VALUING VERTICAL GREEN

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Author : *Dieuwertje den Hartog*
Email: dieuwertje.denhartog@wur.nl
Student number : harto043 (WUR), 5409160 (TU Delft).

1st supervisor: *ir. M.C. (Martijn) Lugten*
Email: martijn.lugten@ams-institute.org
TU Delft. Architecture and the Built Environment, Building Physics.

2nd supervisor: *dr. S. (Sophie) Rickebusch*
Email: sophie.rickebusch@wur.nl
Wageningen University. Department of Environmental Sciences, Environmental Systems Analysis.

In collaboration with Rebel group, team Flora & Fauna.
Contact person: Mark Bode, mark.bode@rebelgroup.com

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Soli Deo Gloria.

ABSTRACT

The rapid development of Dutch DC's near airports pressures the environment. VGS are considered a promising measure toward a more nature-inclusive development of Dutch distribution centers. However, an integral quantitative impact assessment model is needed to retrieve funding and facilitate an evidence-based decision-making process for the implementation of VGS.

This research therefore aims *to develop a multi-criteria decision model to assess the impact of VGS in Dutch DC's near airports to enhance the decision-making process for the implementation of VGS. The main research question was formulated as follows: '*How can a MCDM tool on the quantitative performance of VGS in delivering ecosystem services be developed and applied, in order to facilitate the impact assessment and evidence-based decision-making in the context of Dutch DC's near airports?*'*

The research question was answered through a mixed-methods approach including literature research and expert interviews. A case study was used to apply and validate the MCDM model. VGS were found to offer a range of supporting, regulating, provisioning and cultural ecosystem services. The performance of VGS in delivering these services was mainly determined by the plants, substrate and support system. In general, living walls have a higher performance than green façades, among which modular living walls perform best. However, context-specific valuation was considered key.

Evaluating VGS on the interaction effects between the main system components and the ecosystem services is an effective approach for developing a MCDM model that enhances decision-making and creates support base for implementation. A context-specific impact assessment can be achieved by weighing the relevance of the ecosystem services. Further research that compares the impact of distinct types of VGS is needed to further develop and validate the model, specifically with regard to grey water treatment, education, and wellbeing.

KEYWORDS: Vertical Greenery Systems | Ecosystem services | Multi-Criteria Decision-Making | Distribution Centers | Impact Assessment

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LIST OF ABBREVIATIONS

DC – Distribution Center

ESG – Environmental, Social and Governance

KPI’s – Key Performance Indicators

MEA - Millennium Ecosystem Assessment

MCDM – Multi-Criteria Decision-Making

UHI – Urban Heat Island

VGS - Vertical Greenery Systems

WLAI – Wall Leaf Area Index

01 INTRODUCTION

While driving over the highway from Rotterdam to Breda, the view is barely comparable with the view of a few years ago. The Dutch natural landscape has been rapidly interchanged with a high number of distribution centers, and the demand for such *XXL-distribution centers* (DC's) is steadily growing (Nefs et al., 2021; BCI, 2021). In five years, their floor space has increased by 20 percent, up to 28 million square meters, and based on Forrester's latest forecasts the need for an additional 16.7 million m2 of logistics facilities in Western Europe is needed to meet the growth of online retail over the next five years (Freriks, 2019; Martinasso, 2020). Due to the diversity of transportation services and economies of agglomeration, European DC's are specifically clustering around Schiphol (Warffemius, 2007).

However, an uncontrolled growth of warehouses can have a variety of negative results, such as:

- Ecological landscape degradation
- Aesthetic landscape degradation
- High amounts of traffic, resulting in:
    - traffic congestion
    - air pollution
    - noise pollution

Accordingly, social resistance towards this 'boxing of the landscape' is growing (Nefs et al., 2021). Besides, consumers are increasingly paying attention to sustainability and *ESG* (Environmental, Social and Governance) activities in the logistics sector have become an important factor in consumers' choice of e-commerce platforms (Kim et al., 2021).

Consequently, the development of DC's is under pressure and there is increasing competitiveness within the logistics sector on ESG performance. Besides this social resistance, an increasing amount of regulations forces developers to make a social and environmental impact as well (CBRE, 2020). On the other hand, however, governments are still in favor of such DC's due to their large economic value. Researchers plea for a new way of implementing these centra, in which spatial integration and landscape resilience are key (Nefs et al., 2021).

In this context, vertical greenery systems (VGS) can be considered a promising solution. VGS have a wide range of positive implications for the urban context – varying from financial, ecological, environmental, aesthetic and social benefits (Pérez-Urrestarazu et al., 2015; Rosasco & Perini, 2018). Thereby VGS can be seen as natural features that benefit human and non-human species, sometimes referred to as ecosystem services. In short, ecosystem services are any sort of natural service that sustains and contributes to a healthy and thriving environment. Accordingly, VGS are gaining attention among researchers, designers, and practitioners (Pérez-Urrestarazu et al., 2015). As a result, VGS are optimized, and new types are developed by the implementation of new technologies.

However, the increasing variety in VGS complicates the decision for the best type of system within a specific context. Accordingly, a quantitative model to assess the impact of different VGS is experienced to be a necessity. Such a model can facilitate an evidence-based decision for a VGS and can enhance investments in vertical greenery (Ascione et al., 2020). Consequently, earlier studies have defined and modeled criteria to choose the most appropriate system within a specific context (Hollands & Korienic, 2021; Jim, 2015; Manso & Castro-Gomez, 2015). These integral studies were mostly focused on the technical requirements related to the design, installation, and maintenance of a system. Due to the increasing pressure on ESG performance, the benefits of VGS are highly relevant in this decision-making process as well. However, although numerous studies on the performance of vertical green have been conducted, a clear overview of the key performance indicators including the boundary conditions, is still lacking (Ascione et al., 2020). This is the result of the following shortcomings within academic literature. First, due to the lack of methodological consistency results are often incomparable (Hollands & Korjenic, 2021). Besides, publications often insufficiently describe the variety of factors that play a role in the functioning of a green wall (Koch et al., 2020). Thus, integral research on VGS is needed to integrate the benefits of VGS into multi-criteria decision models.

1.1. Research objectives

This research is a first attempt to define and model the ecosystem services of VGS. The overall aim of this research is '*to develop a multi-criteria decision model to assess the impact of VGS in Dutch DC's near airports to enhance the decision-making process for the implementation of VGS'* [main objective].

Multi-criteria decision-making (MCDM) requires the definition of decision alternatives. The enormous variety in types of VGS complicates the discussion among researchers, practitioners, and governments (Koc et al., 2017). Many system components of VGS, such as its materials, structure, plant species and substrate play a role in the performance (Wong et al, 2010). The definition, identification, characterization, and classification has therefore become a necessity.

- *Accordingly, this study aims to provide a clear and appropriate classification of the diverse types of VGS based on the key system variables that determine impact differences [sub-objective 1].*

Impact measurement is crucial to retrieve funding (Bueno, 2017). However, measuring the impact of VGS is considered to be a challenge. Therefore, the European Commission recommended to develop *key performance indicators* (KPI's) for nature-based solutions to enhance public procurement (Mačiulytė & Durieux, 2020).

- *Therefore, this study aims to synthesize the available knowledge regarding the impact of VGS [sub-objective 2] and to develop a set of KPI's in order to facilitate the quantitative impact assessment of VGS [sub-objective 3].*

The impact of VGS is multifunctional (Medl et al., 2017; Wang et al., 2020), and multi-level, with an impact on both the building and its urban surroundings (Wood et al., 2014). Therefore, it is important to adopt a holistic impact assessment approach. The **ecosystem approach** (Figure 1) was found to be an effective and consistent way to present the wide diversity of benefits of green infrastructure (EEA, 2011). Therefore, the impact of VGS will be assessed on their performance in delivering these ecosystem services.

- *To do so, this research also aims to identify the ecosystem services that have been related to VGS [sub-objective 4]*.

Figure 1

Ecosystem approach

Ecosystem approach

The 'ecosystem approach', as defined by the MEA (Millennium Ecological Assessment), is widely used for the holistic analysis of the holistic and complex interrelations and dynamics of social–ecological systems (Hansen & Pauleit, 2014). In this approach, the ecosystem services reflect the benefits that humans obtain from an ecosystem (MEA, 2005). As people seek to obtain many services from ecosystems, the condition of an ecosystem is perceived as the ability to provide these services. The ecosystem services are generally divided into four categories:

- Supporting services: services necessary for the production of all other ecosystem services.
- Provisioning services: products that are obtained from the ecosystems, such as food or fresh water.
- Regulating services: benefits obtained from regulation of ecosystem processes, e.g. climate mitigation, climate adaptation and disease control.
- Cultural services: nonmaterial benefits obtained from ecosystems- aesthetic, educational, recreational.

1.2. Research questions

Based on these research objectives, the research questions were formulated. These questions are guiding for this study.

MAIN QUESTION: How can a MCDM tool on the quantitative performance of VGS in delivering ecosystem services be developed and applied, in order to facilitate the impact assessment and evidence-based decision-making in the context of Dutch DC's near airports?

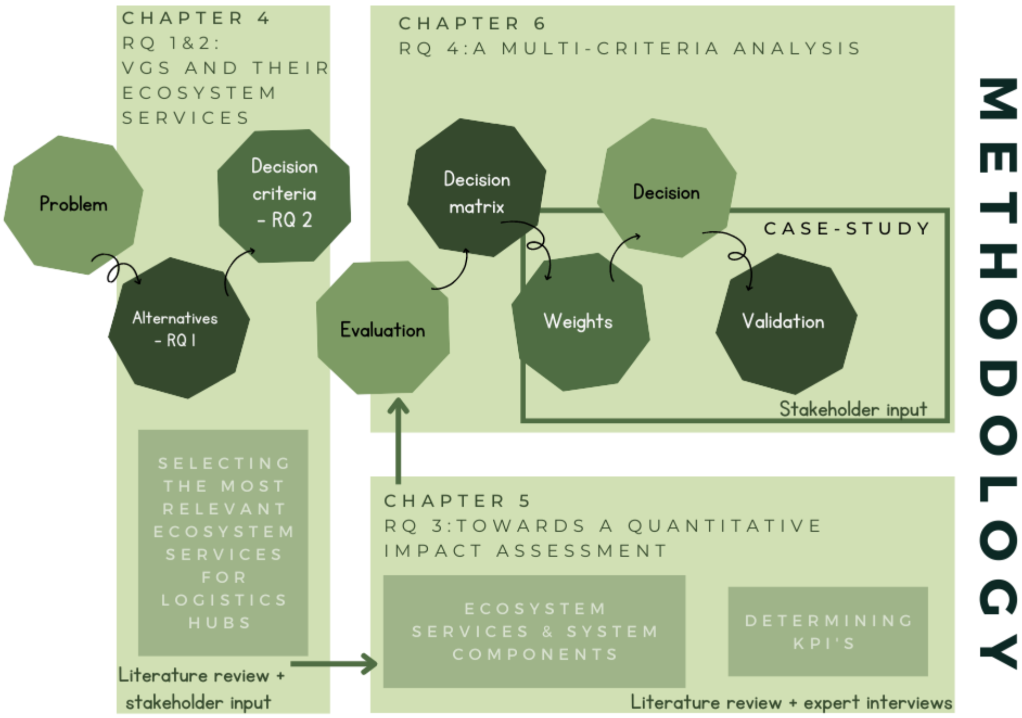
SUB-QUESTIONS:

- What key variables determine differences in performance among diverse types of VGS *[sub-question 1]*?
- What are the ecosystem services offered by VGS *[sub-question 2]*?
- How to quantify ecosystem services to assess the performance of VGS in the context of Dutch DC's *[sub-question 3]*?
- How can a MCDM model help to assess the performance of VGS and identify the type of VGS that delivers the best mix of ecosystem services for specific Dutch DC's near airports *[sub-question 4]*?

02 METHODOLOGY

This research studies the performance of VGS on ecosystem services in order to develop a multi-criteria decision support tool. The research methods used in this research are based on the steps of MCDM as formulated by Sons (1998). The first step relates to formulating the problem, alternatives and decision criteria. Next, the alternatives are evaluated, and a decision matrix is developed. Subsequently, weights are assigned to the decision criteria and integrated into the model. This results in a decision. In this study, the last steps of the MDCM process were applied to a specific case. Through this case study, the usability and validity of the tool were tested. An overview of the methodological approach is presented in Figure 2.

Figure 2
Methodological framework



Methods used for chapter 3

Research question 1: classifying the variety of VGS

The first research question, which was used to classify a set of VGS as decision alternatives, was answered through an explorative literature review. In order to enhance the usability of the multi-criteria decision model, this review was focused on creating a common classification. Accordingly, the classification was based on systems and system components that were classified as common in various articles.

Research question 2: identifying the ecosystem services of VGS

The second research question was focused on identifying the ecosystem services of VGS, which will function as the decision criteria. It was answered by means of a systematic literature review. Due to the abundance of studies on VGS, only reviews from the past five years are included in the study. These reviews were considered to provide a synthesis of the current state of knowledge. Afterward, these articles were selected on their relevance. Due to the importance of climatic differences on the impact of VGS (Jim, 2015), all articles that specifically focused on climates other than the Cfb climate, as classified by Köppen, were excluded. Besides, all articles that did not apply to the vertical greenery systems, as classified in chapter 3.1., were excluded as well. Further methodological details can be found in Appendix 1.

Subsequently, the relevance of the ecosystem services identified for VGS within the context of distribution centers near airports was assessed. Accordingly, the ambitions of two developers of logistics hubs near airports: BIC (Brainport Industries Campus) Eindhoven and SADC, were compared to the ecosystem services. These ambitions were first explored via desk research. Next, a contact person from both parties was consulted on the crossovers between the ecosystem services and their ambitions. A detailed overview of the method and output can be found in Appendix 2.

Methods used for chapter 4

Research question 3: data collection

The next step of MCDM is the evaluation of the alternatives based on the decision criteria. Prior to this step, an in-depth understanding of the relation between the ecosystem services and the systems' components is needed (Radić et al., 2019). Accordingly, the third research question was drawn up. This research question was answered via a mixed-methods approach (chapter 4). Primarily, both quantitative and qualitative data were collected via literature research. In this literature research, the articles that were included in the systematic literature review for sub-question 2 were taken as a starting point. Additional articles were first retrieved via the snowball method: relevant studies that were referred to in these articles were screened. If this approach was not sufficient to find relevant data, a broader literature search was conducted. In this case, the search query consisted of a term for the ecosystem service, a term related to measurement and a term related to vertical greenery. If the available quantitative data was not considered sufficient to evaluate the different types of VGS quantitively, this service was excluded from the set of decision criteria. When expert input was considered a necessity for the researcher to correctly interpret the literature regarding the MCDM process*, additional input on the impact of the ecosystem services was retrieved via semi-structured expert interviews. The interview guide as well as the summaries of these interviews can be found in Appendix 3-10. One interview was structured by a different interview guide, focused on the impact of plants. (Appendix 5) All interviews were recorded.*

The results of chapter 4 were synthesized to enhance understanding. First, the different indicators that are found were assessed by the criteria from the CIVITAS framework (CIVITAS Initiative is a network of cities that supports the European Commission in achieving its sustainable mobility and transport goals). This framework was found to provide criteria for the definition of a good set of KPI's (Rooijen & Nesterova, 2013). Second, the interaction effects between the system components and the performance of VGS in delivering ecosystem services were mapped.

Methods used for chapter 5

Research question 4: multi-criteria analysis

The last research question was answered by following the final steps of the MCDM process. Firstly, the different systems were evaluated based on the data collected in the previous chapter. This evaluation was quantified and visualized in a decision matrix. Subsequently, a context-specific application of the model was tested by means of a case study (Figure 2). Accordingly, case-specific stakeholder input was used to assign weights to the ecosystem services. The integration of these weights into the decision matrix resulted in a concept multi-criteria decision model. Finally, the accuracy of this concept model was tested in a discussion with the case-related stakeholders. In this discussion, the best alternative according to the model was compared to the decision made.

Figure 3

Case study: Virgo Aalsmeer

03 THE BENEFITS OF VERTICAL GREENERY SYSTEMS

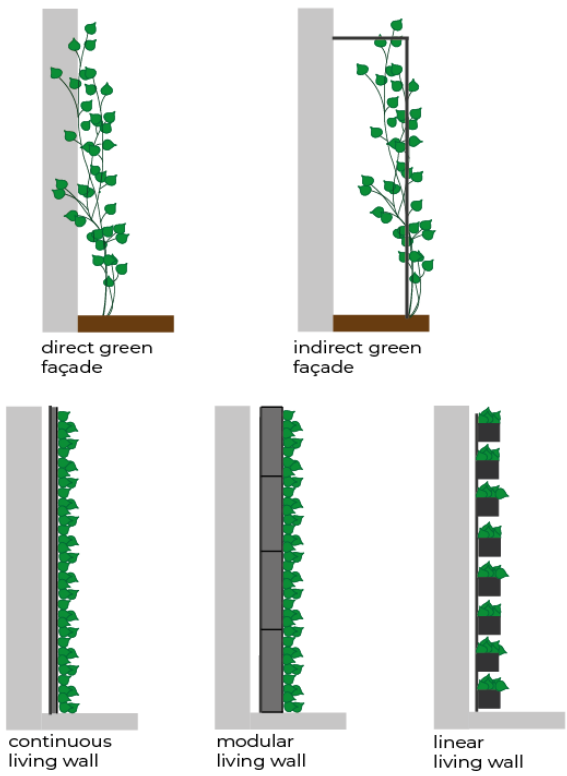
This chapter provides the results of an explorative literature review on vertical greenery systems and their ecosystem services. First, a conceptual framework for the different types of VGS is established based on the main system components. Secondly, the range of ecosystem services that have been related to VGS in academic literature is presented. Thirdly, an exploration of the most relevant ecosystem services for the context of Dutch DC's near airports is described.

3.1 A classification of VGS based on their main system components

Vertical greenery systems (VGS) have been classified in numerous different ways. Most classifications focus on the distinction between a ground-based system (green façade) and a wall-based system (living wall), while some classifications also include green terraces and vertical forests. This study focuses solely on vertically oriented VGS: the living walls and the green facades. Therefore, the definition of a vertical greenery system by Wood et al. (2014, p.15) – "a system in which plants grow on a vertical surface, such as a building façade, in a controlled fashion and with regularly maintenance" - will be used in this study. The main components of VGS are (Wood et al., 2014):

- Vegetation
- Growing media (substrate)
- Support system
- Irrigation system

Figure 4
Types of VGS



Note. Based on Medl et al. (2017).

This study focuses on the impact assessment of VGS based on their differences in these elements. Medl et al. (2017) give an overview of the system components for the common types of VGS. Therefore, this classification (Figure 4) is taken as a starting point for the selection and classification of VGS within this study (Table 1).

Green façades

The most traditional approach for vertical greening is the *direct green façade*. For a direct green façade, vegetation is placed in the ground and is supported directly by the building envelope. Therefore, only self-adhesive climbing plants are suiTable for a direct green façade. The most well-known self-supporting climber is the Boston Ivy. The Boston Ivy is a perennial deciduous vine that functions well under a wide range of circumstances. The direct green façade is low in cost and environmental burden and is easy to implement as it does not require a support or irrigation system. However, this type of vertical greening comes with the risk of envelope deterioration plant detachment (Manso & Castro-Gomez, 2015).

For an *indirect green façade*, also referred to as a double-skin green façade, climber plants are attached to a support structure. This results in an air cavity between the system and the building envelope. The support structure can be made of various materials: cables, ropes, nets, trellis in stainless steel, galvanized steel, wood, plastic, or glass fiber. The plants are placed in a ground-based planter box or directly into the ground. The most common climber for an indirect green façade is the Hedera Helix. An indirect façade also allows for an irrigation system, which consists of a drip line inside the vessels. Compared to the direct green façade, this system comes with higher installation costs and a higher environmental burden. Both types of green facades have the disadvantage of slow surface coverage and scattered growth along the surface (Manso & Castro-Gomez, 2015).

Living walls

Living walls are more advanced, pre-vegetated systems that are placed in front of a wall. Living walls can be classified in three types (Medl et al., 2017):

1. a continuous system
2. a modular system
3. a linear system

Perini et al. (2011) classified these systems as follows: a living wall based on planter boxes, a system based on foam substrate and a system based on felt layers. In this study, a synthesis of both classifications is used. Continuous living wall are often based on a geotextile-felt system, which also serves as growing media (Manso & Castro-Gomez, 2015; Medl et al., 2017). The system consists of a frame, a base panel and a waterproof membrane that protects the construction material from moisture. A hydroponic system is used to provide water and nutrients to the plants. A modular living wall consists of a structural frame with modular panels, which holds (foam) substrate. Foam is a lightweight substrate opportunity. Compared to a continuous living wall, modular systems are easier to maintain as the modular components can be separately replaced if necessary. Linear green walls are composed of planter boxes, often made from plastic (HDPE) and filled with mixed substrate, which are applied above each other (Medl et al., 2017). A linear system based on planter boxes is often also referred to as a modular system. Both systems allow for a wide range of plants, varying from shrubs, perennials, grasses, and succulent plants, and have an irrigation system with a drip line in each module/planter (Manso & Castro-Gomez, 2015). Compared to green façades, living walls are more advanced. Therefore, they come with higher installation costs and implementation complexity. On the other hand, living walls allow for a higher variety of plants and have a higher aesthetic potential.

Table 1

An overview of the most common VGS and their characteristics

Vertical greenery systems		Support system	Growing media	Vegetation	Irrigation system
Green façades	**Direct**	x	Soil	Self-adhesive climbers, e.g., Hedera Helix	x
	Indirect	Structural frame of cables, meshes, trellis or nets	Soil	Climbing plants, e.g. Hedera Helix	Drip line inside vessels
Living walls	**Continuous**	Aluminum frame with geotextile felt layers	x	Shrubs, grasses and perennials	Hydroponic system: Drip line on the top of the wall
	Modular	Structural aluminum frame with modular panels	Foam substrate	Shrubs, grasses, perennials, and succulent plants	Hydroponic system: Drip line on top of each module
	Linear	Modular plastic planter boxes and aluminum frame	Soil	Shrubs, grasses, perennials, and succulent plants	Hydroponic system: Drip line on top of each module

Note. Based on Fernández-Cañero et al. (2018); Medl et al. (2017); Manso & Castro-Gomez (2015) & Reyhani et al. (2022).

3.2Ecosystem services of VGS

Different researchers have listed the benefits of vertical greenery (Besir & Cuce, 2018; Hop & Hiemstra, 2013; Manso et al., 2021; Radić et al., 2019). This chapter synthesizes the results of a systematic literature review on the most recent knowledge regarding the benefits of VGS (Table 2).

Although it is considered holistic, a downside of this framework is that it lacks the opportunity to describe the impact on different scales (EEA, 2011; Hansen & Pauleit, 2014). However, differentiating the interactions of a system on different spatial scales is considered a requirement to properly evaluate the benefits of green infrastructure (Hansen & Pauleit, 2014). Accordingly, the impact scales of the ecosystem services have been distinguished as well. The impact of VGS occurs on two spatial scales: the individual building scale and the wider urban surroundings (Ascione et al., 2020; Wood et al., 2014). The Table below provides an overview of the multi-dimensional ánd multi-level benefits of VGS.

Table 2

Outcomes of systematic literature review on the benefits of VGS

Ecosystem services		Impact scale Urban	 Building	Sources
Supporting	Biodiversity support	X		(Besir & Cuce, 2018; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)
Regulating	Weathering control		X	(Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)
	Sound regulation	X	X	(Ascione et al., 2020; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)
	Thermal regulation	X	X	(Antoszewski et al., 2020; Ascione et al., 2020; Bakhshoodeh et al., 2022; Besir & Cuce, 2018; Koch et al., 2020; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021; Wong et al., 2021)
	Greywater treatment	X	X	(Addo-Bankas et al., 2021; Boano et al., 2020; Liu et al., 2018; Manso et al., 2021; Pradhan et al., 2019; Teotónio et al., 2021)
	Stormwater management	X		(Addo-Bankas et al., 2021; Loh & Stav, 2008; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)
	Air filtration	X		(Addo-Bankas et al., 2021; Manso et al., 2021; Ysebaert et al., 2021)
	PV performance		X	(Manso et al., 2021; Zluwa et al., 2021)
Provisioning	Food provisioning	X		(Prihatmanti & Taib, 2017; Teotónio et al., 2021)
Cultural	Aesthetic value	X	X	(Besir & Cuce, 2018; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)
	Education	X		(Radić et al., 2019)
	Health & Wellbeing	X		(Besir & Cuce, 2018; Manso et al., 2021; Radić et al., 2019; Teotónio et al., 2021)

3.3 The relevance of the ecosystem services for Dutch DC's

To assess the relevance of the ecosystem service as identified in chapter 3.2, the ambitions of SADC and BIC Eindhoven were explored.

Schiphol Area Development Company (SADC) is a developer of business premises in the Amsterdam Airport Region. SADC has the aim to develop a cohesive portfolio of high-quality, accessible, (inter)nationally competitive working environments in the Amsterdam Airport Region. Therefore, three policy pillars were set:
1. circular economy, 2. digitalization, 3. business ecosystems.

Brainport Industries Campus (BIC) is an international campus for high-tech manufacturing industry, located in Eindhoven. Sustainable and open innovation are at the core of the identity of BIC. Similarly to SADC, Brainport Eindhoven works from three main focal points:

1. An attractive business climate,
2. To attract talent,
3. To excel at innovation.

The Table below shows the crossovers between the ecosystem services of VGS and the ambitions of both parties.

Table 3

Relevance of ecosystem services of VGS for logistic hubs

Ecosystem service	Relevance to ambitions of logistics hubs	
	SADC	BIC
Biodiversity support	Integrated in the development of new KPI's (1)	Sustainability
Energy savings	Important. Sustainability requirements (2)	Sustainability
Mitigation UHI effect	Sustainability requirements (3)	Less relevant -> outside area
Sound regulation	Relevant due to proximity to Schiphol (16)	Relevant due to proximity to Eindhoven airport
Greywater treatment	Sustainability requirements (12)	Sustainability
Storm water management	Sustainability requirements (11)	Sustainability
Air filtration	Sustainability requirements (10)	Sustainability
Weathering control	Sustainability requirements (4)	Interesting
PV performance	Sustainability requirements (5)	Solar energy is relevant
Food provisioning	Integrated in development of new KPI's (6)	Relevant at pilot scale
Aesthetics – landscape value	Space scarcity (9)	Attractive working environment
Aesthetics – property value	Space scarcity (8)	Attractive working environment
Education	Image building (7)	Integration work and education
Health: safety	Sustainability requirements (13)	Attractive working environment
Health: recovery	Sustainability requirements (15)	Attractive working environment
Health: stress reduction	Sustainability requirements (14)	Attractive working environment

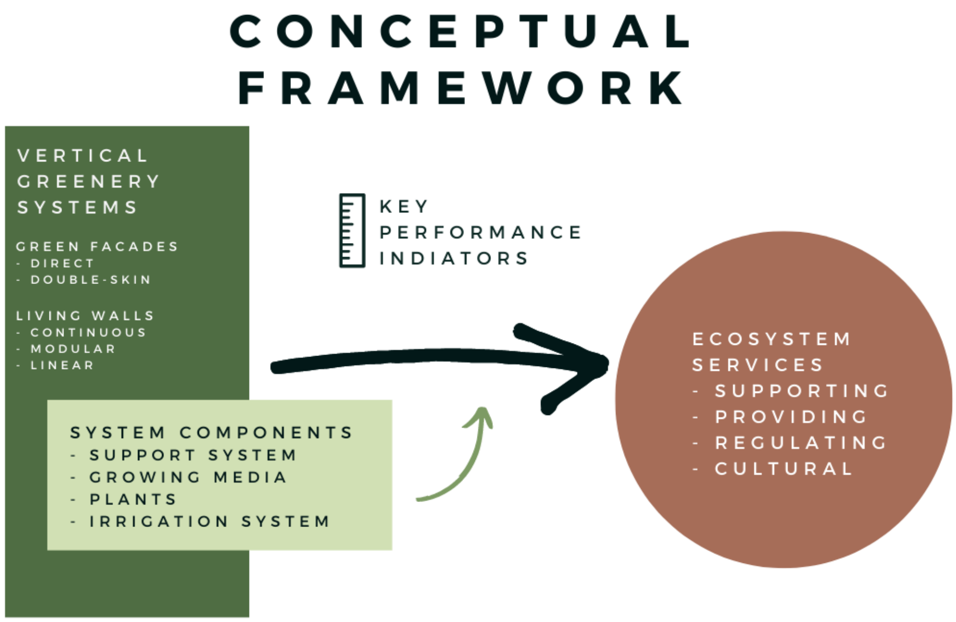
Main takeaways

All ecosystem service were found to be relevant within the context of Dutch DC's near airports. Accordingly, all ecosystem services are researched more in-depth in the next chapter.

04 TOWARDS A QUANTITATIVE IMPACT ASSESSMENT OF VGS

The identification of ecosystem services of VGS in chapter 3, gives an understanding of the potential impact of VGS. Besides, chapter 3 provides a simplified overview of the decision alternatives for implementing VGS. As a next step towards a decision-support tool for the implementation of VGS, this chapter explores what is needed for the quantitative impact assessment of diverse types of VGS as follows (Figure 4): Firstly, this chapter will provide a more in-depth explanation of the ecosystem services and their relevance. Secondly, it explores the potential performance indicators and the available quantitative data for each of the ecosystem services. Thirdly, this chapter gives an overview of the available knowledge regarding the interaction between the performance and the system components for each of the ecosystem services.

Figure 5
Conceptual framework chapter 4



4.1. Assessment of the supporting services

4.1.1. Biodiversity support

Biodiversity is the variability among living organisms, relating to the variability of species within and between ecosystems (MEA, 2005). Biodiversity supports the ecosystems condition and can influence the supply of other ecosystem services. When it comes to biodiversity, fitness to the local ecosystem and scalability is crucial (Appendix 4). The key elements for biodiversity support are, to provide place for food, connectivity, reproduction, or shelter.

VGS can contribute to biodiversity by providing a habitat for flora and fauna (Mayrand et al., 2018). However, the spontaneous growth of plants that are not integrated in the system design might be limited by maintenance measures. VGS allow for an increase in vegetated area and are associated with increasing presence of insects, spiders, beetles, and snails (Madre et al., 2015; Mayrand et al., 2018). Moreover, green façades were found to be a place of food, shelter and nesting for birds (Chiquet, 2014; Chiquet et al., 2013). Double the amount of bird flocks were found on or around green façades compared to bare walls (Chiquet, 2014).

However, when it comes to enhancing biodiversity, ecological connectivity, which refers to the degree of connection between the various natural environments within a landscape, in terms of their components, spatial distribution and ecological functions, is found to be crucial (Shanahan et al., 2011).

But due to their patch size, quality, abundance, and isolation, VGS do not provide a habitat for urban-avoider or urban-adapter species (Mayrand & Clergeau., 2018). Thus, although VGS are beneficial as exclusive habitats, the potential of VGS in relation to urban wildlife corridors remains questionable (Mayrand & Clergeau., 2018; Mayrand et al., 2018).

Experts therefore mentioned that VGS might be an example of greenwashing when they are implemented as a measure of biodiversity (Appendix 4). VGS are a measure on local scale, which can have ecological value to the environment when they are implemented as a part of the local ecosystem. This means that for example the plant species or type of system are adjusted to the (needs of) the species that are present in the environment.

Quantitative data & potential indicators

Marshall et al. (2022) did research on the simulation of biodiversity offsetting. By researching six offset metrics - vegetation area; vegetation condition; habitat suitability; species abundance; metapopulation connectivity and rarity-weighted species richness – they found that there is no 'one size fits all' approach for measuring biodiversity, and that specific ecological objectives must be related to the offsets of developments. Overall, it was found that none of these metrics was found to counterbalance the long-term impact of developments. Therefore, measures to avoid the ecological impact of new developments are most successful. In order to measure the effect of targeted measures, specific objectives and species-specific measures are needed (Marshall et al., 2022). The species-specific impact of VGS on biodiversity can be indicated by species richness and abundance of species, in total or per m^2 (Madre et al., 2015; Mayrand et al., 2018, Table 1). Species richness refers to the number of species and abundance to the number of individuals (Appendix 4; Madre et al., 2015). Experts also mentioned that a quantitative assessment of biodiversity is complex as biodiversity is so context-specific. Qualitative measures that are used in effect studies relate for example to species rareness, quality of maintenance and complementarity to the local ecosystem (Appendix 4).

Table 4

Relative performance rates on biodiversity

Indicator	**Values**			
	Green façades		*Living walls*	
	Direct GF	*Indirect GF*		
Plant variety (Number of species possible)	3. (Max. 8)	2. (Max. 10)	1. (Max. 250)	
Species richness (total)				
Birds	1. (Est. 6)			
Snails	2. (Est. 7)		1. (Est. 10)	
Insects	1. (Est. 210)		2. (Est. 130)	
Mean species richness (per m^2)			*Modular*	*Continuous*
Beetles	2. (Est. 3.7)		3. (Est. 3.5)	1. (Est. 3.9)
Spiders	3. (Est. 2.1)		1. (Est. 4)	2. (Est. 3.1)
Total abundance				
Birds	1. (Est. 60)		2.	
Snails	1. (Est. 495)		2. (Est. 60)	
Insects	1. (Est. 6200)		2. (Est. 1100)	
Mean abundance (per m^2)				
Beetles	2. (Est. 11)		1. (Est. 12)	3. (Est. 7)
Spiders	3. (Est. 3)		1. (Est. 26)	2. (Est. 15)

Note. Scored from best (1) to least (3) performing system Est. = estimated value. Based on Mayrand et al. (2018) & Madre et al. (2015).

System components

The specific properties of VGS have a major influence on their ecological and floristic specifications (Madre et al., 2015). For example, green façades are warm and dry habitats, whereas living walls provide damp and cool habitats. Overall, living walls were, through a monetary valuation of biodiversity, considered to have a higher value of biodiversity than green façades (Collins, 2017). However, as Table 4 shows, the preferred system preference depends on the species focused on.

- *Vegetation.* Living walls allow for a wider variety of plants that can be modified to the local ecological needs, whereas green façades allow for fewer suiTable planting species that do not lead to establishment of further plant species (Francis, 2011). Mayrand et al. (2018) identified the number of possible plant species for different systems as follows: four species for bare walls, eight for direct façades, and up to 250 different species for living walls. Valuing the different systems is less straightforward for fauna, as preferences of animals are species-specific. Beetles and spiders are more abundant in living walls. Green façades, on the other side, show a significantly higher abundance of snails. Besides, only green façades have been identified as a place of food, shelter, and nesting for birds (Chiquet, 2014; Chiquet et al., 2013). For birds in specific, evergreen climbers with a higher growing height are recommended (Chiquet et al., 2013). In general, the most important design measure regarding the ecological value is the use of plants with a thicker layer of vegetation or a higher foliage density (Appendix 4). The foliage density can be expressed by the wall leaf area index (WLAI), which represents wall coverage in m^2 of leaves/m^2 of the façade. Overall, a rough order from a low to a high WLAI for the potential types of plants as classified in this study can be made as follows: succulents, grasses, perennials, shrubs (Appendix 5). Besides, Mayrand et al. (2018) suggested to use native species and to choose seedlings over pre-grown plants. They also suggested to design for diversity, by selecting plants with different functional traits. For example, by combining evergreen and seasonal plants and varying fruits. Further, the use of non-cultivated plants is preferred (Appendix 4). The cultivated plants that are often used due their survival under a variety of conditions, minimize the ecological value of VGS. Finally, it was suggested to decrease maintenance in order to enhance a seasonal effect as well as the spontaneous growth of plants. A decrease in maintenance can also help to minimize the disturbance of animals and to increase habitat support by the litter of for decaying plants for example (Mayrand et al., 2018).
- *Substrate.* Besides, these decayed plant materials enhance the organic matter content in the substrate, which can enhance microbiological activity (Mayrand et al, 2018). A higher level of microbiological activity in the substrate has been positively related to biodiversity and can replace artificial fertilizers. Besides, a larger substrate that enhances rooting is recommended (Mayrand et al., 2018). This means that green façades or linear living walls are preferred.
- *Irrigation system.* Water-nutrient availability is a driver for the presence and abundance of different plant species (Mayrand et al., 2018). The equipment with hydroponic irrigation systems for living walls therefore contributes to the plant variety. The damp and fresh habitat that results from such a system attracts certain animal species, where others prefer a warm and dry environment (Mayrand et al., 2018). This underlines the conclusion of Marshall et al. (2022), that species-specific objectives are needed for biodiversity support.

Main takeaways - biodiversity

Biodiversity support relates to provisioning place for food, connectivity, reproduction, or shelter. It can be measured by species richness and abundance. A context- and species-specific design is key for the ecological value of VGS and can be enhanced by the use of native species, increasing plant variety and larger substrates. However, ecological connectivity is key in biodiversity support. In that respect, the value of VGS in relation to the wider ecosystem is limited. The ecological value of VGS as a separate habitat is considered to be higher for living walls, due to the higher variability in plants.

4.2. Assessment of the regulating services

4.2.1. Thermal regulation

When it comes to the benefits of VGS, by far most articles are related to the thermal regulation of VGS (Bustami et al., 2018). Thermal regulation has a positive impact both on the building level and on the urban level (Ascione et al., 2020; Besir & Cuce, 2018; Manso et al., 2021)

Building energy savings

On a building level, VGS are a key solution to decrease energy consumption for heating and cooling (Besir & Cuce, 2018). The main mechanisms related to the energy saving capacity are shading, isolation and evapotranspiration, among which shading is the most significant (Ascione et al., 2020; Koch et al., 2020). The highest potential benefits are therefore related to the reduced cooling demand. The cooling effect is further enhanced by the evapotranspiration which decreases the accumulation of heat within the façade (Appendix 6). Besides, VGS can also reduce heating costs in wintertime due to the isolating effect. The isolating effect of VGS is enhanced by the wind reducing effect of VGS. Wind along the façade causes a loss of energy when there is a temperature difference and VGS help to reduce the speed of this wind flow (Appendix 6).

Quantitative data & potential indicators

Numerous parameters have been mentioned in literature to refer to this thermal performance of VGS. Various parameters, such as wind speed reduction within the foliage and air cavity, heat transfer coefficient, heat flux reduction, evapotranspiration rate, can be used to monitor the mechanisms listed above (Besir & Cuce, 2018; Koch et al., 2020). Another important parameter to express the isolating effect of a façade is the heat resistance (Appendix 7). These parameters can be regarded as process indicators for the thermal regulation.

Koch et al. (2020) gave an overview of the different indicators that have been used in earlier literature, which are the following: the difference with and without VGS in temperature, both indoors and outdoors, and both for the wall surface as well as the ambient temperature, the difference in heat transfer and the energy savings for heating and cooling. In this review quantitative values for thermal performances were mapped as well. Similarly, Besir & Cuce (2018) also did a review on the thermal performance of VGS. The synthesized results of both studies are shown in Table 5. It was found that the external wall surface temperature can be reduced up to 34 °C. However, it should be considered that the studies executed in the Netherlands showed the lowest temperature differences compared to other studies in the Cfb climate. This implies that the given values are optimistic for the Dutch context. Besides, the different values, that this Table is based on, are from different studies. Therefore, this Table cannot be used to compare performances.

Table 5

Quantitative thermal effect

Thermal effect	Values		
Temp. difference of external wall (degrees Celsius)	*Direct GF*	*Indirect GF*	*Living walls*
Cooling	Avg. -4,2, Min. -1,2, Max. -7,2.	Avg. -13,8, Min. -2,7, Max. -34.	Avg. -9,6, Min. -1.98, Max. -20.
Insulating	Avg. +2,1, Min. + 0,5, Max. +3,6	Avg. +2 Min. +2, Max. +2	Avg. Min. +2, Max. +2
Energy savings (%)			
Heating	Avg. 29%, Min. 8%, Max. 50%		
cooling	Avg. 19,4%, Min. 5%, Max. 33,8%		

Note. Synthesized findings of Besir & Cuce (2018) & Koch et al. (2020).

The most recent review on the thermal performance of VGS identified two key indicators for the thermal performance of VGS (Bakhshoodeh et al., 2022): The difference between ambient air temperature and the temperature inside the gap (ΔT_{gap}), which indicates the thermal comfort, and the temperature difference of the external wall with and without green façade ($\Delta T_{external\ wall}$), which can be used to give an indication of the energy saving potential. These temperature differences should be determined for each system interface in order to fully understand the thermal regulation of the system and to determine the temperature gradient (Appendix 6). Moreover, the isolating value of a system might be different across the wall. The validity of the measurements can be increased by increasing the amount of measurement points across the wall (Appendix 7).
The temperature differences can subsequently be converted to heat resistance. Besides, these values are related to the impact in terms of energy savings and thermal comfort (Appendix 7). A conceivable way to quantify the latter, might be the productivity of employees (Appendix 7).

System components

- *Substrate.* The substrate is the most determining component in the thermal performance, through its characteristics in thermal conductivity and moisture content (Koch et al., 2020). First, the thickness of a substrate is key in the isolating capacity (Appendix 6). Besides, the porosity and moisture content of the substrate have an effect. During the winter, a substrate with a lower moisture content and a higher porosity is preferred (Appendix 6; Besir & Cuce, 2018). In summertime, however, a higher moisture content is preferred as it enhances cooling through evapotranspiration and isolation (Appendix 6, Bakhshoodeh et al., 2022). Organic soil has a higher moisture absorption capacity and a low porosity, compared to inorganic materials, such as mineral rockwool (Appendix 6).
- *Vegetation.* Besides, the plants also play a vital role in thermal regulation. In this context, the WLAI is the most determining factor (Koch et al., 2020). The higher the WLAI, the higher the cooling potential through shading as well as insulation. The isolation is enhanced by the formation of a stationary air in the foliage layer (expert interview). Evidence also shows that, when combined with a high WLAI, small-leaved species have a higher cooling potential (Charoenkit & Yiemwattana, 2017). Furthermore, plants with high leaf stomatal conductance (transpiration capacity) and thin and light color leaves provide better cooling (Monteiro et al., 2017). For green facades, Hedera and Stachys are suggested as the best plants regarding cooling potential (Cameron et al., 2014). For living walls, the several types of plants can be ordered in terms of transpiration rate as follows (from low to high): succulents – grasses – perennials – shrubs (Appendix 5).
- *Support system.* Finally, regarding the support system, the width of the air cavity has been related to thermal performance. A wider air gap increases thermal performance both through insulation and ventilation (Bakshoodeh, 2022; Besir & Cuce, 2018). This contributes to the fact that direct green façades have the lowest performance in terms of thermal regulation (Appendix 6).

Overall, living walls were found to have a significant better performance than green façades due to the substrate (Koch et al., 2020; Manso et al., 2021). Perini et al (2011a) researched serveral types of VGS in the Netherlands during autumn season. They found that the external wall surface reduction was 1,2 ^{o}C, 2,7 ^{o}C and 5 ^{o}C respectively for a direct green façade, an indirect green façade, and a living wall. In this case, the living wall system was a linear living wall system based on planter boxes. Additionally, it has been found that a LWS based on planter boxes has a higher energy saving potential for heating compared to the system based on felt (Koch et al., 2020; Perini et al., 2011b). Finally, it was found that modular LWS have a higher cooling performance compared to continuous felt systems as well (Koch et al., 2020). Finally, modular systems outperform linear systems in terms of evapotranspiration

(Appendix 6; Van de Wouw et al., 2017). The continuous living wall is considered to have a lower impact due to the thinner substrate compared to the other living walls. The linear system might have a higher performance in summer due to the moisture absorbing capacity of the soil, but in wintertime the modular system will have a higher performance due to the continuous layer of isolation.

Main takeaways – energy savings

The thermal regulation of VGS is mostly indicated by the temperature differences of the external wall. The impact can be monetized by the amount of energy savings. The substrate is crucial in thermal regulation on building level. Thicker substrates have a stronger isolating effect. Vegetation isolates to a lesser extent but contributes mainly through shading and evapotranspiration. The size of the air cavity also contributes to the isolating effect.

UHI mitigation

On the urban level, the cooling potential of VGS can improve the local microclimate by mitigation of the urban heat island (UHI) effect. The UHI effect refers to higher temperatures in urban areas compared to rural areas. This effect is caused by increased surface area for absorption of solar radiation, more anthropogenic heat sources, reduced ventilation within street canyons, increased longwave emission due to the polluted atmosphere, a lower albedo which results in more heat absorption and by reduced evaporation which results in higher levels of sensible heat flux (Wong et al., 2021). Greenery can mitigate the UHI effect by reduced heat absorption through higher albedo levels and by a reduction of sensible heat flux due to evapotranspiration. Although most studies on the thermal performance of VGS have referred to the mitigation of the UHI effect, this effect has been researched very limitedly compared to the building effect.

Quantitative data & potential indicators

The ΔT external wall, which was found a good indicator on the building level, is also relevant with regard to UHI mitigation. However, it cannot be used on its own (Ascione et al., 2020; Hoelscher et al., 2016). On the urban level, the ambient air temperature is often used as a key indicator. In addition, the air velocity and humidity or latent heat flux can be measured for a more complete picture (Appendix 6; Ascione et al., 2020; Susorova et al., 2014). The heat index was suggested as a possible aggregated indicator (Feitosa & Wilkinson, 2018). Studies that have been carried out on UHI mitigation by VGS show that the significance of this effect is debaTable. The limited extent of quantitative evidence shows mixed results.

For green roofs, which have been researched more abundantly than green walls, values for a reduced ambient temperature in the continental climate varied between 0.5 °C and 1 °C (Al-Kayiem, 2020). Additionally, a study by Alexandri & Jones showed that green walls have a higher effect than green roofs. In this study, green façades were found to reduce urban temperatures between 1 and 3 degrees in a Cfb climate. These results indicate a high potential of green walls in UHI mitigation. However, other studies did not find a significant difference in proximal ambient temperatures between a green and bare wall (Hoelscher et al., 2016; Paull et al., 2020). The reason that the effect is not found because it is directly absorbed in the wider air, which does not mean that there is no effect. However, a few considerations are important for the interpretation of the UHI effect:

Firstly, the case-study of Alexandri & Jones was executed during the hottest month of the year, with an average temperature of 18 °C. It must be noted that the effect is smaller under cooler conditions.

Secondly, in this case-study both sides of the street canyon were fully covered with green façades. However, it has been found that the UHI mitigation effect only occurs when VGS are implemented on a larger scale (Köhler, 2008). Therefore, it is likely that these results are not applicable when VGS are implemented on a smaller scale and should be interpreted very carefully.

Related to this, is that the effect is only felt at a very local scale. In the best situation, the effect was found to be sensible at a distance of 0.6 meter. In this study, executed in a tropical climate, a maximum reduction of 3.33 °C was found at 0.15 meters away from the façade. In order to effectively enhance UHI mitigation, it is therefore suggested that to combine different green infrastructures in areas where building occupants and pedestrians can benefit most (Wong et al., 2021). However, as distribution centers are mostly located on large plots and the building is often not directly attached to a recreational place, this effect might be less applicable to DC's.

Finally, there are some other conditions, such as urban geometry, which influence the urban cooling effect, which should be taken into consideration. It was found that the influence of the wind direction and canyon orientation is less important for the cooling effect of green wall compared to the vegetation itself (Alexandri & Jones, 2008). However, the canyon width is a significant factor that should be taken into consideration. The wider the street canyon, the weaker the UHI mitigation effect (Alexandri & Jones, 2008). As DC's are generally not located within dense urban areas with street canyons, this effect is not considered relevant within this context.

Main takeaways – UHI mitigation

For thermal regulation on urban scale, similar system components play a role as on building level. However, the impact is hardly measurable. Besides, the benefit of UHI mitigation is negligible in the context of most distribution centers.

4.2.2. Sound regulation

Noise pollution is an increasing problem, especially in urban areas, due to densification and increasing amounts of traffic. Environmental noise pollution can lead to serious health effects – cardiovascular disease, cognitive impairment, sleeping problems, tinnitus, or metabolic outcomes (WHO, 2018). Noise pollution in the urban environment is caused by various noise sources, such as road traffic, railway, aircraft, wind turbines and leisure (Yang & Jeon, 2020).

The building envelope affects the urban acoustic environment through reflection or absorption of sounds. The acoustic performance of building envelopes depends on the material and geometry. A textured or fragmented surface can reduce specular sound reflection. In combination with the use of sound absorbing building materials, these design principles can increase sound reduction. VGS can have similar acoustic benefits as such design principles (Yang & Jeon, 2020). VGS have a sound regulating function on the urban building level as well as on the building level (Ascione et al., 2021; Radić et al., 2021).

On the building level, VGS can decrease indoor noise pollution through a reduced sound transmission through the façade (Radić et al., 2021). On the urban level, the noise reduction by VGS the result of their absorption effect. The sound absorbing effect of VGS is mainly caused by physical-thermal absorption (Appendix 8). During this process, noise is transformed to heat by friction with the pores of a sound absorbing surface. Vegetation also improves urban acoustics through its visual effect and enhancing natural sounds, by creating a positive soundscape (Radić et al., 2019; Yang & Jeon, 2020). Although this effect is hard to quantify, quantitative interview data has evidenced that the sound scaping effect significantly reduces noise annoyance.

Quantitative data & potential indicators

Noise abatement can be measured in various ways. In an experimental setting, the urban noise reduction can be measured by comparing a scenario with and a scenario without a VGS or by the reverberation time (Appendix 8). However, due to the abundance of confounding variables these measures cannot be used for measuring in-situ effects. The most common indicator to measure the noise abating effect of VGS is the insertion loss (Yang & Jeon, 2020), which reflects the loss of signal power of a sound wave from the insertion into the green façade. Therefore, this indicator can be used for the effect on both levels. Besides, the insertion loss can be used to measure in-situ effects (Pérez et al., 2016). Vegetation on the building façade has an insertion loss of 5.0 – 9.9 dBA compared to 5.5. – 7.3 dBA for materials and geometry (Yang & Jeon, 2020). The range of insertion loss that is found for living walls is 0-10 dB with an average of 5.5 dB (Manso et al., 2021). As a reference, the recommended noise levels in residential environments generally range from 45 to 55 dB and the mean street noise level was 73.4 dBA (King et al., 2012; McAlexander et al., 2015).

Frequency levels are important with regard to the indication of noise annoyance. Urban background noise, such as traffic, aircraft, industrial machinery, and air movement machinery, are mostly low-frequency sounds (20-250 Hz). Humans can observe sound from 20-20.000 Hz (Berglund et al., 1996), with a higher sensitivity around in the speech domain (1000-3000 Hz) (Appendix 8; Olman, C., 2022). Therefore, dBA assigns different weights to frequencies around different sound bands. However, when measuring sound reduction, it is important to take the frequency levels into account as the noise mitigating of VGS varies among different frequency levels (Pérez et al., 2016; Wong et al., 2010). Accordingly, the insertion loss of VGS can be expressed in dB as well. The differences of noise mitigation among the different frequency levels are directly linked to the system components.

System components
Differences in the noise abating between VGS mainly depend on the vegetation type and the growing media (Yang & Jeon, 2020). The substrate is the most important system component in sound reduction and can be responsible for up to 80% of the noise reducing effect (Appendix 8).

- *Substrate.* Regarding the substrate, the thickness, porosity, and moisture content were found to be the main factors for the sound regulating performance of VGS (Radić et al., 2019). The absorption effect of the substrate is mainly determined by its porosity, which also relates to the moisture content. The lower the moisture content and the higher the porosity, the higher the absorption effect. For the reduction of noise transmission into the building, the thickness of the system is the most important (Appendix 8).
- *Vegetation.* Wong et al., (2010) found that the absorbing effect of the substrate at low to middle frequencies is more dominant than the effect at high frequencies, which is related to the scattering effect from the vegetation. With regard to the vegetation, the density and thickness of the foliage (WLAI) is crucial to the sound reducing performance (Horoshenkov et al., 2013; Pérez et al., 2016; Wong et al., 2010). Besides, Horoshenkov et al. (2013) identified the leaf area density and the angle of leaf orientation to be the main morphological factors for noise reduction. Plants with large leaves and a low water need – shade loving plants – have the highest potential in sound reduction (Appendix 8).
- *Support system.* The support system has an effect through the size of the air cavity between the system and the wall. A larger cavity increases performance of lower sound frequencies can be absorbed. Finally, the irrigation system can have an effect by the distribution of water, which also depends on the porosity. However, this effect can be considered negligible (Appendix 8).

Similarly, living walls also have a substantial higher potential in noise reduction because of the substrate (Appendix 8). However, an experimental study by Pérez et al. (2016) showed a better soundproofing performance for a double-skin green façade compared to a living wall. A 1 dB reduction was found for traffic noise among both systems, but for pink noise the living wall resulted in 2 dB reduction, while the green façade performed a 3 dB reduction. The difference was ascribed to difference in vegetation as the green façade had a broadleaved plant and the living wall had a small leaved shrub. Contrarily, Attal et al. (2019) found, with a standardized system thickness, that a green façade and continuous living wall had an average absorption coefficient of 0.2 compared to 0.9 for a modular living wall. An expert classified the performance of the different system as follows: The modular living wall has the highest potential in terms of noise reduction as it allows for a thick layer of porous growing media and an evenly distributed layer of vegetation (Appendix 8). A continuous living wall was considered to have a lower performance due to the other living walls due to the thin substrate layer. The performance of a linear living wall depends on how the planters are situated but allows for a thicker layer of porous material compared to the continuous system. With regard to the green façades, the indirect system is considered to have a slightly better performance due to the air cavity.

Main takeaways – sound regulation
VGS have potential in urban noise reduction on urban and building scale. The porosity and thickness of the substrate are key. Besides, a thicker foliage layer with a high porosity can contribute. The size of the air cavity also plays a role, especially for lower frequencies.

4.2.3. Storm water management

VGS are also considered to improve (storm) water management (Manso et al., 2021). The storm water management of nature-based solutions relates both to the retention as well as the purification of rainwater runoff (Orta-Ortiz & Geneletti, 2021). However, research focused on the impact of VGS regarding this specific service is scarce. Experimental evidence for the benefits related to storm water management was not found at all (Ascione et al., 2020).

Water retention

VGS are found to be effective as urban drainage systems (Lau & Mah, 2018). The systems reduce surface runoff by retaining water from the roofs that percolates through the system (Lau & Mah, 2018; Sheweka & Magdy, 2011). Among the ecosystem services related to water management, this effect stands out in an urban sustainable context (Pérzez & Coma, 2018). However, the amount of research on water retention that is specifically focused on VGS is limited. The water retaining impact of VGS is two-fold: the retention of storm water during extreme weather events and the reduction of regular runoff flows to the sewage system (Appendix 9).

Quantitative data & potential indicators
With regard to storm water management, it was found that a green wall can reduce runoff by 55%. This effect was found for a simulated situation with an average recurrence interval of 1 year and a 5-minute duration of the storm (Lau & Mah, 2018). When locally observed rainfall data were used to test the effectiveness, it was found that the water retaining performance reduces with a higher rainfall intensity and duration. The average runoff reduction gradually reduced from 87% to 52% for an increasing average rainfall intensity from 2.0 to 42.5 mm/h. These results were found for a modular living wall in a tropical climate. For green roofs, it was found that the storm water retention in tropical climates the water retention capacity was significantly lower than in drier climates due to substrate saturation and air humidity (Manso et al., 2021). These values might therefore be conservative for the Dutch context.

The effectiveness of a green wall as an urban drainage system can be measured by the hydrologic performance, which shows the runoff deviation with integration of a VGS (Lau & Mah, 2018). A key indicator to assess the impact is the water collection capacity in m^3/year (Appendix 9). The impact can be expressed monetarily, by calculating the avoided purification costs. A more advanced method for monetization, to specifically express the impact with regard to storm water management, is the reduction of damage costs. To do this, the water collection capacity is translated to the flood reduction. Subsequently, the reduced damage costs can be calculated using local damage models (Appendix 9).

In order to assess the impact of a system, it is important to define the objective: runoff reduction or storm water retention. The impact on storm water management is mainly determined by the water storage capacity of the system. For the overall impact on runoff reduction, the evaporation capacity of the system should be guiding (Appendix 9). The evapotranspiration rate of the system is equivalent to the runoff reduction (Pérez & Coma, 2018; Roehr & Laurenz, 2008). The effect of green façades is considered to be minimal when the climbers are planted directly in the ground (Appendix 9). When they are placed in a planter box, they do have impact. In this case, the water retention capacity is determined by the size of the planter box (Appendix 9). With regard to living walls, linear systems perform better in terms of water collection capacity than modular systems (Van de Wouw et al., 2017). The water collection capacity, expressed in the capacity of a vertical m^2 as an equivalent percentage to a horizontal m^2, was on average in 18.8% for the modular and 33.0% for the linear system. Contrarily, in terms of evapotranspiration rate, the modular system had a higher performance (Van de Wouw et al., 2017).

System components

- *Substrate.* For green roofs, which have a comparable water-retention process to VGS (Loh, 2008), the substrate was found to be the key factor (Berndtsson, 2010). The water retaining capacity of the substrate depends on various substrate characteristics: the thickness, degree of saturation, composition, and pore volume (Manso et al., 2021). According to Gert-Jan Wilbers, the dimension of the substrate is thé defining factor for the water retaining capacity (Appendix 9). A higher water retaining capacity is achieved for substrates with a higher organic matter content and a higher porosity, which both increase with age (Berndtsson, 2010; Getter et al., 2007; Speak et al., 2013). For VGS in specific, growing media with a higher porosity or void between the soil particles have a higher water infiltration rate (Lau & Mah, 2018). The effectiveness of a substrate can be indicated by the saturated hydraulic conductivity or the evapotranspiration rate (Mah & Lau, 2018; Pérez & Coma, 2018).
- *Vegetation.* The storm water management is also related to the due to the evapotranspiration capacity of the plants. Although the evapotranspiration was mainly associated to the regular runoff reduction (Appendix 9), it can be stated that plants with a higher evapotranspiration rate also increase the water retaining performance (Berghage et al., 2017; Pérez & Coma, 2018; Roehr & Laurenz, 2008). This effect is the greatest for the first 5 days after a rain event, when the plants can increase the capacity with more than 40%. They suggested that more research is needed to examine the potential of different plant species with regard to water retention in detail. However, it has been found that a thicker plant layer as well as plant species with taller heights, larger diameters, and larger shoots and roots of biomass enhance the water retention (Nagase & Dunnet, 2012; Teemusk & Mander, 2007). Thus, when comparing grasses, shrubs and sedum, grasses have the highest water retaining performance and sedums the least (Nagase & Dunnet, 2012). However, not all studies show a significant effect of vegetation. Therefore, it can be concluded that the effect of plants is of much less importance than the substrate (Berndtsson, 2010).
- *Irrigation system.* Finally, the use of rainwater reduces the costs for irrigation (Appendix 9). As the dependency of VGS on water supply is an important barrier for deployment, strategies to enhance irrigation by rainwater were considered promising (Pérez & Coma, 2018). An example of such a strategy is to connect VGS with nearby roofs that have a water retaining capacity. However, when the system is designed to be fully dependent on rainwater, it is important to select plant species that are resilient and that can survive under dry as well as wet conditions (Appendix 9)

Main takeaways – stormwater retention

VGS positively contribute to storm water management in two ways: water retention and runoff reduction. The dimension of the substrate is crucial in performance of storm water management, followed by porosity. The transpiration rate is specifically important for runoff reduction.

Runoff quality control

Most research on the storm water management potential of VGS is related to the purifying function (Orta-Ortiz & Geneletti, 2021). As storm water percolates through the substrate, VGS increase runoff quality via filtration, sorption, and biodegradation of storm water. This process only relates to the upper part of the substrate, which means that the purifying potential is not impacted by the height of the wall. Although VGS have the potential to absorb rainwater pollutants, it has been found these systems also negatively impact the runoff quality by leaching pollutants (Hachoumi et al., 2021). Overall, this risk is the highest for substances with low soil–water partitioning coefficients (logKoc) and a high water solubility. Research on green roofs showed that these systems are effective in the removal of NH_4^+-N and the neutralization of the pH of rainfall (Zhang et al., 2015). On the other hand, such systems were found to be a source of NO_3^--N, K^+, Si_4+, Ca_2^+, TOC and Dal in runoff.

System components

The leaching as well as the absorption of pollutants is affected by the type and properties of the materials that are used for the VGS (Hachoumi et al., 2021). Optimizing the system with regards to these properties is a form of mitigation-at-source to prevent runoff pollution. With regard to the water purifying function of VGS, most research is actually related to greywater treatment (Ascione et al., 2020).

- *Substrate.* The negative effect of VGS on runoff quality is mainly related to the soil substrate (Zhang et al., 2015). The type of substrate and the use of fertilizers influence the nitrogen concentration in the runoff. Higher levels of organic matter in the soil are related to higher concentrations of nitrogen as well as TOC (total organic carbon) and COD (chemical oxygen demand) in the runoff (Berndtsson, 2010; Zhang et al., 2015). An inorganic lightweight substrate material is the best to minimize the release of pollutants (Berndtsson et al., 2009).
- *Vegetation.* Overall, non-climbing plants are more effective in pollutant removal compared to climbing plants (Pradhan et al., 2019). With regard to non-climbing plants, *Carex appressa* and *Nephrolepis obliterata* are considered to be the best performing plant species with regard to nitrogen ánd phosphorus removal (Addo-Bankas et al., 2021).
- *Support system.* The support system can be optimized to diminish runoff pollution (Hachoumi et al., 2021). The use of coated materials can significantly decrease the release of pollutants. Moreover, the type of coating material also has an impact.

Due to the mixed results of both pollutant removal and pollution, VGS should, similarly to green roofs, not be seen as a runoff quality improvement measure (Berndtsson et al., 2009). Therefore, this ecosystem service was not further taken into consideration.

Main takeaways – runoff quality control

VGS have a water filtrating function, but also cause leaching of pollutants in the sewage system. Due to this mixed effect, VGS cannot be considered a measure to improve water quality.

4.2.4. Greywater treatment

Vertical greenery systems can also be implemented as greywater filtration systems. In this context, green walls are a form of a constructed wetland, which is considered efficient and environmentally friendly systems for wastewater treatment (Rahman et al., 2020). Various mechanisms, such as sedimentation, adsorption, filtration, precipitation, and biodegradation, play a role in the purification process (Pradhan et al, 2019).

The integration of a biofilter column is needed to use VGS for greywater treatment. This can be achieved by using a specific filtering media as substrate. In the case of green façades, greywater treatment requires the use of planter boxes for the climber plants (Fowdar et al., 2017). For living walls, greywater treatment requires a biofilter column within the support system or the selection of specific filter media as substrate (Svete, 2012; Rysulova et al., 2017).

Quantitative data & potential indicators

The performance of VGS in greywater treatment can be measured by removal efficiencies (%) and removal rates for total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), phosphorus (P) and nitrogen (N) and Escherichia *coli* (Addo-Bankas et al. 2021; Prodanovic et al., 2017). A clear trade-off was found between the removal efficiency and the removal rate (Prodanovic et al., 2017). Available data on the removal efficiency is given in Table 6. For a qualitative removal efficiency, the removal rate for different plants was found to be under 110 mm/day (Pradhan et al., 2019).

System components

The greywater treatment performance is mainly determined by the substrate and the vegetation. Although Pradhan et al. (2019) considered the role of vegetation and the substrate to be equally important, Addo-Bankas et al. (2021) stated that the substrate is the principal factor in greywater treatment. Anyhow, it can be stated that the substrate is a key factor in the greywater treatment.

- *Substrate.* a specific filtering media is needed for greywater treatment. Various substrate characteristics were related to the treatment performance, such as the resistance to clogging, moisture content and bed height (Addo-Bankas et al., 2021). Besides, a key factor is the hydraulic loading rate or retention time of the substrate (Prodanovic et al., 2017). Slow filtering media – media with a longer retention time - have a higher removal efficiency for most pollutants (Table 6). The smaller grain size of slow media is associated with a longer retention time and a higher surface area for treatment (Prodanovic et al., 2017; Svete, 2012). However, slow filtering media are very prone to clogging (Prodanovic et al., 2017). The high porosity of fast media avoids clogging. Besides, fast media obviously have a higher removal rate. Therefore, a mix of filtering materials is suggested, in order to achieve a balance between porosity, density and physical-chemical interactions, is ideal (Pradhan et al., 2019). The type of media is also of profound influence. Perlite was found to be the best performing fast media and coco coir is the best option of slow media (Prodanovic et al., 2017). Besides, the addition of biofilm as well as the use of biochar was found to enhance the treatment performance (Addo-Bankas et al., 2021; Pradhan et al. 2019). With regard to the bed height, it was found that 80% of COD was removed in the upper 100 cm and a limited additional removal for greater depths (Svete, 2012). On the other hand, the nitrification process, for which a bed height of 20 cm was earlier found sufficient, mainly started after 100 cm. This might be related due to the heigh organic loading rate (COD). Thus, for substrates with high organic loading rate, a deeper substrate can be used to support nitrification (Svete, 2012). Finally, the addition of a geotextile layer to a filtering media was found to only have a trivial effect on removal efficiency (Svete, 2012). Since aeration of the substrate can increase removal rates, linear living walls might have a lower performance compared to modular and continuous living walls. On the other hand, continuous living walls have a greater substrate depth. For each type of system, optimization of the hydraulic loading rate is key. This is the easiest for modular and linear living walls.
- *Vegetation.* Plants have minor impact compared to substrate and microbes for TSS, BOD, COD (Addo-Bankas et al., 2021; Pérez & Coma, 2018). On the other hand, for the removal of nitrogen and phosphorus plants do have a considerable influence. It was found that ornamental species can play a role in water purification. Regarding nitrogen removal, a wider range of plants are effective, while only a few species are effective in phosphorus removal, of which *Carex appressa* and *C. lilies* perform the best (Fowdar et al., 2017). *Carex appressa* is also more effective in nitrogen removal than traditional biofilter species.

Table 6
Average removal efficiencies for fast and slow filtering media.

Indicator	**Values**	
Avg. removal efficiency (%)	*Slow media*	*Fast media*
TSS	90%	80%
TN	50%	30%
TP	30%	15%
COD	70%	30%
E. coli	80%	20%

Note. Based on Prodanovic et al. (2017).

Main takeaways – greywater treatment
Earlier research on the integration of greywater treatment in VGS indicates high removal efficiencies as well as high potential for sustainable urban development (Addo-Bankas et al., 2021; Boano et al., 2020; Liu et al., 2018; Pradhan et al., 2019). The key element for the performance is the hydraulic loading rate. However, the empirical evidence is still limited. Most studies are still on a lab-scale or other small-scale and there are no studies that have tested greywater treatment on larger, or industrial buildings (Liu et al., 2018).

4.2.5. Weathering control: increased lifespan of the building façade

Another regulating benefit of VGS, is the reduction of climatic effects on the building façade (Radić et al., 2019; Rosaco & Perini, 2018). Façades wear out due to the effects of, among others, solar radiation and rain (Appendix 6). By reducing weathering effects, VGS can prolong the lifespan of the building façade and subsequently decrease maintenance costs for the façade. The degree to which a VGS protects against these effects is depends on the system. However, the performance of different systems is hard to measure as the effect depends on numerous factors.

The best approach to measure performance is a binary assessment: whether a system is or is not capable of extending maintenance of the façade with 25 years (Appendix 6).

System components

- *Support system.* With regard to the system, the wall coverage is most important. If the support system consists of waterproof panels is separated by an air cavity, façade protection is ensured (Haggag, 2010). For continuous and modular living walls, the support system facilitates a 100% protection, and these systems are therefore successful in prolonging the lifespan of the façade (Appendix 6). It has been stated that linear living walls have a lower performance in protecting the façade as the system does not form a protecting layer around the façade (Appendix 6).
- *Vegetation.* The shading effect of plants can also contribute to the lifespan of the façade as it limits the diurnal fluctuation of surface temperatures (Wong et al., 2010). On the other hand, plants can also have a damaging effect on the façade which is often mentioned as a negative side-effect of green façades. Although evidence suggests that this effect is often exaggerated and modern building façades are resilient to the plants, it is still a critical point of consideration for the implementation of direct green façades (Johnston & Newton, 2004). Especially when the plants are implemented on an older façade, deterioration by plants might be a potential risk. As this is not the case for an indirect green façade due to the space between the system and the façade, this system is considered to have a better performance in terms of façade protection (Appendix 6).

When considering the extension of façade maintenance as a potential benefit, it is also important to consider the lifespan of the system. Direct green facades are the most sustainable option (Perini et al., 2013). With regard to indirect green façades, metal support systems have a longer lifespan than wooden structures. However, when moisture absorbing and well-growing plants are used, wooden support structures can perform as good as metal systems (Appendix 6). For living walls, the lifespan makes a significant difference. Continuous living walls based on geo-textile felts have a lifespan of 10 years, while modular living walls that are built up from HDPE last 50 years (Perini et al., 2013). Therefore, it can be concluded that the modular living walls have the highest potential in terms of façade protection. However, there were no major differences in the financial savings between systems that prolong maintenance with 10 or with 15 years (Rosaco & Perini, 2018).

Main takeaways – weathering control

VGS can enhance the lifespan of the building façade, which can be indicated by the ability of a system to prolong façade maintenance up to at least 15 years. The level of wall coverage of a system is the key variable in terms of performance.

4.2.6. Air quality

Quantitative data & potential indicators

VGS are considered to have a high potential in removing urban pollutants (Jayasooriya et al., 2017). Although trees are considered the most important and effective strategy for air pollutant removal, VGS can have a substantial complementing role to other urban green infrastructure (Currie & Bass, 2008; Jayasooriypa et al., 2017). Important urban pollutants are, among others, ground-level ozone (O3), nitrogen dioxide (NO2), particulate matter less than 10 µm in diameter (PM10), sulfur dioxide (SO2) and carbon monoxide (CO) (Manso et al., 2021). In combination with other green infrastructures, VGS were found to contribute to the removal of these pollutants by as much as 11,7%–40% of NO2, and 42%–60% of PM10, 40% O3, 3,5% SO2, 1,34% CO and 1,34% PM2.5 (Manso et al., 2021). These pollutants are mainly caused by road and air traffic as well as the concentration of industries. Therefore, the removal of these pollutants is also explicitly relevant in the context of Dutch DC's.

In this context, VGS especially have a high potential with regard to the removal of NO_x. High levels of NO_x provide a serious health threat (De Vries, 2021), which has even led to a nitrogen crisis in the Netherlands. The variety of restrictions and policies that are put in place to limit emissions, also have a negative effect on distribution centers (Verbraeken, 2019). VGS were found to have a high potential in the removal of NO_x, higher compared to both green roofs as well as planar vegetation (Pugh et al., 2012). A green wall coverage of about 50% was considered enough for an street urban canyon to remove an equal amount of NO_x as a regular green space.

VGS were also found to have a high potential in PM removal. The PM deposition consists of various mechanisms: impaction, resuspension, sedimentation, diffusion, and interception.

The relevant processes are different for the different PM size fractions. It has been outlined that the main mechanisms are impaction and deposition (Appendix 6). Deposition is the result of gravity and is also influenced by the wind speed. High wind speed inhibits deposition. Accumulation rates of 10^{10} to 10^{11} particles per m^2 leaf area were found along a high intensity traffic road (Ysebaert et al., 2021). However, these simulated findings may have overestimated the in-situ effects (Paull et al., 2020). Peak concentrations for $PM_{2.5}$ can be reduced up to 71.4% (Viecco et al., 2018).

Finally, VGS also improve air quality through a reduction in carbon dioxide. Not only do by a reduction in carbon emissions through energy savings, but also through carbon sequestration (Besir & Cuce, 2018). An annual accumulation of 0.99–0.14 kg carbon/m^2 was found for VGS (Marchi et al., 2015).

The performance of air quality control by VGS is usually assessed by two types of approaches: an estimation of the pollutant deposition or the calculated difference in the pollutant concentration values (Manso et al., 2021). The level of deposition can be expressed by the deposition density (m^{-1} s^{-1}) (Ysebaert et al., 2021).

Table 7

Available quantitative data for air quality control

Indicator	Values
Carbon sequestration (kg carbon/ m^2/ year)	Min. 0.14, Max. 0.99.
PM accumulation rate (particles/ m^2 leaf area)	Min. $10^{10,}$ Max. 10^{11}

Source. (Marchi et al., 2015; Ysebaert et al., 2021)

A widely recognized model for the estimation of greenery effects is i-Tree Eco. In this model, the air pollutant removal for a specific location can be calculated by the annual removal of a pollutant in kg/year (Jayasooriya et al., 2017). Overall, most authors use the level of dry deposition, which although it does not explicitly provide the impact in improved air quality, is considered a good indicator (Manso et al., 2021). The reduction of carbon dioxide can be expressed by the level of carbon sequestration in kg carbon/m^2/year.

System components

- *Vegetation.* The air pollutant removal function of VGS mainly relates to the vegetation (Appendix 6). By their surface enlarging capacity, plants have potential in enhancing the deposition capacity. Besides, plants act as natural air filters through the uptake of air for photosynthesis by the leaves stomata (Jayasooriya et al., 2017). As the leaves are responsible for the air filtration, the use of evergreen species is preferred (Jayasooriya et al., 2017). Besides. the deposition rate depends on more specific plant characteristics: vegetation density, porosity, leaf morphology and micromorphology (Jayasooriya et al., 2017; Weerakkody et al. 2018). First, a higher porosity of the foliage layer enhances the potential by increasing the amount of stationary air, which allows for deposition (Appendix 6). Secondly, a higher LAI increases the deposition capacity. Related to this, smaller-leaved species are preferred (Jayasooriya et al., 2017; Weerakkody et al. 2018). Finally, more specific plant characteristics play a role. Finally, although the effect of micromorphology is not entirely understood yet (Ysebaert et al., 2021), it can be stated that more hairy leaves with a rougher surface enhance deposition of PM (Appendix 6). For gaseous pollutants, conversion capacities for specific pollutants come into play. For example, in areas with high nitrogen levels plants with a higher nitrogen conversing capacity can be used (Appendix 6).
- *Support system.* With regard to green roofs, it was found that deeper substrate depths enhance air pollutant benefits by allowing for plants with greater biomass (Rowe, 2011).

Overall, research on the impact assessment of VGS in terms of air quality benefits is limited. Therefore, it was stated that "more studies are needed which compare how various types of VGS constructions (consisting of different supporting constructions, soil types, and plant species) could contribute to improvements in air quality and to suggest which VGS types serve this purpose best in which environment and climate region" (Radić et al., 2019, p.18). However, compared to the vegetation, the type of system is of negligible relevance (Appendix 6). Thus, theplant type should be specifically considered to enhance air pollutant removal.

Main takeaways – Air quality
VGS have high potential in regulation of urban air quality. The most important aspect of a system is the vegetation. A thick foliage layer with high porosity is preferred. However, more research is needed to compare systems.

4.2.7. Increased PV performance

Although implemented and researched very limitedly, VGS can be combined with PV panels. With regard to green roofs more research is executed. This research has proven that the combination with greenery increases performance of PV panels (Manso et al., 2021). Under extreme temperatures, this effect was also found for PV panels in front of green walls (Moren & Korjenic, 2017). In this study it was found that the VGS can reduce PV operating temperatures from 1 to 4 degrees Celsius.

System components
Zluwa & Pitha (2021) did research on design consideration for the combination of building greenery and photovoltaic energy production. With regard to green roofs, they found that in order to avoid shade on the panels, shallow substrates and low growing plants are required. Besides, as the cooling effect of the greenery on the PV panels depends on the gap between both, a minimum distance of 60 cm between the panels and the substrate was recommended. Moreover, the cooling effect is a result from evapotranspiration of the system. Therefore, the moisture content of the substrate was found to be important and a VGS without or a dry substrate does not have an effect (Zluwa & Pitha, 2021). In relation to this, although the effect might be marginal, plants with a higher transpiration capacity would be preferred.

Main takeaways – PV Performance
VGS can enhance the performance of PV panels on the façade. This requires a shallow system, a gap between the system and the panels. The effect is mainly related to the evapotranspiration capacity.

4.3 Assessment of the provisioning services

4.3.1. Food provisioning

VGS might also have a potential role in addressing food security in the urban context by providing a vertical edible landscape in high-rise buildings (Prihatmanti & Taib, 2017). Integrating crops in VGS can have added value by increasing the vegeTable consumption, decreasing the emissions of fossil fuels for transportation, minimizing use of pesticides and by reducing expenditures on food and vegeTables. However, the potential is concerned with a variety of side-factors, such as plant type, climatic conditions, maintenance, and pest issue.

Quantitative data & potential indicators
The performance of a VGS in urban food provisioning can be expressed by the yielded in mass or produced value per year (Bustami et al., 2018). A pilot study on living wall found a potential yield of 7,44 kg/m2, which represents a value of $70.3/m2 (Nagle et al., 2017).

System components
The potential of food provisioning was found both for green façades as for living walls with perennials. On green façades, various types of gourds, beans and vines can be used to facilitate food provisioning (Prihatmanti & Taib, 2017). Integrating urban food production in living walls has worked well with basil, chives, cilantro, collards, dill, Asian leafy crop, mustard greens, radishes, salad mix, sugar snap peas, swiss chard, cherry tomatoes, hyssop, thymes, raspberries, and strawberries, along with other perennial plants (Mårtensson et al., 2016; Nagle et al., 2017). However, the success of these species was specified for the Dutch climate. In general, it can be stated certain types of shrubs and perennials

allow for food provisioning, but that for systems that are vegetated with grasses or succulents this service is never applicable (Appendix 5).

Main takeaways – Food provisioning
VGS can be used to produce food. However, the impact is considered to be limited. Besides, more research is needed to evaluate the distinct systems.

4.4 Assessment of the cultural services

4.4.1. Aesthetic value

The aesthetic value is the most important factor for implementing a VGS (Juszczyk & Zima, 2018). Aesthetic value, or beauty, can be defined and understood in multiple ways. In earlier research, three categories have been identified: enjoyable, admirable, and ecological beauty (Sutton, 2014). Where enjoyable beauty describes beauty from a subjective and sensory-based perspective, admirable beauty gives an objective, normative understanding from an artistic perspective. However, both types of beauty were considered too shallow. Ecological beauty provides a more holistic understanding of beauty, which integrates the subject, object, and its context. In order for VGS to provide aesthetic value, it is therefore crucial that it must be seen and experienced (Thayer, 1989). Aesthetic value is therefore mostly expressed qualitatively, by means of interviews with questions on the perception of green (Appendix 10).

Quantitative data & potential indicators
However, it was found that, regarding the validity of valuing the aesthetics of VGS, the aesthetic judgement is influenced by its functional performance rates (Arch & Iranfar, 2019). Due to this complex interaction between the user, the system and the landscape, ecological beauty can never be entirely understood (Sutton, 2014). Therefore, measuring the aesthetic value is complex.

There are four main principles of architectural design, which also might be useful in the evaluation of VGS (Appendix 10): 1. Unity, 2. Balance, 3. Enclosure and 4. Rhythm. Unity in landscape design enhances a feeling of safety and familiarity. The balance in composition, in terms of, for example quantity, unity, rhythm and surprises, is key. Enclosure might be less relevant with respect to VGS and refers to a defined space with clear boundaries. Rhythm refers to the predictability of a pattern.

Building level

VGS can be implemented on a building with different intentions. For example, the framing of a building within the urban context, the advertisement of a particular company or to add identity/mark distinction of a certain building (Manso & Castro-Gomez, 2015). However, these intentions are hard to translate to measurable KPI's. Moreover, there is no direct effect of building greenery on organizational image (Rashid, 2012). With regard to property value, however, a positive effect is proven (Perini & Rosaco, 2013). It has been found that property values functions as proxy for indicating the aesthetic benefits on a building level (Hernández-Morcillo, 2013). It is considered as one of the most qualitative indicators of cultural ecosystem services (Hernández-Morcillo, 2013). The impact of VGS on the real estate value is three-fold: it contributes to enhanced building aesthetics, reduced pollution, and an increased greenery level (Perini & Rosaco, 2013). Table 8 shows the aesthetic benefit of increased property values for different VGS. Overall, it was found that VGS can increase the real estate value with 2-5%. However, the value for industrial buildings was significantly lower compared to other buildings. A survey among real estate engineers and professionals showed that 88% estimated a *property value increase* between 0-4%, with a weighted average of 2,3% (Rosaco & Perini, 2018).

Urban scale

The aesthetic value of VGS is mostly related to the building scale (Appendix 10). However, the aesthetics have been related to an increased landscape value as well (Manso et al., 2021). Where the aesthetic value of VGS can be expressed quantitatively on a building scale, the landscape value has not been expressed quantitatively yet (Perini & Rosaco, 2013). It was found that areas with non-monetary values, such as natural beauty, are valued higher by respondents (Klain & Chan, 2012). Therefore, it is also important to value sites by reasons besides income generation. A universal method to measure landscape aesthetics is the scenic beauty estimation (SBE). SBE is a popular method that is considered accurate to quantify human preferences with regard to landscape management (Zhang et al., 2012). Additionally, it was found that landscape aesthetics can be objectively qualified by aggregating the Shannon's Diversity Index, the Shape Index, and the Patch Density (Frank et al., 2013). Another study quantified landscape aesthetics by subjective indication of the naturalness and terrain roughness (Brandt et al., 2014). Thus, various indicators have been identified to value landscape aesthetics. However, there is no data available yet for the value of VGS on the urban scale.

Table 8.
Increased property values

Aesthetic effect	Values		
Context-specific increased property value (€/year)	*Direct GF* Avg. 962, Min. 577, Max. 1264.	*Indirect GF* Avg. 962, Min. 577, Max. 1264.	*Living wall* Avg. 1690, Min. 1869, Max. 2036.
Increased property value (%)	Avg. 2.3% Min. 0% Max. 4%		

Note. Based on (Perini & Rosaco, 2013) & (Perini & Rosaco, 2018).

System components

The aesthetic value is related to the composition of the system (expert interview). The system components allow for differentiation in composition.

- *Vegetation.* The vegetation is the most important system component in composition (expert interview). The aesthetic effect of specific plant characteristics, such as color, blooming and foliage type, depends on the particular design-relate dintentions of the building (Manso & Castro-Gomez, 2015). However, a few generic conclusions are possible. Overall, ornamental resources, such as flowers, are considered to serve aesthetics (Layke, 2009). Besides, a higher plant variety was related to a higher aesthetic potential. The variety in plants requires adequate irrigation and nutrient suppletion, which can be facilitated by hydroponic systems. Moreover, appropriate irrigation as well as regular maintenance are key to plant health, which is a requirement for the aesthetic performance (Bustami et al., 2019). The survival rate is therefore a relevant parameter for the selection of plants for aesthetic benefits. Besides plant variety and plant health, color and density aspects of vegetation also affect the aesthetic value. Plants with high density and good color freshness were found to enhance the aesthetic value (Sulistyantara & Sesara, 2017). Finally, biodiversity and wilderness might enhance to a certain extent by increasing a sense of naturalness (expert interview). However, it was found the presence of spiders and spider webs reduces the aesthetic value (Bustami et al., 2019). However, these are positively related to the habitat supporting services of VGS. Therefore, it is suggested to apply regular maintenance including the removal of visible webs in the plants while maintaining those in the growing media or planter boxes (Bustami et al., 2019).

- *Support system*. The support system is related to aesthetics as it can be used to create a pattern (Appendix 10).

With regard to the selected systems, there is a gradient between more artificial and natural systems (Appendix 10). Green façades are more natural, which is related to aesthetics by getting close nature. On the other hand, living walls facilitate the design of an interesting pattern on the wall, for example by the planter boxes. This is another way of aesthetics, which is more related to artistic instead of natural value. Finally, VGS might enhance urban aesthetics as they prevent against graffiti (Appendix 7).

Overall, the aesthetic effect of living walls is reported to be higher (Collins et al., 2017; Manso & Castro-Gomez, 2014). These systems allow for an artistic composition due to the possible differentiation in plant species, exploring the use of patterns, variations in color, texture, foliage forms and density, vitality, and growth. However, it should be noted the desired effect is context-specific. It depends on the design of the building as well as the preferences of local stakeholders. The best way to evaluate different systems is therefore by showing visualizations to designers and, more importantly, to local residents (Appendix 10). Finally, the level of maintenance should also be considered as bad maintenance can lead to negative aesthetic effects (Pérez-Urrestarazu, 2015).

Main takeaways - aesthetic value
The aesthetic value is considered an important service of VGS. The aesthetic value of a system is subjective and depends on the context. The composition is mainly determined by the vegetation. Principles such as unity, balance, enclosure, and rhythm can be used in the design. On building level, the impact can be indicated by the increase in property value. On urban level, more research related to measuring the aesthetic value is needed.

4.4.2. Education

Education is one of the cultural ecosystem services. In the context of forests for example, *spatial accessibility of environmental educational-related forest facilities in a specific region of investigation* in people/ha, is used as an indicator to assess the educational benefit (Tiemann & Ring, 2022). However, Radić et al. (2019) concluded in their review that the knowledge on the educational benefits of VGS in specific is scarce. Based on a limited number of studies, it can be concluded that VGS can contribute to education, by providing a physical tool to teach about the environment, biology, art or environmental science, when they are implemented on or in the nearby environment of a school. VGS might also have a broader educational effect by raising environmental awareness among viewers, which would increase relevance in the context of Dutch DC’s. However, more research to gain understanding in the impact assessment of the educational service of VGS.

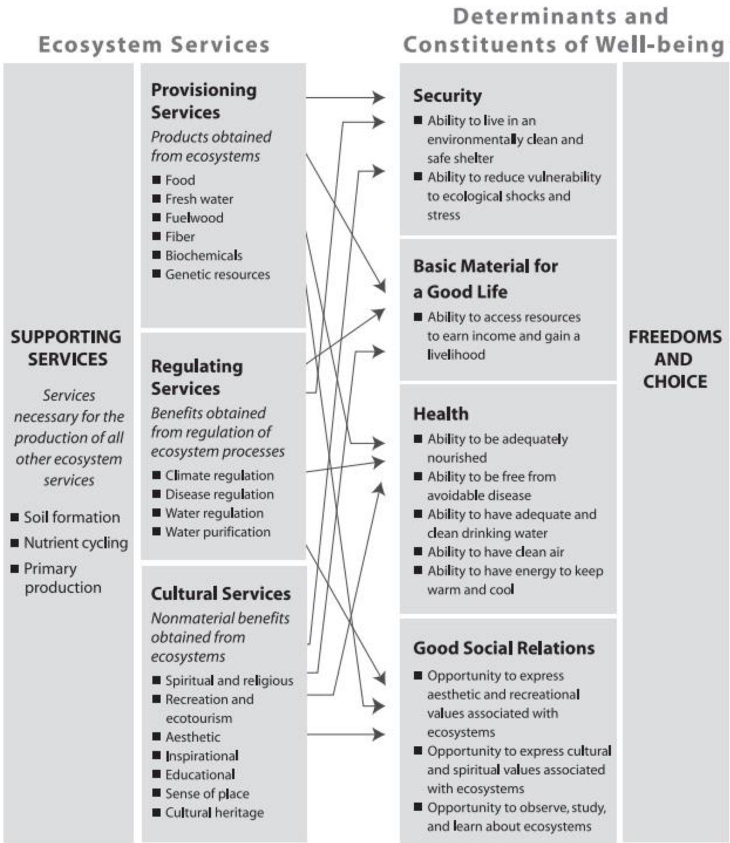
Main takeaways - education
VGS might have an educational value. However, more research is needed to understand this impact.

4.4.3. Health & Wellbeing

The link between the ecosystem services and human health is often mentioned, but hardly understood (MEA, 2005). In order to facilitate decision-making, the founders of the ‘ecosystems services’-concept have developed a framework on the links between ecosystem change and human wellbeing (Figure 5). The main constituents of wellbeing were outlined as: security, basic material for good life and good social relationships. The regulating, provisioning and cultural ecosystem services have a direct positive effect on these constituents. For example, thermal regulation can decrease heat stress-related mortality and increase sleep quality (Besir & Cuce, 2018). In turn, these aspects of wellbeing impact and are impacted by freedom and choices, which also determines wellbeing. According to this framework, the ecosystem services can be seen as a mechanism towards improved health & wellbeing. From this perspective, health benefits of VGS should not be considered as an ecosystem service.

Figure 6

The links between Ecosystem Services and Human Wellbeing



Note. Source: (MEA, 2005).

However, researchers have also suggested a more direct relationship between ecosystem changes and health. Sheweka & Magdy (2011), for example, outlined the health benefits of VGS as being stress reduction, improved patient recovery and resistance to illness.

Recovery rate

Firstly, Ulrich (1984) found that greenery enhances patient recovery. Meanwhile, this effect is supported by other reports as well (Walker et al., 2022). Ulrich's study showed that for patients recovering from gall bladder surgery, a view to nature resulted in a reduced hospital stay of 8.5% (Ulrich, 1984). However, within the context of distribution centers this benefit can be considered irrelevant. Sheweka & Magdy (2011) also stated that a green wall can increase resistance to illness. However, no validation for this statement was found.

Safe environments

Moreover, VGS may create a safer environment through reduced violent behavior, fewer incivilities and a higher perceived safety (Tong, 2017). Although this has not been experimentally evidenced for VGS, there is a wide body of research written on the relationships between green space, crime, and violence. Overall, these studies show a positive impact of green space on the safety. Besides, earlier research indicated that safe places help to improve mental health in the urban environment (UD/MH, 2016). Therefore, green space was considered promising in shaping health-promoting environments (Bogar & Beyer, 2015). However, as this effect has not been researched for VGS in specific, knowledge regarding the quantitative impact assessment of this benefit is lacking.

Stress reduction

VGS can also provide psychological benefits. Many studies on well-being include measures related to the Attention Restoration theory (ART). This theory describes how natural environments can help to recover from mental fatigue after prolonged periods of attention (Kaplan & Kaplan, 1989). This restorative effect is enhanced in settings that provide a sense of being away (Kaplan, 2001), with opportunities for effortless attention or 'compatibility' with one's environmental demands (Kaplan, 1995). From a psycho-evolutionary perspective, natural environments provide such a setting. This restorative effect of nature was validated for the first time by Ulrich et al. (1991). More recently, this effect was also confirmed for VGS (Lotfi et al., 2020). Exposure to vertical green can enhance the restorative effect and contribute to lower stress levels. Besides, VGS can also have a preventive function towards stress and form a buffer against urban environmental stressors (Chan et al., 2020). These studies experimentally indicated stress levels by physiological indicators, such as *heart rate variability* and *blood pressure* (Chan et al., 2020; Lotfi et al., 2020).

System components

The restorative effect of VGS is positively correlated to the aesthetic value (Hoyle et al., 2017). Flowering plants therefore have a stronger restorative effect. Moreover, subtle green planting with a high natural structure was found to have the strongest natural effect (Hoyle et al., 2017; Liu et al., 2022). This means that green façades have a higher performance in stress reduction compared to living walls (Appendix 10).

Quantitative impact assessment & potential indicators

In The Green Benefit Planner, a decision-support tool from the RIVM (Dutch Governmental Institute for Environmental Health) on the ecosystem services of urban green in Amsterdam, quantifies the health benefits by means of three indicators (Paulin et al., 2019): 1. *Reduced number of visits to GP (visits/green ha/yr), 2. Reduced health costs due to urban green thousand (€/green ha/yr), 3. Reduced health-related labor costs due to urban green (thousand €/green ha/yr).* However, the modelled values that were assigned to those indicators, cannot be extrapolated to another context. Besides, these indicators were used to assess urban green on a larger scale. VGS could play a role in Green Neighborhoods for example. However, due to the small scale, these indicators are not useful to assess the effect of VGS in specific. More research is needed to quantitively assess the impact of VGS on health.

Main takeaways - Health & Wellbeing

Health benefits of VGS are retrieved via a safer environment, a quicker recovery rate and the reduction of stress. The latter can be enhanced by 'the naturalness' of a system. It is not yet understood how health benefits can be measured. Therefore, this ecosystem service will not be included in the further steps of assessment.

4.5 Synthesis

4.5.1. Key performance indicators

The multidisciplinary and multi-level benefits of VGS (chapter 3.2) ask for an integrated impact assessment approach. The use of **key performance indicators (KPI's)** offers an opportunity for such integrated impact measurement (Ntafilias et al., 2020). KPI's facilitate integrated decision-making as they can help to incorporate both physical and social science knowledge into the decision-making process. A KPI is a metric for measuring performance in relation to specific assessment criteria. Within this study, the potential benefits of VGS are the assessment criteria. The CIVITAS framework provides criteria for the definition of good set of KPI's (Rooijen & Nesterova, 2013):

- ***Relevance**: each indicator represents an assessment criterion, i.e., an ecosystem service*
- ***Completeness**: the set of indicators should consider all potential benefits of VGS*
- ***Availability**: for all indicators data – applicable to the Netherlands - is available*
- ***Measurability**: the indicators can be measured - objectively or subjectively*
- ***Reliability**: based on a peer-reviewed, scientific research*
- ***Familiarity**: the indicators should be easy to understand*
- ***Non-redundancy**: indicators should not measure the same aspect of an assessment criterion*
- ***Independence**: slight changes in the measurements of an indicator should not affect preferences assigned to other indicators of the evaluation model.*

The potential indicators that have been found will be discussed here along these criteria. A summary of this discussion is shown in Table 9.

Biodiversity support. The main indicators that were found to measure biodiversity the mean species richness and the mean species abundance. These indicators are based on peer-reviewed research and the relevance was validated by experts. The indicators are non-redundant and independent as they measure a different aspect of biodiversity. The data reported in earlier research, suggests that the indicators are measurable. However, biodiversity should be measured by specialized experts and measurement methods that are focused on VGS specifically are not common sense within the field yet. Due to the need for context-specific data, the available data is considered insufficient.

Thermal regulation. Among the variety of indicators for thermal regulation reported in literature, indicators related to the temperature differences (ΔT) were considered key (Appendix 6). On urban scale, this refers to the ΔT in ambient air. As this effect is hardly measurable, there is little reliable data available. Accordingly, the air humidity and air velocity can be used as complementary indicators. On the building scale, the ΔT in the air cavity and the ΔT of the external wall are considered key (Bakshoodeh et al., 2022). Due to the relevance of these indicators, most studies on the quantitative thermal regulating effect of VGS integrated the ΔT of the external wall and data is widely available. From a critical point of view however, it has been underlined that the ΔT of the external wall is related to the UHI mitigation as well (Ascione et al., 2020). This suggests that the indicators are not independent. However, although the thermal regulating effect on the urban and building scale are indeed interlinked (Appendix 6), the measurement is independent as both indicators are measured at different points: in front of the system and behind. A more specific indicator for the effect on building scale that has been used in academic literature, is the percentage of energy savings for heating or cooling. However, as the energy savings depend on the degree of heating and cooling, the values are difficult to interpret and compare. Especially in the context of distribution centers, where the requirements for heating and cooling are lower compared to for example office buildings, this indicator is not considered less relevant than the indicators mentioned above.

Sound regulation. Regarding the sound regulating effect, the insertion loss was, in contrast to the noise reduction effect, considered useful at both scales. Therefore, this indicator is more complete than noise reduction in general. The measurability is also higher, as it the insertion loss can be measured in-situ as well.

Water management. The key indicators for greywater treatment are the removal efficiency and the removal rate. Regarding storm water management, an expert in this field considered the water retaining capacity considered to be the key indicator (Appendix 9). However, the interviewed expert had no specific expertise on VGS and earlier research focusing on VGS specifically, used the runoff reduction. This indicator is therefore more reliable. Besides, the water collection capacity is directly related to the greywater removal rate and is therefore not independent.

Food provisioning. With regard to food provisioning, the two main indicators are not complete in reflecting the social and recreational benefits. However, they are complete in indicating the provisioning service. The yielded mass can be considered most complete as it also gives an indication of the other benefits related to vertical farming, such as vegeTable intake, as described in chapter 4.3.

Aesthetic value. The best quantitative indicator for the aesthetic value is the increased property value. The property value is mostly expressed in percentage, which is also the only way in which data for industrial buildings was found (Perini & Rosaco, 2013). As earlier research has indicated specific values for the increased property value, this indicator is considered measurable.

Weathering control. For the prolonged lifespan of the façade, the possibility of maintenance delay is the only potential indicator found in this research. For the benefits regarding health, education and PV performance, more research is needed in order to determine the key performance indicators.

Table 9

An assessment of the potential indicators according to the CIVITAS framework.

Ecosystem service	Indicators	Rv	Co	Av	Me	Rb	Fa	NR	In
Biodiversity	***Mean species abundance + mean species richness***	x				x	x	x	x
Thermal regulation Building energy savings	Energy savings heating + Energy savings cooling	x	x	x		x	x	x	x
	ΔT total	x	x		x		x	x	
	ΔT external wall	x	x	x	x	x		x	x
Reduction UHI effect	***ΔT ambient air***	x	x	x	x	x	x	x	x
	ΔT ambient air + air velocity + air humidity	x	x		x	x		x	x
Sound regulation	***Insertion loss***	x		x	x	x		x	x
	Noise reduction	x		x		x	x	x	x
Storm water management	***Runoff reduction (%)***	x	x	x	x	x	x	x	x
	Water collection capacity (m3/yr)	x	x		x		x	x	
Greywater treatment	***Removal efficiency (%) + Removal rate (mm/day)***	x	x	x	x	x	x	x	x
Weathering control	***Procrastination maintenance by 15 yrs***	x	x				x	x	x
PV perf.									
Food provisioning	***Yield (kg/m2/year)***	x	x		x	x	x	x	x
	Produced value (€/m2/year)	x	x		x	x	x	x	x
Aesthetics	Incr. property value (€/year)	x		x	x	x		x	x
	Incr. property value (%)	x		x	x	x	x	x	x
Education									
Health									

Note. Rv = relevance, Co = completeness, Av = Availability, Me = Measurability, Rb = Reliability, Fa = Familiarity, NR = Non-redundance, In = Independence.

4.5.2. System components

Besides performance indicators, this chapter explored the relation between the ecosystem services and the main systems' components. Table 9 provides a comprehensive overview of these effects. As shown, the irrigation system, which was identified to be one of the main system components by Wong et al. (2010), was not found to be a key variable for the performance VGS. With regard to the substrate, vegetation and support system, a variety of aspects were found to have an, either positive or negative and either strong or weak, effect on the performance. This Table provides the basis for the evaluation of the systems in the next chapter.

Table 10

Relation between systems' characteristics and ecosystem services of VGS. Interaction effects between system components and the systems' performance

Ecosystem services	Supporting	Regulating										Provisioning	Cultural
	BS	BTR	UTR	BNC	UNC	WQC	WR	GWT	WC	AQ	PVP	FP	AV
Substrate													
Moisture content	+/-	+/-	+++		--	+			-		+++		
Porosity		+		+	+++	+/-	++						
Thickness	+	+++	++	+++	++		+++				--		
Depth	+					+	+++						
OM Content	+						+	--					
Vegetation													
WLAI	+++	++	+++	+++	+		++		++	+++			+
Leaf size		-		+			+			--			
Transpiration rate		++	+++	-			+		--				
Plant height							+				---		
Leaf angle orientation				++									
Rough leaves										+			
Light colored		+											+/-
Variety	+++												++
Plant type	Native											Crops	Orna-mental
Support system													
Coated materials								+					
Size air cavity		+++	+	++	++				++				
Waterproof panels									++				

Note. BS = Biodiversity Support, BTR = thermal regulation building, UTR = urban thermal regulation, BNC = building, UNC = Urban noise control, WQC = water quality control, WR = water retention, GWT = greywater treatment, WC = weathering conrol, AQ= air quality control, PVP = PV performance, FP = food provisioning, AV = Aesthetic value

05 TOWARDS A MULTI-CRITERIA DECISION-MAKING MODEL

The previous chapters have identified the factors that are important for the impact of vertical greenery systems. A problem statement is included in the introduction. The MCDM alternatives and decision criteria were identified in chapter 3. This chapter describes the final steps towards a multi-criteria decision support tool. Based on the data gathered in chapter 4, this chapter evaluates the different types of VGS as distinguished in this study on their performance. The case will be used to allocate context-specific weighing of the ecosystem services and to test the validity of the model.

5.1 Multi-Criteria Decision-Making method

Dozens of multi-criteria methods have been developed in order to accommodate different applications (Velasquez & Hester, 2013). For new applications alterations are made to previous methods. The Simple Multi-Attribute Rating Technique (SMART) will be used as a guiding method for this multi-criteria analysis. This means that the utilities of the different alternatives (U_j) will be calculated by the formula: $U_j = \sum_k w_k u_{jk}$. In this formula w_k stands for the weights assigned to the decision criteria and u_{jk} refers to the specific utilities of an alternative for each of the decision criteria (Bhatt et al., 2017). Advantages of this method are that it is simple, allows for any type of weight assignment technique and requires less effort by the decision maker (Velasquez & Hester, 2013). It has been earlier applied to problems in environmental, construction and transportation and logistics areas. As this case study is linked to each of the areas, this method was considered appropriate for this study.

5.2 Evaluation & Decision matrix

As described in chapter 4, the performance of VGS depends on a variety of factors. This chapter evaluates the VGS as classified in chapter 3, based on these factors. Subsequently, the utility scores of the systems are presented in Table 11.

5.2.1. Evaluation

Supporting service

As the value of a system depends on the context as well as the species focused on, it is not possible to determine general utility values for biodiversity support. Implementing VGS does not automatically provide ecological value. This requires specific fitting to the local ecosystem. Overall, the biodiversity support of an vertical greenery system considered to be limited (Appendix 4). However, when implemented on a larger scale, added value can be enhanced. Other general principles for enhancing the ecological value of VGS are outlined in chapter 4. Due to these principles, VGS were still considered to have the potential to score 'good' (Table 11).

Regulating services

The systems performances in terms of thermal regulation and noise control is directly based on the sequence as described by literature and expert input (chapter 4). For both services, living walls have a higher performance due to the substrate. The smaller impact of vegetation is among others affected by the leave size. Where the thermal performance is enhanced by small-leaved species, the performance in noise control is greater for broad-leaved species. The effect of vegetation is less relevant for the noise control on building level. Therefore, the impact of green façades is considered very poor. In terms of UHI mitigation, this counts for all system types. For both services, the linear and modular were considered the best performing systems. The variance of modular and linear systems in thermal regulating performance is caused by the seasonal effect.

As the dimension of the substrate was considered to be the key factor in storm water management, living walls are considered to have a higher performance. Consequently, the impact of green façades is negligible unless they are placed in planter boxes. The range in utility value reflects this requirement (Table 11). Due to its minimal substrate size, the continuous system is the least performing living wall. The porosity and dimension of a modular living wall based on a foam substrate is considerably higher. However, due to the organic matter content and the thickness of the growing media is regarded as the best performing system. Finally, systems based on plants with a high evapotranspiration capacity have higher utilities.

With regard to greywater treatment, it can be assumed that living walls have a higher potential in greywater treatment. The larger volume of growing media allows for a larger biofilter and a higher treatment capacity. However, there is too little research to compare different systems based on the system components. With regard to the system components, much research is executed on the substrate as this is the most impactful. However, as a specific filter media is required for each type of system, the systems cannot be compared based on the substrate. Therefore, this service will not be taken into account in the MCDM model.

Continuous and modular living walls perform best in protecting the façade as they provide a 100% coverage. Although continuous living walls have a shorter lifespan, they have a perfect performance as long as they are in place. As linear systems do not fully cover the façade, they are evaluated less impactful. Although green façades with a high WLAI can very well protect against sunlight, green façades have a lower overall performance in terms of façade protection.

In terms of air quality improvement, all systems with a high WLAI have a relatively good performance. However, specific research on the impact assessment of VGS in terms of air quality improvement is limited. Therefore, it was stated that "more studies are needed which compare how various types of VGS constructions (consisting of different supporting constructions, soil types, and plant species) could contribute to improvements in air quality, and suggest which VGS types serve this purpose best in which environment and climate region" (Radić et al., 2019, p.18). The performance of a system mainly depends on the plant species (expert interview). Thus, the plant type should be specifically considered in order to enhance air pollutant removal. However, as modular, and especially linear systems allow for a greater biomass compared to continuous living walls, they are evaluated to have a higher potential. Green façades were considered to have the highest potential in WLAI as they can have a foliage thickness up to 2 meters. Accordingly, these systems were evaluated to have the highest potential.

Provisioning services

As a shallow substrate is required for combining VGS with PV panels, linear systems were evaluated very poorly in enhancing PV performance. Living walls with succulents were poor due to the limited evapotranspiration capacity. For the same reason, continuous living walls and façades were evaluated lower than modular living walls.

As most fruits are not edible, the overall potential of VGS in food provisioning is considered limited (Appendix 5). Both climber plants and perennials can be used for food provisioning, but succulents and grasses cannot be used for food provisioning. Too little research has been executed to compare the performance of VGS in food provisioning.

Cultural services

A proper valuation on aesthetic performance is not possible either, as this value is subjective and context-specific. However, in general living walls are evaluated better compared to green façades. However, in specific scenarios, such as on monumental buildings or with bad maintenance, VGS might negatively affect aesthetics (Appendix 10). Therefore, all systems were evaluated in a range starting from very poor.

5.2.2. Decision matrix

As described above, most ecosystem services are intangible and require a certain degree of subjective assessment. Earlier studies have dealt with a similar issue by using a numerical scale of 0 to 20 in assigning evaluation scores, in which the scores can be interpreted as follows: 0–4 = very poor; 5–8 = poor; 9–12 = good; 13–16 = very good; 17–20 = excellent (Chen et al., 2010; Hatush & Skitmore, 1998; Mustafa & Ryan, 1990). This scoring system is considered flexible enough to differentiate

between various levels of performance as well as allowing for the construction of utility curves (Chen et al., 2010). Accordingly, this rating system will be used in this study as well.
Although most varying factors are reflected in in the evaluation and utility scores, the following assumptions were integrated in order to be able to develop a decision matrix. These should be taken into account for the interpretation of this evaluation:

- The green façades were considered to have a high WLAI, with a wall coverage of at least 100%. In general, a lower WLAI will decrease the performance. In case of a lower coverage, performance scores should be adjusted accordingly.
- For the linear living wall systems, the planter boxes were assumed to be located at a maximum proximity to each other. In general, this enhances the performance.
- The performance of plant types in living walls both in WLAI and transpiration rate is ordered from poor to high as follows: succulents – grasses – perennials – shrubs. Succulents have an overall lower performance (Appendix 5).

Table 10
Interaction effects between system components and the systems' performance

Vertical Greenery Systems	BS	BTR	UTR	BNC	UNC	WR	WC	AQ	PVP	FP	AV	Max. total score
Direct green façade	1-12	4	1	1	5	0-4	1-4	9-20	9-12	4-8	0-16	**87**
Indirect green façade	1-12	8	1	4	7	0-4	1-12	9-20	9-12	4-8	0-16	**104**
Continuous living wall	1-12	10-12	1-2	10-12	10-12	9-12	17	9-12	9-12	0-8	0-20	**131**
Shrubs		*12*	*2*	*12*	*12*					*4-8*		
Perennials		*11*	*2*	*11*	*11*					*4-8*		
Grasses		*10*	*1*	*10*	*10*					*0*		
Modular living wall	1-12	16-20	1-3	13-16	17-20	13-16	20	9-16	13-16	0-8	0-20	**176**
Shrubs		*20*	*3*							*4-8*		
Perennials		*19*	*3*							*4-8*		
Grasses		*18*	*2*							*0*		
Succulents	*1-4*	*16*	*1*			*13*			*8*	*0*		
Linear living wall	1-12	12-16	1-3	9-12	13-16	16-20	14	9-16	0-4	0-8	0-20	**141**
Shrubs		*16*	*3*		*16*					*4-8*		
Perennials		*15*	*3*		*15*					*4-8*		
Grasses		*14*	*2*		*14*					*0*		
Succulents	*1-4*	*12*	*1*		*13*	*16*			*4*	*0*		

Note: HS = Habitat Support, BTR = thermal regulation building, UTR = urban thermal regulation, BNC = building noise control, UNC = urban noise control, GWT = Greywater treatment, WR = water retention, WQC = water quality control, WC = weathering control, AQC = air quality control, PVP = PV performance, FP = food provisioning, AV = aesthetic value, HWB = health & wellbeing

5.3 Case study

5.3.1. Context-specific weights

In order to develop a decision model that allows for a context-specific assessment, stakeholder input was used to allocate weights to the ecosystem services. Multiple case-related stakeholders, who had an influence on the design of the vertical greenery, were consulted.

The SMART method of MCDM allows only a limited number of decision criteria (Bhatt et al., 2017). Accordingly, the stakeholders were asked to rank the six most relevant ecosystem services within the context of this specific case. These rankings were transposed into relevance scores by turning the order around. For example, number 1 becomes 6, number 2 becomes 5 etc.. Subsequently, the scores for the different criteria were accumulated into a total score. Finally, the weights were determined by dividing the total score by a factor of 10. The outcomes are presented in Table 12.

Table 11
Weight allocation by case-related stakeholders

	Architect	Plan developer	Total score	Weights
Biodiversity	6	6	12	1.2
UHI mitigation	2	/	2	0.2
Greywater treatment	/	1	1	0.1
Air quality control	5	2	7	0.7
Aesthetic value: property	3	3	6	0.6
Aesthetic value: landscape	4	4	8	0.8
Stress reduction	1	5	6	0.6

By integrating the weighed scores into the decision matrix and deleting the decision criteria the were not considered most relevant, a context-specific decision model was created (Table 13). According to this model, the green façades are the best alternative in the context of Virgo Aalsmeer.

Table 12
Case-specific assessment of VGS

Vertical Greenery Systems	HS	UTR	AQ	AV		Total score	Weighed score
Weights	1.2	0.2	0.7	0.7			
Direct green façade	0-12	1	9-20	0-16		10-49	6,5-39.8
Indirect green façade	0-12	1	9-20	0-16		10-49	6.5-39.8
Continuous living wall	0-12	1-2	9-12	0-20		10-46	6.5-37.2
Modular living wall	0-12	1-3	9-16	0-20		10-51	6.5-40.2
Linear living wall	0-12	1-3	9-16	0-20		10-51	6.5-40.2

5.3.2. Model validation

In order to test the validity and usability of the model, a conversation with the case-related stakeholders was initiated. In this conversation, the decision-making process was discussed and compared to the modeled MCDM process. Where the model points towards a modular or linear living wall, an indirect green façade has been implemented at the case location. The aim of this meeting was to get an understanding of the main drivers in their decision-making process and to identify potential shortcomings of the MCDM model. Further elaboration on this meeting can be found in the appendices (Appendix 11).

Description of the decision-making process

An independent landscape architect was involved in the project for the design of the greenery. In the process of selecting a vertical greenery system, he collaborated with the architect and an external ecologist. Heembouw aimed for a more nature-inclusive development of a DC at Virgo Aalsmeer. This project is considered a pilot in terms of the nature-inclusive development of DC's, especially in terms of the financial calculations. In this process, the developers' aspirations for the project and the expertise of the landscape architect were guiding in this decision.

The first step of the process, choosing the type of system, was executed in a collaboration between the architect and landscape architect. In this part of the process, an indirect green façade was chosen over the direct green façade for two reasons: to protect the building façade and to have a wider range of plants to choose from. Living walls have not been taken into consideration.

The next step of the process was about choosing the type of plants. For this part of the process, the landscape architect worked together with an ecologist. The ecologist was involved to study the local environment, in order to see what is there and to identify the opportunities for ecological connectivity. The decision was based on the expertise of both decision-makers: the aesthetic and ecological value.

Main motivations for decision-making
The three key factors that determined the decision-making process were: 1. the image, 2. the ecological value and 3. the costs.

The pupursuitf a 'natural' image is reflected in the choice for a green façade. This system is considered more natural for two main reasons. Firstly, in contrast of a living wall, green façades rely less on irrigation and maintenance, which was referred to as 'a higher level of autonomy' by the landscape architect. A lack of human interventions is reflected by the growth pattern of the wall as well. The evolution of the wall mirrors natural selection, which means that the thickness of the foliage or the composition of plants is harder to control and predict beforehand. This is not considered a problem, as it fits the approach that was chosen for this project. Secondly, green façades have a more 'natural experience' compared to living walls. Plants that grow in wall-based container systems were considered to have a more 'artificial feel' to it, compared to plants that grow in the ground. Besides, the architect considered planting boxes to be too 'frumpy' (In Dutch: 'tuttig') in this type of context and on this scale. Thirdly, with regard to the aesthetic value, they have chosen for a combination of deciduous and season-coloring plants.

The focus on ecological value is partly related to the plants' autonomy within the green façades. By choosing for such a system that allows a natural growth pattern, they aim to create more 'space for nature'. Space for nature was also created by choosing an indirect over a direct green façade, as a wider variety of plants can be used in such a system. In this way, multiple plants were combined which enhances biodiversity. But, more importantly, a wider range of plants can increase opportunities to optimize the suitability of plants in the local ecosystem. This suitability was guiding in the decision for the type of plants.

The financial costs have played a major role in decision-making. Living walls were not considered due to the high costs. The context of a DC plays a role here, as DC's have relatively cheap building façades. The costs, which can be up to a tripling of the usual façade costs, are considered high in relation to the façade. Besides, in the context of a DC, VGS are still considered as an extra addition, which is mainly implemented by intrinsic motivation or to make a statement. As the costs for the vegetation are minor compared to the system, the financial aspect did not play a role in choosing the type of plants.

Reflection on the MCDM model
In the conversation, the value of the model was specifically underlined. It is considered useful as it can help to convince clients of the value of VGS. Besides, this study was considered especially valuable in mapping all relevant decision criteria. As such an overview was not available yet, this wide range of variables has not been taken in the decision-making process of this project. Even though not all benefits can be assessed quantitatively yet, this model was considered helpful in taking all variables into consideration. Besides, it was mentioned that the type of people involved in decision-making can determine the outcomes. For example, an architect might prefer a living wall as it allows for influence

on the design, whereas an ecologist or landscape architect might, based on ecological expertise, prefer a green façade. The decision-making model can help to make a more objective decision.

However, despite its value, this conversation also revealed some potential shortcomings of the model. First, the landscape architect considered the relevance of some decision criteria in the context of DC's to be discussable. On the other hand, the architect pointed toward the increasing mixed land use, in which DC's are also located in more urban areas. Moreover, this research identified that all ecosystem services can be relevant in this context (chapter 3.3) and therefore this discussion point is not considered an issue of validity.

Second, the need for context-specific valuation of aesthetics was underlined in this meeting. As already pointed out in this research (Appendix 10), this conversation underlined the distinction between a 'natural' or a more 'artistic' preference. Subsequently, based on this preference, some objective valuation can be given. Therefore, it might be valuable to distinguish between both types of aesthetic value within the model.

Similarly, the complexity of objectively valuing habitat support was discussed. In the case of Virgo Aalsmeer, the local ecological study as well as the use of immature plants and various plant types probably resulted in the decision for a system that stands out in ecological value. However, this was not reflected in the modeled outcome. The development of a guide to objectively include such variables in valuation might be a valuable addition to the model. However, in order to validly give context-specific values on habitat support, the involvement of an ecologist is always needed (Appendix 4). The architect pointed toward another project in which an ecologist created an excel Table to value various plant types in terms of ecological value. Further development of such an approach, might help ecologists objectively identify a score on habitat support.

Fourth, the model assumes a 100% coverage for green façades. However, at the case location, only the bottom part of the building will be covered with greenery. Besides, due to the selection of pre-grown plants, the current coverage is completely negligible. Therefore, the modeled value for green façades can be considered too high.

Finally, if wellbeing and greywater treatment could have been integrated into the model, this might have led to a different outcome.

06 DISCUSSION & CONCLUSIONS

6.1 Discussion

This research aimed to develop a MCDM model on the ecosystem services of VGS in order to facilitate impact assessment and evidence-based decision-making. This study was specifically focused on the benefits of VGS in the context of Dutch DC's near airports.
As a first step, the MCDM alternatives were identified through a classification of VGS. For this research, a classification based on the main system components was considered appropriate. The vegetation, substrate and support system were found to be the key variables for the performance of a system. The identified interaction effects between these components and the performance of VGS (chapter 4.5) formed the basis for the development of the MCDM model in chapter 5.

As a second step, the decision criteria were determined through the identification of the ecosystem services related to VGS (chapter 3.2). The following ecosystem services have been related to VGS: biodiversity support, thermal regulation, sound regulation, storm water management, greywater treatment, air quality control, weathering control, enhanced PV performance, food provisioning, aesthetics value, education and health & wellbeing. Each of these services was considered to be of possible relevance in the context of logistics hubs (chapter 3.3). Accordingly, more in-depth research was executed for each of the ecosystem services (chapter 4). Based on this literature review, the services of education, greywater treatment and human health promotion, were excluded from the set of decision criteria due to a lack of evidence for quantitative impact assessment.

As a third step, the retrieved knowledge regarding the other services was evaluated in order to develop a MCDM model. Based on this model, living walls are considered to have a higher overall impact compared to green façades. Modular living walls are considered to have the highest maximal impact and direct green façades the least. However, context-specific valuation was found to be necessary, especially with regard to the ecological and aesthetic performance (chapter 5.5). Therefore, the model was, as a final step, applied and tested in a case-specific context. The case study identified the societal value as well as the shortcomings of the MCDM model.

6.1.1. Interpretations

The MCDM model that was developed in this study, is based upon five types of VGS. However, it should be noted that this classification of decision alternatives is a simplified overview. The combinations of system components as classified in this study are not the only possibility and a much wider variability of VGS is available. Moreover, besides VGS, other types of vertical greenery, such as green terraces or naturally grown walls, are available as well. As they are not integrated in the model, this wider range of vertical greenery, cannot be equally included in the MCDM process. However, the impact evaluation (chapter 3.2) might help to get an understanding in the performance of these systems as well.

Especially with regards to biodiversity, the evaluation of a wider range of possibilities in terms of vertical greening is considered interesting (Appendix 4).

A similar note should be made with regard to the decision criteria. This study is specifically focused on the ecosystem services. However, the decision for a VGS cannot be based upon the benefits only.
First of all, the financial costs for implementing VGS play an important role in decision-making (chapter 5.5). Life-cycle cost are related to the installation, operation and maintenance and disposal of VGS (Radić et al., 2021). Second of all, besides the system components, the interaction between the technical context of a green wall and the system requirements is essential to avoid mismatches and to be able to choose appropriate management measures (Jim, 2015). In relation to the wall properties, for example, design factors for the application of VGS include the structure, surface, dimension, geometry, location, and ambience of the wall.
Third of all, other major factors to consider with regard to the impact are: climatic differences, orientation and season. Climatic differences were accounted for in this study (Appendix 1). However, due to the aim for a general model that is applicable all over the Netherlands in combination with time constraints, orientation and seasonal impact have not been taken into account. Fourth of all, the negative externalities should be considered as well. For example, types of VGS come with varying environmental burdens, they can increase the risk of fire and can lead to issues of equity by increasing housing prices (Ling et al., 2020; Perini et al., 2011b; Radić et al., 2021).
Accordingly, it is important to realize that not all relevant decision criteria are included in the model.

Finally, it should be noted that the model is a tool for evidence-based decision-making. However, the case study showed that emotional associations are relevant to the preferred system as well. This might be another reason to not completely rely on the model for decision-making, but to adopt an approach is balanced between emotional and scientific decision-making.

6.1.2. Implications

Nonetheless, the relevance and value of the model have been underlined (chapter 5.5). Through the development of a quantitative MCDM model, this research can help developers and practitioners by supporting evidence-based decision-making (Ascione et al., 2020). Besides, this model, as well as the set of KPI's that was developed in this study, can also help to create financial support for the implementation of VGS (Ascione et al., 2020; Bueno, 2017; Mačiulytė & Durieux, 2020). In this way, this research might lead to an increased implementation of VGS. The case study also pointed towards an approach for context-specific valuation. When context-dependent valuation is needed, the utility scores is presented by a scoring range in the model. The evaluation in chapter 5.2 can help to determine these context-specific values. However, as identified in the case validation (chapter 5.5), valuation of the ecological and aesthetic value is rather complex. With regard to the aesthetic value, it is important to determine whether a natural or an artistic image is preferred. For a proper valuation of the ecological performance, the involvement of an ecologist is required. Finally, it is important to realize that the demand for and the access to the ecosystem services determine the impact of these services. For example, experts have stated that the implementation of green is not sufficient for a better health, but when greenery is implemented via a participatory approach the benefits are much higher (Faas, 2022). Accordingly, consideration of the social perspective is crucial in the valuation process (Hansen & Pauleit, 2014).

Besides developers, designers and practitioners, the development of a quantitative impact assessment model is relevant for researchers as well (Ascione et al., 2020). Due to the integral approach, this research provides a clear overview of the current knowledge regarding the benefits of VGS. Accordingly, it also gives direction for further research.

6.1.3. Limitations

In this research, a set of KPI's to facilitate quantitative impact assessment of the ecosystem services of VGS has been defined. It must be noted that the valuation on familiarity – one of the criteria to select the indicators – was not based on the research, but on the interpretation of the researcher. As it does not affect the main conclusions of this research, it was not considered a major issue. Nonetheless, it can be considered a limitation.

This set of KPI's can be used for measuring the impact per service. However, due to the lack of comparability, these indicators are not considered useful for an integral impact assessment. Moreover, the current state of literature does not provide a sufficient evidence-base to assign quantitative scores to these indicators for the set of selected VGS. Accordingly, it was not possible to use the identified KPI's to quantitatively assess the systems. Therefore, utility scores – that are based on the executed literature review and expert interviews – were used for the evaluation of VGS. This approach required interpretation by the researcher. As interpretation is always prone to subjectivity, this is considered a limitation regarding the reliability of the modeled outcomes.

As the expert interviews were execute as a support to the interpretation, these can be regarded as a validation step. However, when the interviews are regarded as such, it could be considered a limitation that expert interviews were only conducted when additional understanding was experienced to be necessary by the researcher, as this criterion is subjective as well.

6.1.4. Recommendations

Recommendations for future research

As the model is developed with utility scores that are based on the interpretation of one researcher, it is recommended to test the validity of the model. This could be done through the execution of additional case studies or the application of validity parameters. Validity parameters reflect the probability of the fact that the results of application of multicriteria methods reflect real ratios of advantage between alternatives and are used to evaluate the validity of MCDM (Potomkin, 2018).

As a more advanced way of validation, it is recommended to further develop the model by assigning quantitative values the KPI's. In order to do so, comparative studies on the quantitative impact for distinct types of VGS is required. In specific, more comparative experimental research is needed regarding the stormwater management, air quality control and greywater treatment of VGS. With regard to the educational and health-related benefits, first, more research is needed to gain understanding in how to quantitatively assess these services. Subsequently, it is recommended to translate these quantities into monetary values to enhance the comparability as well as usability.

Finally, although it is not mentioned in the most recent reviews on the benefits of VGS (chapter 3.2), VGS might potentially increase the productivity of employees (Appendix 7). This hypothesis can be supported by research findings that related a positive emotional effect, a decreased task load and a higher workplace satisfaction to the visual effect of living walls (Loh & Stav, 2008; Yeom, 2022). Therefore, it recommended to test this hypothesis in future research.

Practical recommendations

Due to the variety of other factors that are relevant in decision-making, it is recommended to integrate the model developed in this study with existing MCDM models related to these factors. For example, integration with the model of Hollands & Korjenic (2021) will result in a more complete model to guide the decision-making process.

For the same reason, it is recommended to use the model as a conversation starter in the MCDM process rather than a ready-to-use decision-making model.

Finally, as stakeholders from different disciplines might have different values (Appendix 11), it is recommended to adopt an integral decision-making approach in which stakeholders from various disciplines are represented.

6.2 Conclusions

The main question of this research was: '*How can a MCDM tool on the quantitative performance of VGS in delivering ecosystem services be developed and applied, in order to facilitate the impact assessment and evidence-based decision-making in the context of Dutch DC's near airports?'* This question was researched along four sub-questions:

- What key variables determine differences in performance among diverse types of VGS *?*
- What are the ecosystem services offered by VGS?
- How to quantify ecosystem services to assess the performance of VGS in the context of Dutch DC's?
- How can a MCDM model help to assess the performance of VGS and identify the type of VGS that delivers the best mix of ecosystem services for specific Dutch DC's near airports?

As answers to these questions, the following conclusions can be drawn:

First, the key variables that determine impact differences among the variety of systems are the vegetation, support system and substrate.

Second, VGS have an impact by delivering a range of supporting, regulating, provisioning and cultural services. All services were found to be of potential relevance in the context of logistic hubs.

Third, more research is needed in order to quantitatively measure the performance of VGS on these services. Nonetheless, through an evaluation based on the variables stated above, a MCDM tool to quantitively assess the impact of a selected number of VGS could be developed. More research to further develop and validate this MCDM model is recommended as well, specifically with regard to greywater treatment, educational impact and the benefits for human health of VGS.

Fourth, the model shows that, in general, living walls have a higher positive impact compared to green façades, among which the modular living walls have the highest performance. A context-specific impact assessment can be achieved through case-specific valuation of the ecosystem services. The model was found to be helpful for decision-makers by mapping the variety of potential benefits that can be taken into account, and by creating a support base for the implementation of VGS.

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APPENDICES

Appendix 1. Methodological details: systematic literature review

This Appendix provides additional information on the methodological approach to the systematic literature review presented in Chapter 3.2.

Database: Scopus

Search query: (TITLE-ABS-KEY ("impact" OR "benefits" OR "performance" OR "value") AND TITLE-ABS-KEY ("vertical greenery systems" OR "green wall" OR "green façade" OR "living wall")) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018))

- ➔ **Results: 34**

Exclusion criteria:

- Article is not related to the benefits of VGS.
- Article is focused on other types of green infrastructure than the types of VGS as selected in this study
- Article is focused on thermal performance in a climate other than Cfb, as classified by Köppen
- Article is published before 2018
- Article is not written as a review

Excluded studies:

Priya, U. K., & Senthil, R. (2021). A review of the impact of the green landscape interventions on the urban microclimate of tropical areas. *Building and Environment*, *205*, 108190.

Mahmoudi, A., Mousavi, S. A., & Darvishi, P. (2021). Greywater as a sustainable source for development of green roofs: Characteristics, treatment technologies, reuse, case studies and future developments. *Journal of environmental management*, *295*, 112991.

Mannan, M., & Al-Ghamdi, S. G. (2021). Active Botanical Biofiltration in Built Environment to Maintain Indoor Air Quality. *Frontiers in Built Environment*, 99.

Bandehali, S., Miri, T., Onyeaka, H., & Kumar, P. (2021). Current state of indoor air phytoremediation using potted plants and green walls. *Atmosphere*, *12*(4), 473.

Sarr, M. S., Diallo, A. M., & King-Okumu, C. (2021). A review of public versus private reforestation programs in the Senegalese Sahel: taking stock of realities and challenges. *Restoration Ecology*, e13582.

Yenneti, K., Ding, L., Prasad, D., Ulpiani, G., Paolini, R., Haddad, S., & Santamouris, M. (2020). Urban overheating and cooling potential in Australia: An evidence-based review. *Climate*, *8*(11), 126.

Al-Kayiem, H. H., Koh, K., Riyadi, T. W., & Effendy, M. (2020). A comparative review on greenery ecosystems and their impacts on sustainability of building environment. *Sustainability*, *12*(20), 8529.

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Andrić, I., Koc, M., & Al-Ghamdi, S. G. (2019). A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *Journal of Cleaner Production*, *211*, 83-102.

Gunawardena, K., & Steemers, K. (2019). Living walls in indoor environments. *Building and Environment*, *148*, 478-487.

Zhao, X., Zuo, J., Wu, G., & Huang, C. (2019). A bibliometric review of green building research 2000–2016. *Architectural Science Review*, *62*(1), 74-88.
Irga, P. J., Pettit, T. J., & Torpy, F. R. (2018). The phytoremediation of indoor air pollution: a review on the technology development from the potted plant through to functional green wall biofilters. *Reviews in Environmental Science and Bio/Technology*, *17*(2), 395-415.

Appendix 2. Methodological details: selecting relevant indicators

This Appendix provides the methodological details as well as the collected input for Chapter 3.3.

Data collection

Based on personally retrieved contact details, the contact persons from SADC and BIC Eindhoven were reached out to via email. After a short introduction, the contact persons to rank the list of ecosystem services in terms of relevance to their organization. Additionally, they were asked to list, if possible, the relevant ambitions of the organizations for each of the ecosystem services. This question was outlined as follows:

"Hieronder de lijst met ecosysteemdiensten. Zou je (als dat mogelijk is) een volgorde aan kunnen geven welke diensten relevant zijn voor SADC/BIC Eindhoven? En het zou heel fijn zijn als je hierbij ook kunt aangeven aan welke ambitie dit gerelateerd is."

Ecosysteemdiensten	**Impact niveau**	**Type waarde**
Bevorderen biodiversiteit	Stedelijk	Ecologisch
Warmte-regulatie: energiebesparing	Gebouw	Financieel
Warmte-regulatie: vermindering stedelijk hitte-eiland effect	Stedelijk	Sociaal
Geluidsreductie: binnen	Gebouw	Sociaal
Geluidsreductie: buiten	Stedelijk	Ecologisch
Grijs water zuivering	Stedelijk	Ecologisch
Storm water management	Stedelijk	Ecologisch
Verbeteren luchtkwaliteit (reductie van o.a. PM, CO2, SO)	Stedelijk	Ecologisch
Verlenging levensduur gevel	Gebouw	Financieel
Voedselvoorziening: vertical farming	Gebouw	Sociaal
Hogere opbrengsten van zonnepanelen op de gevel	Gebouw	Financieel
Esthetisch effect: verhoging vastgoedwaarde	Gebouw	Financieel
Esthetisch effect: verhoging landschapswaarde	Stedelijk	Financieel
Educatie	Stedelijk	Sociaal
Gezondheid - veiligheidsgevoel	Stedelijk	Sociaal
Gezondheid - sneller ziekte herstel	Stedelijk	Sociaal
Gezondheid - stress reductie	Stedelijk	Sociaal

Stakeholder input

Answer SADC (Pleun van Lith): "*TU Delft task Dieuwertje den Hartog: Potentie van verschillende verticaal groensystemen in de context van bedrijventerreinen/distributiecentra.*

Alle ecosysteemdiensten worden op een manier wel betrokken in de ontwikkelingen door SADC. Sommige worden belangrijker gevonden dan anderen. Dit is een lijstje die ongeveer aangeeft wat het meest relevant is voor SADC en in welke ontwikkelingen vanuit deze ecosysteemdiensten terugkomen."

1. Bevorderen biodiversiteit → belangrijk vormen KPI's
2. Energiebesparing → belangrijk (virtuele net); komt ook voor in duurzaamheidsvoorwaarden (zonnepanelen bijv)
3. Vermindering stedelijk hitte-eiland → belangrijk duurzaamheidsvoorwaarden; groene daken; wateradaptatie; klimaatadaptief
4. Verlenging levensduur gevel → duurzaamheidsvoorwaarden (materialen; de R-ladder staat hierin)
5. Hogere opbrengsten voor zonnepanelen gevel → duurzaamheidsvoorwaarden (zonnepanelen en energie is belangrijk)
6. Voedselvoorziening: vertical farming → SADC wil dit eventueel meenemen in het vormen van KPI's
7. Educatie → JINC (bliksemstages geven); en SADC is ook voor het profileren van dit soort dingen, expliciet maken van de goede dingen die we als bedrijf uitvoeren (dmv KPI's dus bijvoorbeeld)
8. Esthetisch effect: verhoging vastgoedwaarde → schaarse ruimte (belangrijk doel van SADC)
9. Esthetisch effect: verhoging landschapswaarde → schaarse ruimte (belangrijk doel van SADC)
10. Verbetering luchtkwaliteit → duurzaamheidsvoorwaarden
11. Storm water management → duurzaamheidsvoorwaarden
12. Grijs water zuivering → duurzaamheidsvoorwaarden
13. Gezondheid: veiligheidsgevoel → BREEAM
14. Gezondheid – stress reductie → duurzaamheidsvoorwaarden: welzijn
15. Gezondheid – sneller ziekte herstel → duurzaamheidsvoorwaarden: welzijn
16. Geluidsreductie binnen (locaties rondom Schiphol)
17. Geluidsreductie buiten (locaties rondom Schiphol)

Answer BIC (Manon Silverentand): ***"****Zie hieronder de relevantie van de thema's voor BIC."*

Bevorderen biodiversiteit → Relevant voor BIC, ambitie duurzaamheid
Energiebesparing → Relevant voor BIC, ambitie duurzaamheid
Vermindering stedelijk hitte-eiland → Minder relevant, locatie ligt in buitengebied
Geluidsreductie binnen → Relevant i.v.m. ligging bij Eindhoven Airport]
Geluidsreductie buiten → Idem
Grijs water zuivering → Relevant, ambitie duurzaamheid
Storm water management → relevant (t=100)
Verbetering luchtkwaliteit → relevant, ambitie duurzaamheid
Verlenging levensduur gevel → interessant, minder zicht op (vastgoedontwikkelaar heeft hier meer zicht op)
Voedselvoorziening: vertical farming → op kleine schaal, kan me voorstellen dat dit pilotachtig mogelijk is
Hogere opbrengsten voor zonnepanelen gevel → hogere opbrengsten dan op dak? Zonne energie is relevant

Esthetisch effect: verhoging vastgoedwaarde → relevant, creëren stimulerend werklandschap, campusconcept verhogend
Esthetisch effect: verhoging landschapswaarde → relevant, zie voorgaand punt
Educatie → relevant, bij eerste cluster integratie van werken en onderwijs
Gezondheid: veiligheidsgevoel → relevant, stimulerend werklandschap
Gezondheid – stressreductie → idem
Gezondheid – sneller ziekte herstel → idem

Appendix 3. Interview guide

The expert interviews were generally structured along the questions outlined below. As all interviews were conducted in Dutch, the interview guide was set up in Dutch as well. The interview guide is a translated version. This guide was provided to the interviewees in advance of the meeting, supported by Table 1 and Figure 4.

What mechanisms determine te impact of a VGS on [ECOSYSTEM SERVICE]?

According to you, what is/what are the key performance indicator(s) to measure the impact of [ECOSYSTEM SERVICE] ?

A VGS consists of four main system components: the vegetation, the substrate, the support system and the irrigation system. What system components are the most important for the impact in terms of [ECOSYSTEM SERVICE] ?

How does the type of system influence the performance regarding [ECOSYSTEM SERVICE] ?

- What is the influence of the substrate?
- What is the influence of the plants?
- What is the influence of the support system?
- What is the influence of the irrigation system?

What are the main system requirements for optimizing the impact of a VGS with regard to [ECOSYSTEM SERVICE]?

Can you value the system presented below with a score from 1-10 in terms of their performance?

Appendix 4. Expert interview with Ernest Pelders & Barend de Jong (OAK consultancy)

OAK Consultancy gives advice in ambitions on the development of water, nature and parks. They are focused specifically on the following themes: nature restoration & biodiversity, liveable & vital cities and climate adaptation & water safety. The support can be both on the content as well on the process. Ernest Pelders is a landscape architecture with experience in process- and project management. Barend de Jong is ecologist with specific expertise on aquatic ecology.

Welke mechanismen bepalen de impact van een verticaal groensysteem op biodiversiteit?
Verrijken van biodiversiteit gaat daarom om plek te bieden voor de 4 V's: voeding, veiligheid, voortplanting en verbinding.

Het belangrijkste bij biodiversiteit is inpassing in het lokale ecosysteem. Hierbij is het schaalniveau essentieel. Bij groene daken/groene gevels gaat het om stadsecologie. Op kleine schaal heb je dan bij voorbeeld mussenkasten en groene gevels etc. Maar de grotere schaal is nodig om de verschillende diensten te kunnen bieden. Bijv. bloemrijke toestand nodig voor voeding en overwintering. Bij het plaatsen van een groene gevel is het dus een voorwaarde voor biodiversiteit dat al die elementen in de omgeving aanwezig zijn.

Bij een daktuin in Nijmegen hebben we een daktuin gemaakt met substraat uit stroomgraslanden om de rivier. We hebben gekeken wat die graslanden nodig hebben en of we dat kunnen verplaatsen naar het dak. Dat was een natuurlijk substraat en plantensoorten toegepast die passen in de lokale omstandigheden. Zo hebben met insecten en planten echt wat toegevoegd van die plek. Het gaat dan niet zo zeer om het gebruik van dezelfde soorten die al in de omgeving aanwezig zijn, juist niet, maar vooral op inpassing in het geheel.

Biodiversiteit is context-specifiek. Als het gaat om de impact kun je kijken naar het lokale ecosysteem, wat er nog mist, en daarop inhaken bij de groene gevel (als dat nodig is). Maar het is belangrijk bij biodiversiteit om te waken voor greenwashing.

Een enkel systeem kan ook een biotoop op zich zijn, dan voegt het niet per sé wat toe aan de biodiversiteit. Dat kan dan waarde hebben voor andere ecosysteemdiensten.

Verder hangt het af van de soorten die je wil bedienen, dit is opnieuw context-specifiek.

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op biodiversiteit te meten?
Biodiversiteit gaat om aantal soorten per oppervlak, en de hoeveelheid. Dit kan per soort worden gemeten door een specialist. Als het gaat om groene gevels is het nog meer pionieren.
Er is geen uitgedachte methodiek voor de waardering van biodiversiteit van groene gevels voor zover hij weet. Bij effectstudies wordt op specifieke natuurtypes worden er wel waarderingen gegeven op zeldzaamheid of beheer. Maar natuurwaardes als biodiversiteit is altijd lastig te methoden en voor zover hij weet zijn er geen methodes om dit te monetariseren.

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, het support systeem en het irrigatiesysteem. Hoe heeft de keuze voor een systeem effect op de prestatie van biodiversiteit?

- Wat is de invloed van het substraat?

Bodembiodiversiteit is laag omdat het niet aangesloten is op de grond, dus er komen alleen soorten in als je ze er actief in zet. Bij klimplanten die direct in de grond worden geplaatst is de biodiversiteit in het substraat dus beter. Qua type substraat is natuurlijke grond wel het beste. Niet elk substraat uit de omgeving kan worden toegepast, want dan groeit de klimplant minder goed. Het werkt dus echt als een biotoop. Overgangen tussen vochtig en droog nodigen uit tussen leven.

- Wat is de invloed van de planten?

Inheems plantengoed sluit makkelijker aan bij de biotoop, dan niet-inheemse soorten. Dat is beter dan gecultiveerde soorten voor groene gevels, dan is het misschien al green washing.
Klimplanten zijn voor insecten interessant, maar andere dieren hebben er niet zoveel aan. Tenzij je een heel dik pakket maakt zodat er vogels tussen kunnen gaan zitten.

- Wat is de invloed van het support systeem?

Hogere diversiteit aan materialen en/of geperforeerde kunnen interessant zijn.

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?
Het roept de vraag op of dit alles is. Als het gaat om biodiversiteit gaat het ook om materiaal van de gevel, waar groen in kan groeien. Bijv. door kalk. Het zou interessant zijn om het pallet te verbreden door meer soorten, ook dieren, maar ook meer materialen te gebruiken. Holtes, of nisjes of luwtes zijn

interessant. In materialisering zit veel meer ruimte om verschillende biotopen een plek te geven. De kant van de gevel bepaald hierbij wat je kan.
Er is geen standaard waardering van verschillende systemen mogelijk, omdat het altijd context-specifiek is.
Discussiepunt voor de studie: laten zien dat er meer mogelijk is als het gaat om groene gevels, en argumenteren waarom deze gekozen zijn.

Summary with main message by Barend
Belangrijke boodschap, als ik het even samenvat, voor biodiversiteit creëer je meerwaarde door:
- aan te sluiten op natuur in de omgeving
- plek te bieden voor de 4 V's: voeding, veiligheid, voortplanting en verbinding. Zie de handreiking die ik je in de vorige mail stuurde voor verschillende soortgroepen.
- het groenareaal zo groot mogelijk te maken of dik (in die zien dat een dikke vegetatiemat meer ruimte biedt als verblijfplaats, bijvoorbeeld voor vogelnestjes en overwinteringsplekken voor insecten).
Ik denk dat je voor insecten de meeste waarde kunt creëren. Zeker als je inheemse, bloeiende planten gebruikt met veel vruchten en zaden en een 'natuurlijke' bodem.

De baten van biodiversiteit zijn moeilijk in geld uit te drukken. Dat gaat makkelijker voor een baat als verkoeling, groen voor gezondheid, woningprijs, waterberging, CO2-opslag, luchtzuivering, etc. Ken je TEEB-stad (https://www.teebstad.nl/)? In variantenstudies kan je wel kwalitatieve scores geven aan zeldzaamheid van een soort, de mate waarin het groen past bij de omgeving, de mate waarin het beheerd moet worden, de hoeveelheid soorten en het aantal individuen, etc.

Je bent aan het pionieren. Groengevels worden snel verkocht als goed voor de biodiversiteit, het is maar de vraag of dat zo is. Pas op voor greenwashing dus.

Appendix 5. Expert interview with dr. ir. Jelle Hiemstra

Jelle Hiemstra was interviewed regarding his expertise on the effect of plants in relation the ecosystem services. This interview was initiated as an additional interview after the others. It is not focused on a specific ecosystem service, but on the relation between the main plant characteristics (chapter 4.5.2) and the impact of VGS. The questions were prepared on forehand.

Tip: Rol van groen in de stad wordt nog beschreven voor de belangrijkste ecosysteemdiensten in factsheets. Groen in de stad factsheets. Groen in de stad biodiversiteit is een van de serie. Dit is mogelijk interessant.

Is het mogelijk om de verschillende type planten in de living walls (zie tabel) te beoordelen op WLAI? Zo ja, welke planten hebben een hogere WLAI: struiken, vaste planten, vetplanten, grassen of de hedera helix?
Er zijn een aantal dingen belangrijk als het gaat om biomassa/dichtheid van het bladerdek.

1. *Groenblijvende planten is het belangrijkst. Hedera daarom veelgebruikt.*
2. *Voor een dicht bladerdek is de groeiplek belangrijk: water en voeding moet voldoende zijn.*
3. *Leeftijd: oudere planten presteren over het algemeen.*
4. *Type: meerjarig of niet. Vaste planten kunnen een dikker bladerdek krijgen dan bijv. kruiden.*

➔ *Meerjarig en groenblijvend is het belangrijkst.*

Onder goede omstandigheden kan een klimop een bladerdek van een halve meter dicht krijgen (naarmate de jaren toenemen). Dat haal je niet zomaar in een living wall systeem. Massa is belangrijk voor prestatie van ecosysteemdiensten: gewicht en grootte bladerdek/plant. Algemene ranking van laag naar hoog in actieve biomassa: succulents – grasses – perennials – shurbs – trees.

Kunt u iets zeggen over het verdampingsratio van deze plantensoorten?
Verdamping van vetplanten is het laagst. Grassen is discutabel. Over het algemeen laag, maar soms juist weer veel effect. Algemene ranking van laag naar hoog: succulents – grasses – perennials – shurbs. Maar hoeveelheid biomassa/dichtheid bladerdek is hierbij ook weer erg belangrijk. Hoe meer bladeren/biomassa, hoe meer verdamping.

Als het gaat om luchtzuivering blijkt porositeit van de bladeren, kleine bladeren, en planten met harige en ruwe bladeren beter te presteren. Is het mogelijk de verschillende plantensoorten op basis van deze kenmerken te beoordelen?
Harig, ruw en fijnverdeeld blad. Kleinere bladeren zorgen voor hogere porositeit en luchtdoorstroming, wat belangrijk is voor luchtzuivering. Maar bij kleine bladeren moet het dan wel een dicht bladerdek zijn. Men zegt dat vetplanten het relatief goed doen in luchtzuivering vanwege het ruwe oppervlak.
Algemene rating in luchtzuivering van planttypen is niet mogelijk. Het gaat om specifieke bladeigenschappen en vooral om hoeveelheid blad.
Plek in de stad is nog belangrijk. Luchtkwaliteit is vooral slecht in plekken waar lucht niet weg kan. In street canyons kunnen bomen de luchtkwaliteit verslechteren en VGS hebben dan vooral potentie.

Welke planttypen zouden kunnen worden gebruikt voor voedselvoorziening? Zit er verschil in prestatie?
Voor mensen is de potentie in voedselvoorziening matig. Geen voedselvoorziening mogelijk bij succulents en grasses. Andere planttypen zouden wel iets kunnen doen. In bak systemen kunnen nog bosbessen. Alleen de meeste planten hebben geen eetbare vruchten.

Appendix 6. Expert interview with dr. ir. M. (Marc) Ottelé.

Marc Ottelé is assistant professor at the TU Delft. His expertise comprises the integrated durability and sustainability of the building envelope. He has published various articles on the subject of vertical greening systems. Besides his academic career, he is working as senior Lead engineer for the Specialism Material science at Heijmans Infra. He was interviewed with regard to his expertise on the ecosystem services of thermal regulation, façade protection and regulation of air quality. Marc Ottelé was interviewed on his expertise of VGS with respect to energy savings, air quality control and weathering control of the façade.

Energy savings
Welke mechanismen bepalen de impact van een verticaal groensysteem op energiebesparing? Ik had gelezen schaduw, verdamping, isolatie en windreductie.

- *Schaduw. Schaduwseffect ontstaat door omgevingscondities en door het systeem. Systeemonderdelen: Een dikker systeem met een lagere porositeit geeft hoger schaduweffect. Living wal systemen beter dan klimop, door het support systeem. Klimop is altijd poreus.*
- *Isolatie.*
    - *Luchtstroming: Luchtstroming, door wind, zorgt voor convectie (energieverlies). Hoe sneller de wind langs het gebouw stroomt, hoe meer energie verlies bij (als er een*

temperatuurverschil is met binnen). Bladeren remmen wind af of zorgen voor een stilstaande luchtlaag, waardoor er minder energieverlies optreedt. Meer stilstaande lucht vergroot isolatievermogen. Daarom heeft een living wall – met fysieke afscheiding en spouw – een hoger isolerend vermogen.
    - *Compleet systeem: effect van poreuze plantenmassa is marginaal tov isolatiematerialen. Living wall systemen hebben een veel groter effect, al is het niet gelijk aan isolatiemateriaal. Dat komt ook door het vochtcomponent. Vochtgehalte werkt negatief tov isolatie.*
- *Verdamping. Verdamping zorgt voor koeling binnen, doordat er geen warmteaccumulatie optreedt in de gevel. Planten hebben een hitte-regulerend vermogen, waarbij de temperatuur in het blad nooit hoger wordt dan 35 graden.*

Verschillende soorten thermische regulatie.

- *Energiebesparing binnen:*
    - *Koeling. Tot 10% energiebesparing op koeling.*
    - *Verwarming. Isolatie.*
- *UHI mitigatie: minder warmteaccumulatie in de gevel (door schaduw, verdamping en isolatie) dus ook minder warmte-afgifte.*

Alles gaat uiteindelijk om temperatuurverschillen. Bij een temp. verschil is er een gradient, die wil je zo klein mogelijk houden. Of de tijdsduur die warmte nodig heeft om van A naar B te gaan (= warmtestroom/heat flux), zo traag mogelijk houden.

Wat is/wat zijn volgens jou belangrijkste indicatoren om energiebesparing te meten.

Temperatuurverschillen is de belangrijkste parameter. Dit meet je op grensvlakken van materialen, om de gradient te bepalen: bij een extra grenslaag is er een extra meetpunt nodig. Bij double-skin facade dan dus drie meetpunten. 1. Op bladerdek, 2. Op support system. 3. Op gevel. Bij living wall zijn er vier meetpunten. 1. Op bladerdek, 2. Op substraat, 3. Op supportsysteem, 4. Op gevel. Je meet hierbij in eerste instantie de oppervlaktetemperatuur.

Voor UHI effect: omgevingstemperatuur (voor VGS) en oppervlaktetemperatuur. Je meet voor VGS op 20 cm van het systeem geen effect, omdat dit temperatuurverschil direct wordt geabsorbeerd in het grote geheel. Maar het effect is er wel degelijk. De latente warmte (reflectie van warmtegolven) is wel voelbaar, de energiebalans/terugkerende warmtestraling wordt anders. Dit effect kun je modelleren. Uiteindelijk heeft dit ook een effect op binnen, minder warmtestroom naar binnen.

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, het support systeem en het irrigatiesysteem. Hoe heeft de keuze voor een systeem effect op de prestatie van energiebesparing?

Substraat is erg bepalend: dikte, type. Type: Mineraal wol is veel beter dan organisch materiaal. Dat heeft te maken met porositeit en vochtvasthoudend vermogen Dit gaat om isolatie, dus in de winter. Voor de zomer is grond beter, omdat het een grotere massa heeft en er veel vochtopslag plaatsvindt. Living wall systemen zijn ten aanzien van bufferend vermogen in opwarming en ook in mitigatie UHI effect altijd beter, doordat er een substraat in zit. Isolatie en verdamping. Evotranspiratie = transpiratie (verdamping door planten) + evoporatie (verdamping substraat). Dus living walls altijd beter.

Planten hebben invloed door porositeit/WLAI. Een dicht bladerdek, want dit vergroot isolerend vermogen door stilstaande lucht en een groter bladoppervlak zorgt voor meer verdamping. Op 1 m^2 gevel, kun je 8 m^2 bladoppervlak hebben. Dit is afhankelijk van type plant. (ook belangrijk

voor luchtkwaliteit belangrijk). Bladverliezend dus ook minder isolerend vermogen vanwege stilstaande lucht. Maar, het kan bij slecht geïsoleerd ook positief bijdrage vanwege een hogere zonstraling op gevel. Oriëntatie van gebouw kan hierin een rol spelen.
Verdampingsratio. Lastig om een beste plantensoort aan te geven, je kunt het koppelen aan categoriën. Succulenten (o.a. sedums) hebben geen hoog verdampingsratio, al dragen ze wel bij door albedo. Middenklasse is alle planten die relatief makkelijk water verdampen.

Support systeem heeft niet echt invloed. Er is geëxperimenteerd met de kleur. Witte/groene achtergrond ipv donker/zwart. De markt ziet hier nog geen kansen in.
Irrigatiesysteem is gekoppeld aan planten en substraat. Belangrijk, maar als faciliatie van substraat en planten. Substraat meest belangrijk, daarna planten.

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?

1. Modular. 2. Continuous. 2. Linear. 3. Double-skin. 4. Direct.

Double-skin heeft meer impact dan direct facade vanwege spouw. Continuous beter dan double-skin vanwege de substraatlaag als extra materiaal. Modular is ongeveer hetzelfde als continuous, uitgezonderingen daargelaten. Aansluiting van panelen zou nog energiegaten kunnen opleveren. Plantenbakken heeft grotere energiegaten. Verschil tussen modulair en continuous kan er wel zijn door bijv. dikte substraat. Geotextile laag heeft minder dik substraat. Linear is in de zomer gunstig vanwege grote termishce massa, in de winter nadelig vanwege vochtgehalte in substraat.

Air quality control
Welke mechanismen bepalen de impact van een verticaal groensysteem op verlengingsduur gevel/energiebesparing/luchtkwaliteit?
Bij fijnstofopname (deeltjes):

- *Zwaartekracht: windvrije zone, zodat deeltjes tot stilstand kunnen komen*
- *Impactie: een hit, deeltje raakt een oppervlak en blijft zitten*

Gasvorminge componenten.
Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, het support systeem en het irrigatiesysteem. Hoe heeft de keuze voor een systeem effect op de prestatie van verlengingsduur gevel/energiebesparing/luchtkwaliteit?
Fijnstof absorbeert aan elk materiaal, maar planten onderscheiden zich vanwege oppervlakverhogend vermogen.
Planten.

- *Meer porositeit > meer stilstaande lucht en*
- *hogere bladoppervlak, zorgen voor hogere filtercapaciteit (voor fijnstof en gasvormige stoffen).*
- *Planttype*
    - *Fijnstof: bladkarakteristieken spelen een rol bij impactie (hoe makkelijk een deeltje aanhecht). Meer haartjes creeert meer oppervlak en ruwer waardoor ze makkelijker blijven zitten. Absorptie is vnl aan buitenkant van bladerdek. Binnenin bladerdek minder vanwege de stilstaande lucht. Gradient: bepaalde luchtstroming om te kunnen filteren, maar niet te veel zodat er niks blijft liggen.*
    - *Gasvormige stoffen: capaciteiten in omzetting van CO_2 of stikstof. Stikstofminnende planten. Er zijn ook planten die VOC in de lucht brengen en daarmee slecht zijn voor luchtkwaliteit. Alleen ze nemen dit vaak ook weer op, dus hiermee voorzichtig zijn in conclusies.*

➔ *Essentie: planten verhogen specifiek oppervlakvergrotend vermogen, waardoor je in potentie meer fijnstof/vervuilende stoffen kunt afvangen*

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?
Klimplant of living wall maakt niet uit. Het gaat vooral om de plantensoort.
Linear systeem vangt minder af vanwege bladoppervlak. Bladhoudende en volgroeide systemen hebben langere periode van impact.

Weathering control of the façade
Welke mechanismen bepalen de impact van een verticaal groensysteem op verlengingsduur gevel?

- *UV-straling*
- *Regen bescherming en daarmee o.a. vorstschade*

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op verlengingsduur gevel/energiebesparing/luchtkwaliteit te meten?
Lastig te meten. Set van variablen. Bijvoorbeeld UV-straling kan coating degraderen. Heeft ook te maken met concentratie van UV. Regen heeft impact door uitspoeling. Vorstschade.
Onderhoudstermijn uitstellen tot 25 jaar bij goede systemen. Dit kan gebaseerd worden op kennis en ervaring. Binaire meting, wel of niet uit te stellen met 25 jaar.

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, , het support systeem en het irrigatiesysteem.
Hoe heeft de keuze voor een systeem effect op de prestatie van verlengingsduur gevel?

Planten. *Bij goed groeiende en vochtabsorberende planten, werkt een houten systeem net zo goed als metaal. Voorwaarde is dat de materialen gekoppeld zijn aan capaciteiten om planten goed te laten groeien. Klimop is daarin heel goed. Bladverliezende planten of minder bedekkende planten werken dan minder goed in levensduur van support systeem en gevel.*
Direct systeem kan ook schade aan de gevel toebrengen. Bij moderne gevelsystemen zal dat geen invloed hebben, behalve de impact van zure lucht. Dit betekent dat bij verwijdering van het systeem de gevel gereinigd of opnieuw geverfd moet worden. Doubleskin en living walls creeert fysieke afstand waardoor dit geen problemen oplevert.

Support systeem. Bij living walls is gevel 100% beschermt en dus levensduurverlengend. Aantasting zit dan in VGS.

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?
Bij living walls is gevel 100% beschermt en dus levensduurverlengend. Aantasting zit dan in VGS. Bij facades werkt het het beste met bladhoudende planten.
Linear system presteert minder omdat het geen jas om de gevel vormt.

Appendix 7. Expert interview with Richard de Bruin

Richard de Bruin is part of Rebel Group. He has a background in building physics and gained experience in this field during his work at Deerns Nederland B.V. He was interviewed due to his expertise in this field.

Welke mechanismen bepalen de impact van een verticaal groensysteem op energiebesparing?
Groene gevels kunnen significant bijdragen aan isolatiewaarde. Een groene gevel verhoogt isolatie door het creëren van een extra spouw, en de gevel zorgt d.m.v. verdamping.
Temperatuurverschil is de drijvende kracht voor warmte om te stromen. Een extra element zorgt voro weerstand.
Wind heeft invloed op de overgangsweerstand. Warmte wordt afgevoerd, en dus blijven temperatuurverschillen groter. Doordat dit effect er ook is bij een gevel is de warmte weerstand iets minder straigthforward.
Het thermisch effect heeft niet alleen invloed op energiebesparing, maar ook thermisch comfort. Dit kan bijdragen aan een hogere productiviteit van werknemers.
Andere mogelijke effecten van een groene gevel zijn minder graffiti, maar ook weer overlast door ongedierte.

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op energiebesparing te meten?
Bouwbesluit geeft richtlijnen voor de minimale isolatiewaarde , in Rc-waarde . Dit drukt de warmte weerstand uit. Hoeveel energie er per m2 door je gevel heen stroomt. 1/warmteweerstand: zoveel warmte stroomt er doorheen. Je dit relatief makkelijk berekenen als je de warmteweerstand, temperatuurverschil en m2 weet. Dit wordt uitgedrukt in gemiddelde per m2. De Rc- waarden kunnen worden verhoogt tot wel 10-20%.

Temperatuurverschillen kunnen worden omgerekend naar de Rc-waarde: Rc is (m2*K/W). K = temperatuurverschil. Om te corrigeren voor verschillende punten is het verstandig om zoveel mogelijk meetpunten te nemen en daarvan het gemiddelde.

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, dus waar het in groeit, het support systeem en het irrigatiesysteem. Welke systeemcomponenten zijn het belangrijkst voor thermal performance?
Wat wel belangrijk is om over na te denken over het vochtgehalte en of dit goed gaat in combinatie met de gevel

Appendix 8. Expert interview with Jesse Bakker

Jesse Bakker is advisor in building physics at ZRi. He started working there after his master's degree in building technology. During his studies he was research assistant on acoustics, in which he gained interest in the acoustic aspects of building technology. Therefore, he wrote his master's thesis on the acoustic performance of VGS. He specifically focused on the noise reduction of low frequencies in the built environment.

Welke mechanismen bepalen de impact van een verticaal groensysteem op geluidsreductie?
Het fysisch mechanisme achter geluidsreductie is fysisch-thermsiche absorptie. Als een geluidsgolf in contact met een geluidsabsorberend oppervlak kan het door wrijving de akoestische energie omzetten in warmte. Een geluidsgolf gaat in de poriën van het absorberend materiaal en daardoor

ontstaat de wrijving. Een hogere porositeit verhoogt daarmee het geluidsabsorberend vermogen. Het absorptie effect zorgt ervoor dat er minder geluid reflecteert en heeft daarmee vooral effect op de geluidsreductie buiten.
Voor de geluidsreductie binnen gaat het vooral om de massa van het systeem of de muur. Dat heeft niet zo zeer te maken met porositeit.

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op geluidsreductie te meten?
Geluid meet je met een microfoon. Je kunt hierbij het verschil tussen twee scenario's meten: met en zonder wand. Om omgevingseffecten te minimaliseren wordt dit veel gedaan in een lab, in een nagalmkamer. Het geluidsniveau wordt doorgaans in decibel. Je kunt geluid als een functie van de tijd: de nagalmtijd meten, dat is het verval in geluidsniveau. Geluidsreductie in decibel is het beste om geluidsreductie van een VGS te meten.
Wat is het verschil tussen dB en dBA?
Het menselijk stemgeluid ligt rond de 1000 Hz en heeft een hogere sensitiviteit rond die geluidsbanden. Het geluidsniveau op andere frequenties klinkt daardoor minder hard ondanks geluidsdruk. De dBA corrigeert voor het menselijk gehoor.
Welke frequenties zijn het belangrijkst voor de impact assessment van verticaal groen?
Verkeer heeft geluid over alle geluidsfrequenties. Ze hebben een groot aandeel in lagere frequenties, maar dat is moeilijk te absorberen. Dat komt omdat de geluidsgolf groter is bij lagere frequenties en dan minder makkelijk te absorberen middels physical-thermal absorptie. Voor het omrekenen naar dBA moet je de verdeling over verschillende octaafbanden.

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, het support systeem en het irrigatiesysteem. Wat zijn de belangrijkste systeemeisen om de impact van het verticaal groensysteem op geluidsreductie te optimaliseren?
Het substraat is het belangrijkst., tot wel 80% van het absorberende effect. De geluidsaborptie van planten is veel minder.

- Wat is de invloed van het substraat?

De porositeit is vnl belangrijk. Een substraat met kleinere poriën, zoals klei, dan heeft het een lagere geluidsabsorptie. Moisture content is ook belangrijk, omdat dit de porositeit vermindert. Perlite bolletjes in potgrond verhoogt geluidsaborptie en waterafvoerend vermogen.

- Wat is de invloed van de planten?

Planten absorberen ook geluid, alleen dit is lastiger te onderzoeken. Een bladerdek moet heel dicht zijn. Hogere WLAI.
De beste planten zijn schaduwminnende planten: die relatief grote bladeren hebben en relatief weinig water nodig hebben.

- Wat is de invloed van het support systeem?

De spouwdikte is belangrijk. Hoe hoger de spouwdikte, hoe lagere geluidsfrequenties geabsorbeerd kunnen worden. De optimale geluidsabsorptie vindt plaats als de spouw precies zo dik is dat de top van een golf op de grens van het support systeem zit (vanaf de muur). Voor een echt goede absorptie op laag frequentieniveau heb je een speciaal absorberend materiaal nodig.

- Wat is de invloed van het irrigatiesysteem?

De invloed van het irrigatiesysteem is heel marginaal. De verdeling van het water, wat ook te maken heeft met porositeit, heeft nog een effect.

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?
De groene facades presteren stukken minder goed dan de living walls vanwege het substraat. De indirecte heeft nog een iets betere prestatie vanwege het luchtgat.

De geotextile felt system presteert zeker minder dan de andere living wall systemen.
De modular living wall is het beste (evt. hydroponisch steenwol). De laag kan best dik worden en het is gelijkmatig verdeeld. Dit is niet het geval bij de linear wall. Daar zorgen de ge gaten voor geluidlekken. Het effect van het systeem hangt af van hoe de bakken zijn geplaatst. De linear green wall heeft een hogere potentie dan de continuous omdat het mogelijk is om de bakken dicht bij elkaar te plaatsen en een dikke laag poreus materiaal toe te passen.

Appendix 9. Expert interview with dr. Gert-Jan Wilbers

Gert-Jan Wilbers is researcher at the Wageningen University & Research. Recently he published an article on the stormwater management of blue-green infrastructures. In this study, he executed a cost-benefit analysis on the impact of various types of blue-green infrastructure. He was interviewed regarding his expertise on stormwater management.

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op storm water retentie te meten? [In uw onderzoek las ik de preventie van riooloverstroming en water storage potential (m3).]

Ik denk zeg maar, het water opvang niet zo, dat is zeg maar vooral belangrijk als je horizontale systemen hebt. Dan kun je regenwater daarin opvangen. Ik verwacht dat dat met een verticaal systeem wat minder is. Wat je natuurlijk wel hebt, is je kunt je water langer vasthouden in je systeem. Storm water management preventie is denk ik niet zo heel relevant, niet zo'n heel groot voordeel, maar wel om het water vast te houden omdat je het groen daarvoor kunt gebruiken. Normaal stroomt het weg in het rioolsysteem. En dan sla je het op in die groene muur. En hoeveel dat dan is dat afhankelijk van welke beplanting je daarvoor gebruikt hebt. Als je er bomen voor hebt, dat heeft een bepaalde watervraag of wateropvang. Dat kan ook met klimplanten zijn en dan heb je weer andere factoren. Maar die zou ik ook moeten opzoeken, dat zou ik zo niet kunnen oplepelen hoeveel water dat kan opvangen. Maar dat is in ieder geval wel een voordeel, dat het water opvangt in het systeem.

En welke indicator zou je daaraan geven? Hoe vind je dat terug in literatuur, of hoe zou je dat meten?
Ja, ik zou dan kiezen voor de jaarlijkse wateropvang. Normaal zou dat water dan afstromen naar het rioolsysteem, dat is water dat je normaal dan moet zuiveren. Dus dat brengt kosten met zich mee en dat zou je kunnen besparen door zo'n groene muur. Dus je zou als indicator kunnen kiezen: vermeden zuiveringskosten voor het rioolsysteem, door de opvang van het groen. Dan kun je hem ook monetair gaan uitdrukken als je wil. En anders is het gewoon kuubs, kubieke meter water opvang van het systeem. Oké. Er is wel informatie beschikbaar over de retentie van het systeem, nl. dat het water dat van het dak afstroomt wordt opgevangen door zo'n systeem.

En heb je dan aan de onderkant iets van een filtratiebak zitten?
Ja, er zijn vaak wel drainagesystemen aan gekoppeld.

Oké, dus dan loopt het van het dak in het drainage systeem en dan gebruiken de planten dat water.
Ja. En er is een gemodelleerde studie die heeft laten zien dat dat de 'run off' verminderd met 55%.
Oh, oké. Ja dat wist ik even niet. Dan heeft het wel een voordeel voor stormwater management. Dan zorg je dat als er een piekbui komt, dat vang je dan eigenlijk op in je drainage systeem daaronder. En dat komt dan niet meer op de straat terecht of in gebouwen, en dat kun je uitdrukken in kuubs.
Oké. En dat is de jaarlijkse opvang ook? *Ja.*

Oké. Dus je zegt: de belangrijkste indicator om wateropvang te meten is de jaarlijkse opvang in kubieke meter en stel je wil het monetariseren dan kun je dat doen met de vermeden zuiveringskosten.
Ja, dat is de makkelijkste. En de tweede, wat we in Noorwegen gedaan hebben, maar dat vereist weer een extra analyse, is dat je in de huidige situatie de 'stormwater damage' berekent voor een bepaald gebied. Ik weet niet of dat dat er is hoor. Maar er zijn altijd schademodellen, dat als een gebied overstroomt met een bepaalde bui, dan heb je een aantal mm water die op straat staan en er worden dan berekeningen gedaan moet hoeveel schade daarmee is aan gebouwen. En als je weet hoeveel water zo'n verticaal groensysteem afvangt, kun je ook uitrekenen hoeveel minder overstroming je dan hebt. En dan kun je ook de reductie in schade berekenen. Maar dat ver hoor, dan moet je echt een heel schademodel hebben liggen al. En als je dat niet hebt, zou ik dat niet doen en dan zou ik voor de makkelijkste gaan en dat is gewoon de vermeden zuiveringskosten. Want dat kun je gewoon direct relateren aan het aantal kubieke meter. Dan heb je hem toch gemonetariseerd.

Ja, de volgende vraag is: Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, dus waar het in groeit – dat kan schuim, vilt of organisch materiaal zijn-, het support systeem en het irrigatiesysteem. Welke systeemcomponenten zijn het belangrijkst als het gaat om storm water management?
Substraat valt denk ik wel mee, of je schuim gebruikt of organisch materiaal, dat zal denk ik wel ongeveer hetzelfde zijn. Het is vooral de dimensie van het drainage systeem, dus hoeveel water je kan opvangen.

Oké, kun je dat uitdrukken in hydraulic loading rate? Is dat de gebruikelijke indicatie ervoor?
Ja, dat zou kunnen. Ik heb in Noorwegen eigenlijk gewoon gerekend met vierkante meters, met sommige maatregelen het aantal kubieke meters dat je in het systeem kan opvangen. Dus het aantal kubieke meter per uur bijvoorbeeld. Dat is eigenlijk voor water het belangrijkste. Het irrigatiesysteem zelf bepaalt meer de manier waarop je irrigeert, maar dat is voor de wateropvang wat minder relevant.

Dus eigenlijk gaat het voornamelijk om het substraat, en hoeveel water daarin opgevangen kan worden. En jij denkt dat het dan niet zoveel uitmaakt of dat schuim is, of organisch materiaal.
Nou, het maakt uiteindelijk wel uit hoor. Maar dat heeft ermee te maken hoeveel porieruimte je overhoudt in bepaalde materialen. Daar kan dat water inzitten, dat verschilt wel per medium dat je gebruikt, maar ik vermoed even heel snel gezegd, dat dat niet de meest dominante factor is. Dat is meer de grote, de dimensie van dat drainage systeem, dat uiteindelijk bepaald hoeveel water er opgevangen kan worden.

Zijn er nog aan het support systeem of de planten – is dat nog belangrijk?

Ja, die planten, dat heeft eigenlijk te maken met het belangrijkste doel van het verticaal groen. Is dat om piekbuien op te vangen of is dat om ook reguliere, om gewoon minder afstroom te hebben naar het rioolsysteem, om een meer gescheiden systeem te hebben.

Goed om te weten, dat zijn dus twee verschillende doelen.

Als je het wil hebben om minder water naar het riool te hebben, gewoon als afscheidingssysteem, dan zou je het beste kunnen kiezen voor planten die - in Nederlands tenminste – die behoorlijk wat water verbruiken. Dan heb je gewoon meer water wat je afkoppelt.

Dan kijk je dus eigenlijk naar het verdampingsratio van een plant.

Ja, precies. En als het gaat om storm water management, dan gaat het om dat je de opvang bassin of dat drainagesysteem zo groot mogelijk maakt. Dat zijn piekbuien die je dan af wil vangen, dan is eigenlijk gewoon de opslagcapaciteit van je systeem belangrijker dan het groen. Dus het ligt er maar net aan welk doel je wil bereiken.

Oké, goed om te weten. Dus voor stormwater management is de opvangcapaciteit belangrijker en als het gaat om reguliere vermindering van afstroom naar het riool is het verdampingsratio van de planten belangrijker.

Ja, hoe meer water die planten dan verdampen hoe minder water je rioolsysteem hebt.

Ja, duidelijk. Samenvattend, volgens jou zijn dus de belangrijkste systeemonderdelen om het verticaal groensysteem voor waterretentie te optimaliseren, dan zijn dat eigenlijk – als ik het goed begrijp – dan is de opvangcapaciteit het belangrijkste.

Ja, als het echt gaat om stormwater management, dan wel ja. En wat verder wel belangrijk is – dat is iets minder mijn vakgebied – is dat je moet kijken voor die verschillende systemen hoe klimaatbestendig ze zijn. Je hebt natuurlijk ook in Nederland steeds vaker droogteperiodes, dus als je kiest voor planten met een hoog verdampingsratio dan moet je er ook op letten dat ze een paar weken zonder water kunnen. Ja, of dat je dan weer een systeem hebt dat je het water handmatig bijvult, maar dat is dan weer een extra kostenpost. Dus dat is dan ook iets waar je bij het ontwerp rekening mee moet houden, de veerkracht van de planten. Anders heb je zomaar weer een extra kostenpost te pakken om ze in leven te houden in droogteperiodes. Daar zit ook niet iedereen op te wachten.

Ja. En dan heb je nog, als je de systemen ziet die ik je heb opgestuurd, zou je een waardering kunnen geven van 1 tot 5 welke de meeste potentie hebben in wateropvang.

Nee, dat kan ik zo niet heel snel zien, omdat het voor de wateropvang meer belangrijk is hoe dat systeem onder de grond precies zit.

En met onder de grond bedoel je het drainagesysteem?

Ja. Ik kan me ook voorstellen dat het ene systeem grotere opvang nodig heeft dan het andere. Als ik bijvoorbeeld zie, de linear green wall, dan stel ik me voor dat het gewoon via het dak via een drainageysteem in die bakken terecht komt. Nou ja, die bakken zouden dus je opvangcapaciteit zijn, dus de grootte van die bakken en het substraat daarin. Maar je hebt daarboven er twee staan, die green façades, dan zou je in de ondergrond een filtratiebassin kunnen maken. En dan is het een beetje afhankelijk van dat bassin hoe groot de opslagcapaciteit is.

Oké, dus voor klimplanten die gewoon in de grond staan, dan is eigenlijk de opvangpotentie niet zo heel groot?

Nee, dan zou de opvang niet zo groot zijn. Dan zou het meer zijn dat je koelende of klimaat regulerende effecten hebt, maar qua opvang zou dat niet zoveel doen.
Nee, dus het gaat echt om het substraat eigenlijk.
Nee, dus als het gaat om die bovenste twee gaat, die green facades, dan vangt het niet zoveel op als het gewoon in de normale grond staat. Maar die linear green wall en die andere, die hebben natuurlijk wel een opvangcapaciteit. Want dat is dan het water dat in die bakken verblijft. Dat zou zonder die bakken dan gewoon in het riool terecht komen. Maar dat zou bij die green façades minimaal zijn.

En zou je, zoals je dat nu ziet, nog iets kunnen zeggen over de opvangcapaciteit van die onderste drie: die living walls? Of kun je dat op basis van deze informatie niet precies bepalen.
Nee, dat kan ik zo niet precies bepalen. Dat hangt af van de opvangcapaciteit van die bakken en het substraat dat daar gebruikt wordt.

Appendix 10. Expert interview with ir. Sitong Luo

Sitong Luo is a landscape architect and researcher at the Landscape Architecture & Spatial Planning group, Wageningen University & Research. She is also a research fellow at Amsterdam Institute for Advanced Metropolitan Solutions (AMS), where she engages in exploring green infrastructure solutions in urban settings and translates scientific knowledge into real-life living labs with the approach of research by design. In her research and practice, the focus is given to urban interstitial spaces – the small-scale leftover spaces inside the city that opens for the occupation of diverse informal social practices and ecological processes.

Welke mechanismen bepalen de impact van een verticaal groensysteem op aesthetic value?
Aesthetics is part of the cultural ecosystem services. There are three main classifications within the cultural ecosystem services, which each has different categories. The perception of nature, the aesthetics mainly, belongs to the mental benefits. There are also physical benefits, for example, recreation. The mental benefits are often measured by means of interviews with questions on the perception of the green space. This perception can be related to, for example, perceived safety or likeability.

Wat is/wat zijn volgens u de key performance indicator(s) om de impact op aesthetic value te meten?
There are no standard indicators or criteria for the evaluation of aesthetics, each research defines their own. The evaluation is hardly quantitative, but mostly qualitative. Aesthetics does not refer to the urban scale. Aesthetic value is related to the specific measure on local scale.
There are certain criteria for architectural design (not specifically aesthetics), which are:
- *Unity: you need unity to feel safe, or familiar.*
- *Balance. A balance in the composition is desired. It is all about balance between unity, but also a surprise or highlights. This is also related more to the urban scale.*
- *Enclosure: . Enclosure means that you need a defined space with clear boundaries, although this might not relate to vertical green. When you know the boundaries of a certain green space you are more attached to it.*
- *Rhythm. Rhythm is about predictability of a pattern. With vertical green this could relate to a pattern of flowering or a pattern in which buildings are greened.*

The recreational benefit is related to the interaction with the green space. This might be enhanced through vertical farming. It can be measured by the time spent in interaction with the greenery, for *example by how much people walk through a street with vertical greenery. This could be monitored by amount of people passing by at different times. This is a first part of measuring, which should be complemented by interviews with questions on how often people walk there and why.*

Een VGS bestaat uit vier belangrijke systeemcomponenten: de planten, het substraat, het support systeem en het irrigatiesysteem. Hoe heeft de keuze voor een systeem effect op de prestatie van aesthetic value?
From this structure, you can create a gradient between more artificial and natural façades. The valuing depends on how you define aesthetics, from which perspective.

- *Green façades are more natural. Aesthetics also refers to getting close nature. The aesthetic value of green façades is mainly characterized by the natural value, which can be very encompassing to people.*
- *The living walls facilitate the creation of an interesting pattern no the wall, for example by the planter boxes. This is another way of aesthetics, which is more on the artistic value.*

Aesthetics is mainly about how the structure is implemented on the building. It should be designed according to certain characteristics, different types of architecture have different design styles. It is not okay to implement VGS very generically on building façades.

Wat is de invloed van de verschillende systeemonderdelen?
The plants are most important part of the VGS, with regard to the aesthetic value. The choice of plants is again context-dependent. Coverage of green. Texture and shape of leaves. Succulents are more hard, ivies are more soft. A mixture of plants and patterns enhances natural value. Green façades with different types of plants are likely to be preferred. Seasonal effect can be considered. To a certain level, (bio)diversity and a sense of wilderness is positively related to aesthetics. But when it's too much, people start to dislike it.

Kunt u met een score van 1-10 een waardering toekennen aan de impact van de verschillende onderstaande systemen?
The evaluation of different systems is context-dependent. Rating of different visualizations is a most relevant approach for evaluation, by experts but more importantly by local residents.

Appendix 11. Case study: validation and discussion

Methodological details

In order to validate the MCDM model, a meeting with the decision-makers of Virgo Aalsmeer was organized. In this project, the landscape architect and the architect were the main decision-makers. Earlier contact was made at a case visit and at a later stage of the research, the researcher reached out to them. At the start of the meeting, the main objective, methods of the research as well as the developed model were explained by the researcher. The intentions of the meeting, to test the model and gain insights in the decision-making process of the case-study, were openly shared. Although the discussion was organized as an unstructured interview, the questions below were prepared on forehand. During the meeting, the researcher was focused on finding an answer to these questions. As the meeting was held in Dutch, these questions were prepared in Dutch as well.

Discussion guide

- Wie waren betrokken in de keuze voor het verticaal groen?

- Kunnen jullie het proces – van deze keuze – kort toelichten? (Waren er obstakels of *meningsverschillen?)*
- Wat waren de belangrijkste beweegredenen voor dit systeem?
- Waarom waren dit de belangrijkste beweegredenen in deze casus?
- Zijn er naast de ecosysteemdiensten die ik in mijn model heb meegenomen nog andere factoren die een rol hebben gespeeld? Speelden deze factoren een grote rol?

Report of meeting

uitleg model en doel van meeting Dieuwertje: Wat heeft bij jullie een rol gespeeld?

Joost: Ik ben aan het denken wat de belangrijkste beweegredenen waren.

- Bij die living walls ben je afhankelijk van een irrigatiesysteem. In Aalsmeer is ook een waterleiding, maar klimplanten hebben ook als die irrigatie het niet doet de mogelijkheid om door te groeien omdat ze in de volle grond staan. Dus dat was een van de redenen, in ieder geval in mijn hoofd. Je geeft die plant meer autonomie, dus dat die niet volledig afhankelijk is van een extern systeem wat mij moeten controleren. Dat is één ding.
- Daarnaast was er nog een ding, en dat heeft eigenlijk met hetzelfde te maken en is meer een gevoelskwestie. Een plant in een bak, of een plant op een gevel blijft altijd iets kunstmatigs houden. Een plant in de volle grond heeft toch een andere beleving, dat kun je misschien onder aesthetic value scharen. Planten horen in de grond, zeg maar. Een plant in een systeem blijft altijd iets kunstmatigs houden. Dus het gaat ook om het gevoel dat het opwekt. Dat heeft ook te maken met biophilia.
  Dus een plant die in de volle grond staat heeft voor mij een andere laag: meer autonomie en een andere beleving.

Diederik: Past ook beter bij het hele ontwerp. Als je kiest voor een systeem met plantenbakken wordt het een esthetisch iets, met patronen etc. Dan maak je het echt meer een ontwerp onderdeel. Terwijl wij hebben gezegd: dat hoeft het niet te zijn, het is gewoon de natuur die tegen het gebouw aangroeit en dat hoeft niet ontworpen te zijn. Dat is ook waarom ik denk dat we zeiden: die bakjes zijn te tuttig, vooral op de schaal van dit gebouw.

Joost: we wilden de planten de mogelijkheid geven om grillig te kunnen groeien. Er zullen wel plekken zijn die niet helemaal groeien, maar daar tegenover plekken die heel veel begroeien. Die losheid, dat de plant een soort autonomie heeft, is een laag die we mee hebben genomen. Net als het inzaaien van planten in de daktuin: planten ontkiemen op de plekken waar ze zich goed voelen. We geven meer ruimte aan de natuur en dan is het niet erg als een plant een keer niet groeit, dat hoort er dan bij. Dat is ook wel hoe we het hebben ingestoken. Ook de keuze voor verschillende soorten bomen, in plaats van één. Om de biodiversiteit te vergroten en de plant de mogelijkheid te geven om autonomie te hebben daarin. Dus die aesthetic value, die had je als criterium, die is heel context-specifiek denk ik. Het hangt af van de plek wat de voorkeur heeft. Dus dat is een lastige weging denk ik.

Diederik: en dit soort panden zijn dan net niet geschikt, of lijken minder geschikt, voor een living wall. Dat hebben we in Almelo ook onderzocht. Allereerst, viel men van de stoel van wat dat dan ging kosten. Daarbij kun je je afvragen, hoe ziet het eruit en wat gaat het doen. Een grondgebonden systeem heeft aan twee kanten waarde. In Almelo is het nl. een losstaand scherm. Ik denk dat de schaal van dit soort projecten zich niet echt leent voor zo’n living wall systeem.

Dieuwertje: Want jij denkt dat het financieel-technisch niet haalbaar is?

Diederik: Nou het is misschien wel mogelijk, het is natuurlijk wel veel kostbaarder dan zo'n grondgebonden systeem.

Joost: Het kostenaspect is ook wel echt een punt. De planten zijn nooit echt de kosten (tenzij je zegt: ik wil hoger dan 60m), zo'n sandwichpaneel als gevel is misschien wel 60x zoveel. Maar zo'n systeem kost wel veel. Tegelijkertijd, vind ik het ook altijd een beetje lastig hoe ze eindigen op de grond. Ze kunnen net niet de grond raken. Terwijl een klimplant groeit gewoon vanuit de grond. Het belangrijkste vind ik dat de plant niet afhankelijk wordt van onze irrigatie, en dat als de voeding uit die matten is, dat we er voeding aan geven. Dat je de planten 24/7 aan een infuus geeft. Daar wilden we vanaf: vanuit praktisch, maar ook vanuit symbolisch oogpunt. Je kunt je nl. afvragen hoe duurzaam dat is.
Over veel van de waarden in jouw model hebben we niet echt nagedacht. We hebben vooral, met de ecoloog, gekeken naar lokale ecologische waarde: wat is er in de omgeving, en waar kunnen we op aansluiten? De soorten die we hebben gekozen zijn tot stand gekomen met de ecoloog. Dus die laag zit erin. Daarbij heb ik ook gekeken naar de locatie. Een DC is een hele menselijke, technische omgeving. We wilden dat die buitenruimte daar een contrast in was. Dus juist niet aangelegd, maar dat het mag verruigen. Ik heb ook vooral op dat aspect ontworpen. Dus dat het mag verruigen, en dat het niet alleen een plek is die interessant is voor mensen, maar ook voor flora en fauna. Maar over waarden zoals noise reduction hebben wij niet nagedacht. En daarin kan het systeem dat jouw model aangeeft wel heel veel waarde geven denk ik.

Diederik: daar waar het nuttig is. Dat zijn denk ik ook vaak de plekken waar je geen ruimte hebt voor grondgebonden systemen, zoals urban areas. Qua budget is het in de context van een DC ook echt extra, en veel in vergelijking met de gevel (verdriedubbeling van gevelkosten). Bij kantoren is het misschien in plaats van iets, en vallen de kosten denk ik sneller weg. Dus als je het doet, zo'n living wall, is het meer een statement. Maar ik denk dat het minder meerwaarde geeft naar de punten die Joost noemde.

Joost: Een DC is een gigantisch gebouw met bedrijfsfunctie. Mensen komen er om te werken en zien ook de buitenkant niet zoveel. Ik kan me voorstellen dat er in de stad meer ogen naar de gevel kijken. Meer waarden en er is dan ook meer sociale controle van of er water nodig is. Hoe zit dat in jouw model, die speling?

Toelichting biodiversiteit en context-specifieke waardering Dieuwertje: Je gaf aan dat er een ecoloog werd betrokken voor de keuze van een plant, was de keuze voor een klimplant toen al gemaakt of speelde een living wall ook een rol?

Joost: Nee, we hebben vanaf het begin het niet over zo'n systeem gehad. En volgens mij viel het ook direct af vanwege de kosten, omdat het gewoon veel te duur was. We hebben wel een afweging gemaakt tussen een direct en indirect systeem. En uiteindelijk hebben we gekozen voor een indirect systeem: deels om de gevel te beschermen en ook om meer keuze te hebben in verschillende planten soorten. En bij die soorten heb ik met de ecoloog gekeken naar aspecten als nectar, maar ook esthetische waarde, bijv. door te kiezen voor deels groenblijvende en deels verkleurende soorten. Er staan drie verschillende soorten planten.

Diederik: In Almelo is een heel Excel ontwikkeld om een waardering te geven aan biodiversiteit.

Joost: Almelo was daarin een volgende stap, en Aalsmeer was in die zin een soort pilot. En ook een eerste reken exercitie.

Diederik: Ik denk dat het ook een rol speelt wie er om tafel zit, welk systeem er wordt gekozen. Zo kiest een architect wellicht sneller voor een living wall, omdat je dan nog invloed kan hebben op het ontwerp. En vanuit het oogpunt van een landschapsarchitect of ecoloog kiest men misschien weer sneller voor een klimplant.

Joost: ik ben nog wel benieuwd naar de waardering in biodiversiteit.

korte toelichting biodiversiteit Dieuwertje: Nog één laatste vraag: Wie hadden er invloed op/waren betrokken bij de keuze?

Joost: Keuze voor de planten of de keuze voor het systeem?

Dieuwertje: Beide

Joost: De keuze voor de planten heb ik gedaan met de ecoloog. Dat is logisch, want hier heb ik ook meer verstand van. Dat is onze rol. Heembouw geeft aan wat ze willen bereiken en dan kies ik daar de juiste soorten voor. En de keuze voor het systeem was heel erg samen. Bijv. de keuze voor een indirect systeem ipv direct, was echt in overleg. Dit was een samenwerking tussen architect en landschapsarchitect.

Diederik: Keuze voor grondgebonden kwam ook wel vanuit jou. Omdat dat meer dat natuurlijke uitstraalt, omdat ik aangaf dat we wilde. En je kwam ook met de kosten.

Joost: Nog een laatste opmerking. Ik denk dat dat model superinteressant is. Nu hebben we gewoon gekeken naar: wat is het beeld, hoe kunnen we dat ecologisch doen en wat zijn de kosten. Dat waren de voornaamste criteria. En hoe kun je het duurzaam laten groeien: in die zin dat het langer door kan gaan. Het kan dan ook helpen om je opdrachtgever van de waarde van een systeem te overtuigen. Aan de andere kant kun je je afvragen hoe relevant aspecten zoals noise reduction zijn in de context van DC's.

Diederik: Nou ja, DC's worden wel steeds meer ook richting de stedelijke context gebracht. Dan zijn dat soort factoren wel relevant.

Joost: Dat is waar. Daarom is het vooral ook belangrijk dat we die weegfactoren nu weten. Dus ook al heb je er bij sommige nog geen kwantitatief resultaat van, maar dat je weet dat het een thema is en dat dat samenhangt