited for a type of ground connected function then that becomes an externality that can contribute to the adaption typology. We have made a list of adaption typologies that serve as examples using the block in Boerhaavewijk (see illustration 2). The adaption typologies are formed from the externalities and the functions provided by the NBs.

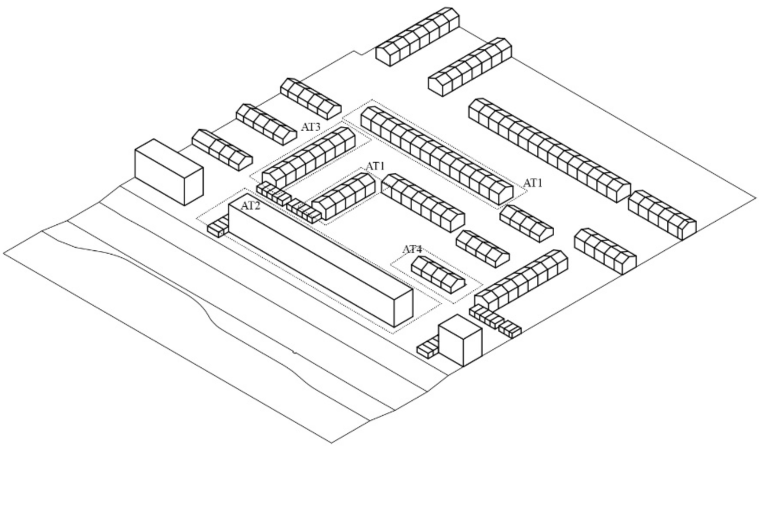
Some houses benefit more from one function than another and require parameters that support those. A building with noise mitigation as priority such as AT1 would benefit from a roof with drier, thicker, higher organic matter substrate, an insulated roof cavity, and with lower priority for vegetation. Designing the roof to retain/detain water, be well irrigated for larger vegetation and better summer building energy use would be less productive; the moisture content would reduce noise absorption, the insulated roof cavity would decrease green roof caused energy use reduction, and stormwater runoff might be richer in nutrients.

AT2 has higher priority for both pollution capture and noise mitigation. The dominant surfaces of AT2 are the facades. Larger vegetation that isn't seasonal and is irrigated properly would be beneficial in this scenario. The higher density to surface space makes building-integrated water treatment less feasible. The taller apartment building is surrounded by larger open spaces. Incorporating larger, more biodiverse, free-flowing constructed wetlands connected to the water canal is preferable.

AT3 has a dominant facade because of the south-north orientation. Microclimate regulation and building energy use are functions that rely on solar irradiation to be effective. Stormwater and water re-use can be integrated as well.

AT4 has a form factor with a lot of facade and roof surface to indoor area which. Using building-integrated greenery to decrease the heat flow in or out, decrease energy use, improve outdoor microclimate, and treat greywater are all compatible.

Illustration 2.



IV. CONCLUSIONS

In this research we looked into the functions nature-based solutions can take in a neighborhood, the various parameters that influence building-integrated greenery and effectively applying them. A block in Boerhaavewijk, Haarlem, was used to showcase an example of externalities and challenges and their spatial arrangements. The parameters that influence the type of system integrated into a building, various forms of green roofs and vertical greens are identified; these are substrate organic matter, substrate moisture, substrate thickness, substrate composition, solar irradiation, seasonal plants, vegetation, and insulation. These parameters influence the type of plants possible, the functions the system can provide, and their restrictions. There isn't a green roof or vertical green system that can provide all benefits, there are opposing parameter preferences that need to be weighed against the challenges and externalities so the most relevant functions can be effectively achieved efficiently. A lot of complexities are met when making decision for how to apply greenery on the building. This topic is still undergoing research and a better understanding of mechanisms are still needed, especially with water treatment and air pollutant capture.

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