Towards a more nature-inclusive and climate resilient built environment

-

A framework and tool for the economic valuation of the costs and benefits associated with the implementation of vertical greening systems on buildings

Faculty of Civil Engineering and Geosciences

TU Delft Delft University of Technology

SWECO

(This page is intentionally left blank)

Towards a nature-inclusive and climate resilient built environment

-

A framework and tool for the economic valuation of the costs and benefits associated with the implementation of vertical greening systems on buildings

MSc. Thesis Report

by

Guy Janssen

In partial fulfilment of the requirements for the degree of

Master of Science
in Civil Engineering

at the Delft University of Technology,
to be defended publicly on Wednesday January 25, 2023 at 10:00 AM.

Student number:	4440021	
Institution:	Delft University of Technology, Faculty of Civil Engineering and Geosciences	
Graduation company:	Sweco Nederland	
Graduation committee:	Prof. dr. H.M. Jonkers,	TU Delft, chairman
	Dr. D.F.J. Schraven,	TU Delft
	Ir. R. Crielaard,	TU Delft
Company supervisors:	MSc. E.J. van de Ridder,	Sweco Nederland
	MSc. G.R. Meijer,	Sweco Nederland

An electronic version of this thesis is available at http://repository.tudelft.nl/.

Colophon

Graduation committee

Prof.dr. H.M. (Henk) Jonkers
Chairman graduation committee
Faculty of Civil Engineering and Geosciences
Department 3MD – Section Materials & Environment

Dr. D.F.J. (Daan) Schraven
Supervisor from Delft University of Technology
Faculty of Civil Engineering and Geosciences
Department 3MD – Section Integral Design & Management

Ir. R. (Roy) Crielaard
Supervisor from Delft University of Technology
Faculty of Civil Engineering and Geosciences
Department 3MD – Section Applied Mechanics

MSc. E.J. (Jelmer) van de Ridder
Company supervisor from Sweco Nederland
Project Leader & Consultant - Climate Adaptation | Water Management | Urban Planning

MSc. G.R. (Gijs) Meijer
Company supervisor from Sweco Nederland
Consultant - Biodiversity | Ecology | Natural law

Graduate student

G.L.E. (Guy) Janssen
Faculty of Civil Engineering and Geosciences
Master Civil Engineering - Track Building Engineering
Student number: 4440021

Preface

Before you lies the final product of my master thesis, which delves into the economic valuation of the costs and benefits of vertical greening systems (VGS). This thesis concludes my time at Delft University of Technology, as it comprises the final part in the curriculum of the master Building Engineering at the Faculty of Civil Engineering and Geosciences. The research was conducted in collaboration with Sweco Nederland. Although I more than happily engaged in the specialisation 'Structural Design', my interests stretched beyond this domain and with this thesis work I got the opportunity to further expand my knowledge in a developing field of study in the built environment: nature-inclusive design. I gladly take along the lessons learned from this cross-disciplinary research on my path to a professional career.

With this research the aim was to make a small contribution to solving the worldwide problem of climate change, especially its resulting impact on the living environment. Numerous solutions are worthy of investigation in this regard. Yet, being interested in building designs and their interaction with nature, observing a lack of this interaction in urban areas and having followed the course 'CIE4100 - Materials & Ecological Engineering', my interests were drawn to benefits of nature-inclusive design. Initial literature review and conversations with committee members, company supervisors and other experts in the field, allowed me to demarcate to vertical greening systems (VGS): an innovative type of solution for adding green in high-density urban areas. This report includes the complete process to arrive at an economic valuation framework for these systems and describes the development of the first version of a 'VGS Valuation Tool', which can guide professionals in their consultancy efforts.

This thesis is a product of a continuous learning process in an innovative field of study and did not come to being without setbacks. Therefore, I would like to express my gratitude to all the members of my graduation committee. Prof.dr. Henk Jonkers, Dr. Daan Schraven and Ir. Roy Crielaard of Delft University of Technology: for urging me to narrow the scope, for their critical thoughts and feedback and for their academic guidance, which improved the quality of my work. Furthermore MSc. Jelmer van de Ridder, MSc. Gijs Meijer and MSc. Jeroen van Eekelen of Sweco as daily supervisors: for their continuous time and support, both professionally and personally, for our sparring sessions and check-ins, for providing me with openings and contacts in the company and industry. Also, I want to thank all other Sweco colleagues and fellow interns, as well as study peers from Delft University of Technology for their interest and help at any given point in the project and for the cooperation during our study.

On a personal note, I could not have come this far without the unconditional support of those who are dear to me. I would like to thank my parents, girlfriend, family, friends and roommates. For providing me with opportunities in life, for their token of appreciation and expression of interest in my journey, for encouraging and motivating me in times of little advancements, for providing me with welcome and pleasant distractions and for helping me to put things in perspective. Thanks for the patience and for always standing by my side. Not only in the past year, but also all previous years of my life. Your motivation and support means a lot to me.

I hope you enjoy reading this thesis work!

Guy Janssen
Maastricht, January 2023

Summary

Introduction

The application of vertical greening systems (VGS) onto building envelopes constitutes an innovative way to implement more green in the living environment. Especially in dense urban areas, where only limited space is available to integrate more horizontal greening at ground level, VGS have the potential to contribute towards creating a greener, healthier, more nature-inclusive and climate resilient urban environment. This by facilitating and contributing to natural ecosystem functioning, hence providing ecosystem services and through those, benefits for society. These benefits include among others an enhanced microclimate, biodiversity and aesthetic appeal, as well as improved physical and mental health, thermal performance, energy efficiency and air quality, and reduction of urban heat island effect and noise disturbance.

Although the amount of studies that are conducted with regards to individual cost or benefit attributes of VGS is increasing, content and knowledge regarding economic valuation of the complete set of cost and benefit is still lacking. The major problem is that studies are not sufficiently linked, nor comprehensive, nor do they focus on the utilization perspective of economic valuation as basis for decision-making. Furthermore, the studies available do not attribute values of perceived costs and benefits to different stakeholder groups involved.

In order to substantiate the total set of costs and benefits associated with VGS implementation and enhance rational decision-making, in present research the development of a framework and interactive economic valuation tool is proposed. Moreover, the valuation tool should be open for further expansion and integration of additional values or starting principles, for whenever new scientific insights become available. To fulfil this development objective, the following main research question was formulated:

> *What framework and tool can be proposed to economically value the costs and benefits of vertical greening systems within the built environment and how can these costs and benefits be attributed among different stakeholders involved?*

Methodology

In order to adhere to the development of the framework and tool, the research was divided into four sub-questions which were aligned with a development cycle that consists of the following phases: analysis, synthesis, simulation, and evaluation. Initially, literature research and exploratory conversations were performed into current state of the art. At the end of this analysis phase, a valuation method and further scope demarcation was determined. During the synthesis phase, a decision-support framework and user-friendly Excel tool were designed and developed. Hereafter, in the simulation phase the VGS Valuation Tool was demonstrated using a case study and validated by means of a user experiment. This provided both insight into the functional and technical capacities of tool input, as well as feedback from the anticipated end users regarding utilization perspective. In the evaluation phase a discussion was initiated, also interpreting the research results. Finally, conclusions were drawn and future recommendations were provided.

Framework

An economic valuation framework and tool were developed which can support the decision-making process regarding VGS application. For a visual representation of the framework, user and automated tool workflow, reference is made to the figures at the end of this summary.

The framework is based on Life Cycle Cost Analysis (LCCA) and Social Cost Benefit Analysis (SCBA). These analyses relate to real estate investors and society (resident focus) respectively. To assess and report on the values of the costs and benefits of these innovative systems, distinct themes were established. The cost themes entail financial costs, environmental costs and potential Ecosystem Disservices. Benefits are distributed over the themes health & well-being, climate adaptation & mitigation, real estate, social & recreational & commercial and biodiversity. This classification builds on literature regarding Ecosystem Services Valuation (ESV), Ecosystem Services Cascade (ESC) framework, the approach of 'Integrated Valuation of Ecosystem Services' and several previously developed tools. Also the themes are related to societal challenges in the living environment and urban planning.

Results and validation

A utilization focussed, interactive tool was designed and established in MS-Excel. In the current version, the tool's infrastructure is full-fledged and operational. First, an extensive tab with background information and a user guide are provided. Then in the input section, the users have to choose several starting principles for valuation and manually insert parameters for case specific and indicator specific input variables. Next, the result section directly displays and visualizes the final outcomes of the analyses in a result dashboard. The cost and benefit sections automatically perform value calculations for the established indicators through identified valuation methods, then providing data used in the result section. They also serve as reference for methodologic transparency.

The results section of the tool provides the user with a total analyses results table. Moreover, the result dashboard provides graphical visualisations of the contributions of different themes and categories towards the total costs and benefits of VGS, by means of charts and graphs. Indicators for economic feasibility are the Net Present Value (NPV) and Benefit-Cost ratio (B/C-ratio). With this, consultants can provide more substantiated advice to clients who are interested in adopting green measures for real estate objects.

Based on a case study, provisional results for a (Modular) LWS were obtained, while this also demonstrated the proceedings for the valuation tool. The current version of the tool is able to perform quantification and monetisation for financial costs, large parts of the environmental costs, reduction of airborne PM_{10}, increased rental incomes (investors) and rental costs (residents), reduced energy usage for heating and MIA & Vamil tax incentives. Based on implemented valuation methods, the case study delivers project specific results. Though, it is explicitly noted that these results do not yet provide a complete representation of all costs and benefits, due to a limited number of (benefit) indicators that are monetised. Hence, this version of the tool should be regarded as initial impetus for further development. This in order to ultimately obtain an all-encompassing VGS Valuation Tool, fit for project specific economic valuation of costs and benefits of VGS. The qualitative indicators for costs and benefits are included in the tool for every project, as means of showing future potential.

During a user experiment, practitioners from Sweco qualitatively validated the user experience, intuitiveness, utilization perspective and future value of the VGS Valuation Tool. This confirmed the soundness and comprehensiveness of the framework and tool. Also minor improvements to the current tool version were suggested and valuable input was provided to enhance its application for consultancy within the organisation.

Conclusion & Recommendations

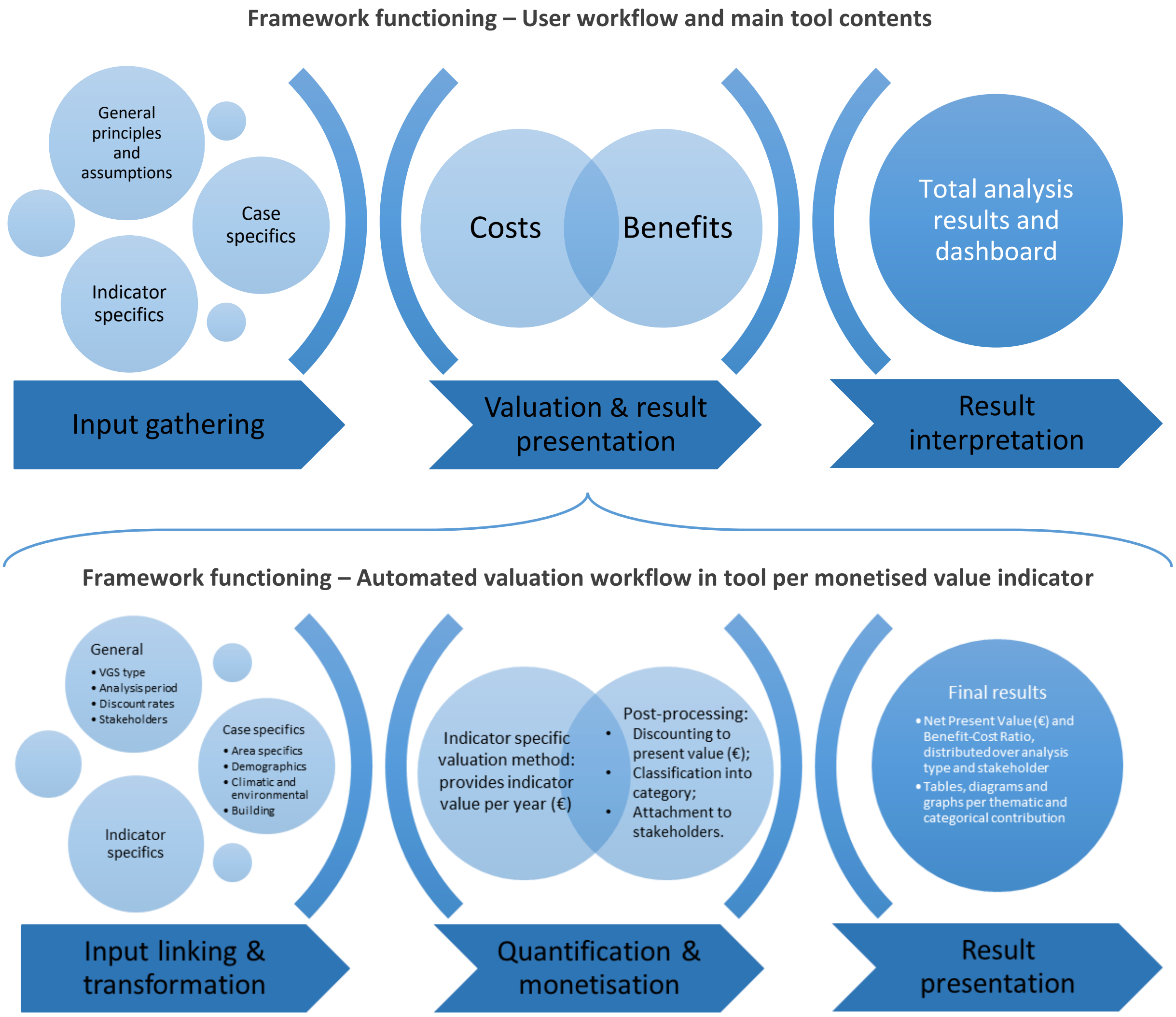
In the end, this research provisionally satisfied the main research goal of developing an economic valuation framework and tool supporting decision-making with regards to application of VGS. Appropriate economic analysis were applied to which different stakeholders could relate. Distinct valuation methods for several costs and benefit indicators were used and elaborated.

To merge this all, a utilization focussed framework and tool were designed and established in Excel enabling decision-support, with consultants being the most prominent anticipated end users. The result dashboard visualises the valuation outcomes and results in clear tables and graphs, generating insights into the contribution of different themes towards the total costs and benefits of VGS. This can initiate further recommendations for a research agenda into distinct aspects of certain VGS. Also, in the future consultants can offer more substantiated guidance to clients, who might be interested in adopting green measures in the built environment. Hence, the VGS Valuation tool could

become a conversational mechanism or steering instrument, to stimulate or justify choices for specific types of VGS at given locations. The test panel of anticipated end users was enthusiastic about the comprehensiveness and user experience of the tool and acknowledged its future practical value.

Since this research acts as the initial impetus to develop a comprehensive framework and tool for economic valuation of VGS, the extensive recommendations can also be viewed upon as research results. They contribute to the identification of required research and efforts in order to further enhance valuation results. Recommendations are taking into account scientific purposes, tool extensions and practical and organisational purposes. For enhanced future use and value, the main recommendations are to further integrate cost and benefit calculations for other established indicators and automate the input procedure based on available VGS specific and location specific data. In the end, this should lead to a final version of the VGS Valuation Tool.

To conclude, the developed framework and VGS Valuation Tool show extensive future potential and are highly anticipated by intended end users. Combined with the recommendations for further research, this thesis contributed to the development of knowledge in the innovative field of VGS valuation.



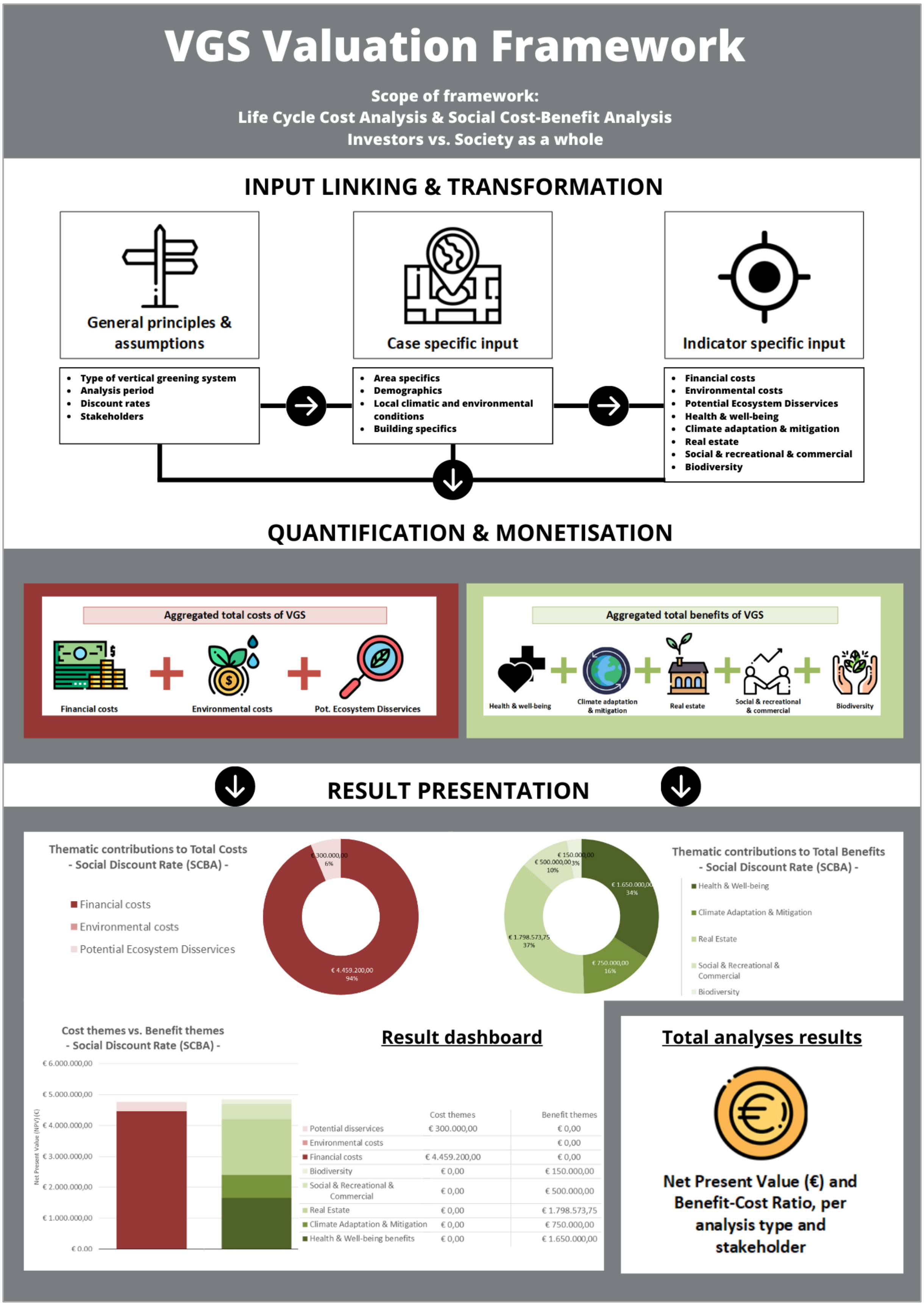

VGS Valuation Framework
Scope of framework:
Life Cycle Cost Analysis & Social Cost-Benefit Analysis
Investors vs. Society as a whole
INPUT LINKING & TRANSFORMATION
General principles & assumptions
Type of vertical greening system
Analysis period
Discount rates
Stakeholders
Case specific input
Area specifics
Demographics
Local climatic and environmental conditions
Building specifics
Indicator specific input
Financial costs
Environmental costs
Potential Ecosystem Disservices
Health & well-being
Climate adaptation & mitigation
Real estate
Social & recreational & commercial
Biodiversity
QUANTIFICATION & MONETISATION
Aggregated total costs of VGS
Financial costs
Environmental costs
Pot. Ecosystem Disservices
Aggregated total benefits of VGS
Health & well-being
Climate adaptation & mitigation
Real estate
Social & recreational & commercial
Biodiversity
RESULT PRESENTATION
Thematic contributions to Total Costs - Social Discount Rate (SCBA) -
Financial costs
Environmental costs
Potential Ecosystem Disservices
€ 300.000,00 6%
€ 4.459.200,00 94%
Thematic contributions to Total Benefits - Social Discount Rate (SCBA) -
Health & Well-being
Climate Adaptation & Mitigation
Real Estate
Social & Recreational & Commercial
Biodiversity
€ 150.000,00 3%
€ 500.000,00 10%
€ 1.650.000,00 34%
€ 1.798.573,75 37%
€ 750.000,00 16%
Cost themes vs. Benefit themes - Social Discount Rate (SCBA) -
Net Present Value (NPV) (€)
€ 6.000.000,00
€ 5.000.000,00
€ 4.000.000,00
€ 3.000.000,00
€ 2.000.000,00
€ 1.000.000,00
€ 0,00
Result dashboard
Cost themes | Benefit themes
Potential disservices | € 300.000,00 | € 0,00
Environmental costs | € 0,00 | € 0,00
Financial costs | € 4.459.200,00 | € 0,00
Biodiversity | € 0,00 | € 150.000,00
Social & Recreational & Commercial | € 0,00 | € 500.000,00
Real Estate | € 0,00 | € 1.798.573,75
Climate Adaptation & Mitigation | € 0,00 | € 750.000,00
Health & Well-being benefits | € 0,00 | € 1.650.000,00
Total analyses results
Net Present Value (€) and Benefit-Cost Ratio, per analysis type and stakeholder

Table of Contents

List of Figures

Main report

Appendices

List of Tables

Main Report

Appendices

Terms and abbreviations

AS	Adaptation services
BCR	Benefit-Cost Ratio
BTM	Benefit Transfer Method
CBA	Cost-Benefit Analysis
CBM	Cost Based Method
CEM	Choice Experiment Method
CVM	Contingent Valuation Method
ECI	Environmental cost indicator
EDS	Ecosystem disservices
EPA	The new Dutch Environment and Planning Act (Omgevingswet)
ES	Ecosystem services
ESC	Ecosystem services cascade
ESV	Ecosystem services valuation
EU	European Union
GDP	Gross Domestic Product
GF	Green Façade
GHG	Greenhouse Gas
HPM	Hedonic Pricing Method
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature
LAI	Leaf area index
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCAV	Life Cycle Added Value
LCCA	Life Cycle Cost Analysis
LCCV	Life Cycle Circular Value
LWS	Living Wall System
MA	Millennium Ecosystem Assessment
MPM	Market Price based Method

NBS	Nature-based solutions
NPV	Net Present Value
PBL	Planbureau voor de Leefomgeving
PBP	Pay Back Period
PCBA	Private Cost-Benefit Analysis
PV	Present value
RIVM	The Dutch national institute for public health and environment (Rijksinstituut voor Volksgezondheid en Milieu)
ROI	Return on Investment
SCBA	Social Cost-Benefit Analysis
TCM	Travel Cost Method
TCS	Total Cost for Society
TEEB	The Economics of Ecosystems and Biodiversity
UHI	Urban Heat Island
UN	United Nations
UNCBD	United Nations Convention on Biological Diversity
VGS	Vertical Greening System
WHO	World Health Organisation
WTA	Willingness To Accept
WTP	Willingness To Pay

1
Introduction

In this first chapter, section 1.1 gives a societal background and personal motivation, which formed the trigger for the thesis work. Reflecting on a preliminary literature research, the scientific relevance of this study is discussed. With help of the identification of research gaps, this will lead to the problem definition of this research in section 1.2. From this, in sections 1.3 and 1.4 the research goals and research questions are derived. In the methodology in section 1.5, a research plan is worked out which should lead to the answers for the sub-questions and subsequently the main research question. Hereafter, in section 1.6 the scope limitations for the study are defined. Ultimately, in section 1.7 the chapter concludes by providing a reading guide for the remainder of the report.

1.1 Motivation and relevance

This section will first delve into the primary triggers and intrinsic motivation for this thesis topic through a societal and personal background, motivation and relevance. Hereafter, the scientific relevance of the research topic, the monetary valuation of vertical greening systems on buildings, is elaborated.

1.1.1 Societal background and motivation

"A code red for humanity. The alarm bells are deafening, and the evidence is irrefutable: greenhouse gas emissions from fossil fuel burning and deforestation are choking our planet and putting billions of people at immediate risk. Global heating is affecting every region on Earth, with many of the changes becoming irreversible." This was the UN Secretary-General's statement on the IPCC 2021 report, dating from August 2021 (United Nations, 2021).

The consequences of climate change are plural and affect us all: from rising sea levels and extreme weather events like heavy rainfall and flooding, extreme heat, droughts, and wildfires, to increased risks for (human) health, loss of wildlife and biodiversity, reduced harvest yields and huge costs for society and the economy. In combination with densification and hard, impervious surfaces in cities, urban areas in particular are extra susceptible to the effects and threats of the imminent climate crisis. This, while nowadays 55% of the world's population lives in urban areas, a figure which is projected to grow to 68% (over 7 billion people) in 2050 (United Nations, 2018). In the Netherlands, being a small but dense country, this number is even as high as 92,2% in 2020 (The World Bank, 2022).

With the building and construction industry contributing to almost 40% of global carbon emissions (of which 10% exists of embodied carbon), the sector has a huge impact on the environment and is one of the drivers of climate change (WorldGBC, 2021). In addition to its 'Net Zero Carbon Buildings Commitment' that urges emission reduction efforts to be prioritised at all opportunities, meaning both the embodied and operational carbon emissions have to be reduced, the WorldGBC also recognizes that in the meantime offsetting residual emissions is critical, in order to achieve those ultimate goals of a net zero carbon built environment in 2050. This, they stated in their update on the recommendations for offsetting emissions: "As part of the transition towards total sector decarbonisation that also enables tangible environment and social co-benefits in support of the UN's

Global Goals for Sustainable Developments (SDGs), WorldGBC also recognises the significant contribution of sector-based compensation offsets, and the role they can play in the short- to medium-term in facilitating systemic change." (Burrows & Watson, 2021).

Where medium- to long-term offsets are usually referred to when talking about technical solutions used to sequester and store carbon (near-) permanently, they are not all commercially available yet. However, short-term offsets or immediate offsets are mostly relying on Nature-based Solutions which are already available. Some examples are reforestation, rewilding and expanding protection of areas of biodiversity. When implemented in a correct way in urban areas, Nature-based Solutions like vertical greening systems can not only help offsetting emissions, but also enable the mitigation of consequences of climate change, by contributing to a more nature-inclusive and climate resilient living environment. This, in combination with their environmental, social and ecological impacts, could benefit all citizens of that particular living environment on multiple levels and contribute to achieving the challenges we face as society today.

Nature-based Solutions in the Netherlands

A growing amount of studies are conducted with regards to the benefits of implementing Nature-based Solutions in the built environment. Although their added value becomes ever more apparent to both scientists as well as practitioners in the field (Teotónio, Silva, & Cruz, 2021), these measures are not standard practice yet in all development or transformation projects in the Dutch built environment. Also, Nature-based Solutions are not yet obligatory in officially applicable legislation, codes or guidelines. Even the new Dutch Environment and Planning Act (EPA, Omgevingswet) does not sufficiently incentivize human implementations with an ecosystem approach (de Graaf, Platjouw, & Tolsma, 2018). This aspect probably contributes to Nature-based Solutions still often being overlooked as a potential piece of the puzzle in relation to creating climate resilient real estate.

However, over the course of the past few years, among others the global climate change (studies), climate disasters and scientific insights regarding the human induced emissions which contribute to these events, led to the emergence and increase of the interest for a more sustainable building sector. This is especially the case among the market's frontrunners. It has led to various parties coming to action in order to lobby for a change in the way we design, arrange and construct our built environment. From enhancing the efficiency in the way architects and engineers design, transitioning from a linear to a circular economy, striving towards using more environmental friendly materials and processes, reducing energy consumption, to implementing nature and enhancing biodiversity in our public spaces; the building industry is searching for cross pollination with several other disciplines in order to trigger a sector transformation for the sake of building a better world.

In the Netherlands, companies like Sweco (architectural, engineering and consultancy firms), Ballast Nedam Development (contractors and project developers) and real estate investors like e.g. Vesteda signed the 'Manifest Bouwen voor Natuur' in 2021. Additionally, last year Sweco dedicated their yearly research theme via the platform 'Urban Insight' to smart, healthy and climate adaptive urban environments. Ballast Nedam Development initiated their own Building Decree, exceeding the minimum demands set in the current 'Bouwbesluit 2012'. Especially their devotion in the field of nature-inclusive developments stands out and it obliges for a new way of designing urban areas and development projects. Together with NL Greenlabel they started a petition that advocates for obligations with regards to nature-inclusive building in the new Dutch EPA.

1.1.2 Personal background and motivation

Ever since I can remember, I was attracted to the interaction between buildings and their natural environment. This attraction was probably mostly fuelled by beautiful designs in which buildings merge with their surroundings and where wide views of epic sceneries were pulled inside through large windows in the facades. Views and sceneries that most buildings unfortunately don't have. However, since I grew up in a rural area where the countryside was nearby, I was lucky enough to experience the presence of nature most of the time though. When I grew older, I noticed that whenever I was surrounded by this nature, it gave me a sense of happiness, released my stress and allowed me to put things in perspective. This nature and biodiversity was however limited within the contours of my hometown itself and in the cities I visited.

Until last year, I thought this was a shame mainly from an aesthetics point of view. Following the course 'CIE4100 – Materials and Ecological Engineering' at Delft University of Technology, it made me realize that nature and green in the built environment can contribute so much more than mere pleasant aesthetics. For example: reduction of the urban heat island effect, storing excess rainwater and thus preventing floods or droughts, filtering air and water and thus increasing their quality levels, capture of carbon and particulate matter, increased heat insulation properties, reduction of noise disturbance and an increase of biodiversity. With this, I realised nature has the potential to be part of the solution with regards to mitigating climate change, but especially in relation to creating an adaptive, enhanced and healthier living environment.

In order to contribute to the growing support for Nature-based Solutions, I decided to pursue my master's thesis research at the interface of buildings and these natural implementations. Since I was personally curious about the exact environmental, ecological and social benefits of adding nature in the built environment, yet convinced of it being part of the solution with regards to both mitigating and adapting to the consequences of climate change as well as creating nature-inclusive cities, the main focus area in this thesis is on that topic.

More specific, I have strived to contribute to expanding the knowledge of vertical greening systems (green façades and walls). This, by substantiating the effects of vertical greening systems that help in the transition towards more nature-inclusive and climate adaptive real estate, and subsequently by economically valuating the costs and benefits associated with these systems. This is pursued through the development of a standardized and interactive framework and tool. Ideally, by contributing to the knowledge regarding economic valuation of these systems, a better insight will be provided and wider support for their implementation is achieved in multiple stakeholder groups, like e.g.: residents, real estate investors, builders and developers, engineering and consultancy firms, and last but not least policy-makers and governments.

For the collaboration with Sweco, I am grateful to have received their backing and for their confidence in the importance of the research topic. Sweco is Europe's largest architectural, engineering and consultancy firm and a market leader in designing and developing the sustainable cities, industries and public infrastructure works of the future. With almost 18.000 employees, Sweco is a company with expert knowledge in a wide variety of fields, which is combined and further developed through the innovative research program Urban Insight. In this program, the main focus is on the following 6 pillars: energy transition, smart and sustainable mobility, climate adaptation, digitisation, circularity and the healthy and safe city.

This implies the thesis topic fits well with the company's progressive vision and mission of creating nature-inclusive and climate-adaptive communities. For me personally, this collaboration with a company was desired, since it enabled direct access to expert knowledge and instantly created a platform where the developed knowledge could be applied and be put to good use. Best case scenario, the academic knowledge gained in the field of economic valuation of vertical greening systems on buildings can later be translated to be used more widely than just in this research project, meaning the thesis could directly contribute to creating societal value.

1.1.3 Scientific relevance

From previous sections it can be derived, that implementing Nature-based Solutions in the built environment can contribute to an enhanced living environment and stimulate the creation of nature-inclusive and climate resilient cities. To narrow the scope, the aim in this thesis work will be to focus on vertical greening systems (green façades and walls) on buildings. In light of this study, also an eye may be cast on green roof systems. In densely urban areas, both of these solutions are often favoured over other Nature-based Solutions, because of land scarcity and their ability to provide multiple ecosystem services (Shafique, Kim, & Rafiq, 2018). Moreover, vertical greening systems attract attention due to their high degree of visual prominence. In the opinion of the author and based on initial literature study, further research into the economic valuation of vertical greening systems on buildings is relevant for several factors.

First, the topic of economic valuation of the costs and benefits of these systems is not fully investigated in general. On the effects of green roof systems ample of studies are conducted and articles are available, while there are also several Life Cycle Cost analyses and Cost-Benefit Analyses performed to determine their economic costs and benefits (Perini & Rosasco, 2013). However, content on the economic valuation of vertical greening systems is far less elaborative and comprehensive.

Only two studies were found on this exact topic. First, in 2013 Perini and Rosasco performed a Cost-Benefit analysis, while the same authors also published an evaluation on their work in 2018 (Rosasco, 2018). Huang, Lu, Wong, and Poh (2019) executed a Life Cycle Cost analysis of 3 different vertical greening systems in a tropical climate. However no extensive review or framework for the values of benefits were included in both of these studies.

Although gaining more support and attention in recent years, expressed by the rapid research growth and publication of substantial amount of literature, the research into vertical greening systems is still behind and above all not sufficiently linked (Teotónio et al., 2021). Yet, more and more articles emerge, elaborating and stressing the beneficial effects of these green façade and wall systems. Hence, comprehensive economic valuation in this area will get the main focus in this thesis.

Even though the amount of literature is relatively limited, Teotónio et al. (2021) conducted a systematic review on 79 scientific articles in 2020, which were particularly focussed on green roofs and green façades/walls. The overall findings suggest a preference for ‘green’ infrastructure over ‘grey’ infrastructure. Although mere financial performance is typically low, or sometimes negative even, the return of economic evaluation improves when ecological and social benefits are taken into consideration. The researchers argue that the lack of standardized, comprehensive and transparent calculation of the economic merits have restricted decision-making processes. The latter statement is acknowledged by van den Biesen (2018), who therefore also recommends the development and creation of a framework to evaluate the benefits of the effects of different vertical garden systems.

This, while already a few years earlier Laurans and Mermet (2014) concluded that “A clear utilization-focus in further developments of ecosystem services valuation (ESV) is necessary to overcome the present ESV “implementation gap” and some of the conceptual and methodological problems underlying it.”. They further acknowledged that “In overcoming the strong tensions and numerous methodological difficulties inherent in combining process-based and content-based valuation approaches, looking at things from the perspective of utilization may provide a new and instrumental fulcrum.”

Hobbie and Grimm (2020) conclude the fact that “there is a need for accurate and comprehensive cost-benefit analyses that consider disservices and co-benefits, relative to grey alternatives, and how costs and benefits are distributed across different communities.”

In line with the previous statement, also Mommers, Dekker, van de Leemkolk, and Handgraaf (2021) indicated in their report ‘Analyse knelpunten natuurinclusief bouwen’ (commissioned by the Dutch national government) that more knowledge should be available on the contribution of nature to solving problems in urban areas and how to value this economically. Furthermore they state that this knowledge should be focussed on the different stakeholder groups that are involved with nature-inclusive building. Ultimately, this could translate into a viable business case for implementation of green and nature in an urban context. The urge for economic valuation of the effects of urban greening are emphasized by de Vries, Kamphorst, and Langers (2022) as well.

Ferreira, Barreira, Loures, Antunes, and Panagopoulos (2021) investigated stakeholders' perceptions of appropriate Nature-based Solutions (NBS) in the urban context (study in Portugal). They concluded that "Although mostly coherent connections were observed between the main concerns and priorities of stakeholders and the perceived NBS benefits, some stakeholders did not present coherent connections. This indicates low awareness of the current policy for implementing NBS to overcome current and future urban challenges." From a study from Wong, Tan, Tan, Sia, and Wong (2010) in Singapore, it was concluded that there was a lack of information in the domains of technique, maintenance and plants suitable for vertical greenery systems. More importantly, there was a lack of awareness of the benefits and performance of vertical greenery systems, as well of their values.

In the Netherlands, van den Biesen (2018) performed an analysis regarding the attitudes of stakeholders towards the implementation of vertical gardens. More specifically, the study examined in what way the stakeholders' attitudes towards the effects of vertical gardens, other stakeholders and critical success factors, constituted their perspective towards the implementation of vertical gardens. All stakeholders regarded the government and municipalities as key players, since their vision, criteria and policies towards the innovation should be stable. Stakeholders stressed the relevance of detailed quantifications of the benefits of the systems in order to access economic viability, or at least calculable effects that support implementation. Therefore, in order to facilitate tangible tools which support decisions for implementation, government bodies were recommended to invest in research regarding valuation of the effects of vertical gardens.

Moreover, it is noticed that since the review that was conducted by Teotónio et al. (2021), containing articles up until April 2020, an abundance of new literature arrived on both green roof systems as well as green façade/wall systems. Overcoming the knowledge gap towards recently published literature and combining its outcomes and contributions might be critical to help promote a more widespread acceptance and implementation of vertical greening systems.

During a constructive conversation with Dr.ir. Marc Ottelé (TU Delft), whose research expertise is in the upcoming scientific field of sustainable building envelopes, the previously mentioned phenomena were acknowledged as well. Additionally, it was discussed that it could be fruitful, at least insightful, to make a comparison between literature regarding green roof systems and vertical greening systems. Focussing on ecosystem services delivered by both of these systems, can potentially increase the understanding of the benefits and coherent values delivered by vertical greening systems. (Marc Ottelé, 2022)

Furthermore, an explorative conversation was conducted with Mark Rotteveel (Ambassador for a liveable city and project advisor at Koninklijke Ginkel Groep), who is specialised in greening cities and the benefits of doing so. He stated that the industry would definitely benefit from the development of a valuation tool for vertical greening systems, since it would offer opportunities to start dialogues with stakeholders and potential clients. This highlights the relevance for the sector as well. (Rotteveel, 2022)

The previous statements are interpreted by the author as such, that more focus should be on the practicality, ease of use, comprehensiveness and transparency of economic valuation of vertical greening systems. This could give decision-makers the tools and guidance to evaluate potential costs and benefits of these systems, enhancing their insight and open mindedness for these measures in an early stage.

Furthermore, accounting for the distribution of costs and benefits over stakeholder groups in an economic valuation model, could also raise awareness and create more widespread acceptance among different parties. At least, the valuation model could be used as a conversational mechanism to initiate and substantiate discussions among the stakeholders involved. Together, they can then work towards feasible business cases for implementation of vertical greening systems in the urban fabric.

1.2 Problem definition

From section 1.1 it can be concluded that both the societal as well as the scientific relevance is present, which supports and ratifies a thesis research in the area of economic valuation of vertical greening systems. This section will state the problem definition based on the previously elaborated research gaps.

Based on prior knowledge and a preliminary literature review, it is believed that urban NBS can positively contribute to creating more nature-inclusive and climate resilient real estate. Additionally, the implementation of NBS can enhance the living environment to become healthier and have a positive effect on human well-being. Nowadays, these kind of claims are generally made qualitatively and they are not always expressed or supported by quantitative numbers and figures.

Scientific research in this innovative field of application of nature is in its infancy compared to the research of e.g. green roof systems. Additionally, due to several reasons, the implementation of urban NBS in general is not yet considered to be a standard design criteria in development or transformation projects. This means these solutions do not simply catch the eyes of the public at large. This is especially the case with vertical greening systems. Despite numerous reported benefits as well as supporting policies, their application in the construction market is still low. Huang, Tan, Lu, and Wong (2021) claim this is largely due to: 1) prevailing perception of high investment an maintenance costs combined with lacking data to understand true costs of VGS; 2) lack of technical information for climatic feasibility for different species and maintenance instructions; 3) insufficient awareness of benefits and performance of VGS among wider public.

In order to contribute to the further development of both, the knowledge in the field of (financial, social, and ecological) costs and benefits of vertical greening systems, as well as to the creation of a more widespread acceptance and support for these systems, this thesis will delve deeper into the economic valuation of such systems. Economic valuation could allow for justification of the decision to implement these kinds of systems. Surely it can facilitate adequate and rational decision-making based on facts and figures.

The problems and research gaps on which this thesis will substantiate are twofold:

1. *Firstly, till date, content and knowledge on the economic valuation of vertical greening systems on buildings are not available in abundance. The major problem is that conducted valuation studies are not sufficiently linked, nor comprehensive, nor do they sufficiently focus on the implementation or utilization perspective for decision-making.*
2. *Secondly, the current studies available do not attribute the values of perceived costs and benefits related to vertical greening systems to different stakeholder groups.*

By performing an extensive and comprehensive analysis, taking into account costs and benefits delivered by vertical greening systems, this thesis work tries to seek a solution for the predefined statements. This is aimed for through the development of an interactive economic valuation framework and tool. Upon completion, the tool should at least be suitable for performing cost-benefit quick-scans in preliminary project phases, which enhances rational decision-making or consultancy. Moreover, the valuation tool should be open for further expansion and integration of additional values or types of vertical greening systems. This in case when new (scientific) insights become available.

Aside from combining the outcomes and results of previously conducted research on vertical greening systems, also a call may be made upon scientific studies focussed on green roof systems. Since research in this area is more elaborative, this thesis will make an attempt to expose and utilize the (qualitative) relations between both types of systems.

Additionally, the focus is placed on assessing the perceived values of the costs and benefits and their distribution over different stakeholders. This requires an analysis of these stakeholders and their roles and interests with regards to the implementation of vertical greening systems in the urban fabric.

1.3 Research goals

To contribute to a solution for the problems and gaps that were identified in the previous section, goals are formulated in relation to this.

1.3.1 Meta goal

One can define an overarching ambition which basically corresponds to the trigger for performing the research. This so-called "meta" goal is the following:

> *To stimulate the implementation of Nature-based Solutions in building projects in general, in order to contribute to creating a greener, healthier, more nature-inclusive and climate resilient built environment.*

1.3.2 Research goal

Additionally, a specific research goal is formulated which is aimed to be accomplished by the execution of this thesis work. The research should increase the scientific knowledge in the field of economic valuation of vertical greening systems and lead to a framework and tool which allows for the valuation of costs and benefits of these systems. This is reflected in the main research goal:

> *To develop a framework and tool, which enable the economic valuation of the costs and benefits related to vertical greening systems in an urban context and which account for the perceived values of these costs and benefits for different stakeholders involved.*

1.4 Research questions

In order to achieve the research goal as described in section 1.3, research questions are formulated. Answering these questions should provide the total collection of information, data, variables, parameters and the generation of knowledge and insight needed, to come to a desirable level of elaboration for the thesis. These questions help to attain the final product of the research; a generally applicable framework and tool by which costs and benefits of vertical greening systems can be economically valuated.

1.4.1 Main research question

The research goal is translated to the main research question:

> *What framework and tool can be proposed to economically value the costs and benefits of vertical greening systems within the built environment and how can these costs and benefits be attributed among different stakeholders involved?*

1.4.2 Sub-questions

In order to produce a viable end-product and answer to the main research question, the thesis is divided into a series of 4 sub-questions. These sub-questions help to acquire the necessary knowledge in order to propose a standardized framework and develop an interactive model, able to calculate costs and benefits of vertical greening systems. The sub-questions either have an exploratory nature, or they refer to the proposed methodology, the obtained results or the implications of the research. Sub-question 4 is answered in the discussion of this research. The 4 sub-questions, which also provide a general structure for the thesis, are listed below:

1. *What is the state of the art regarding the effects of vertical greening systems and the economic valuation of these systems for different stakeholders?*

2. *Which analysis method and valuation methods are proposed to enable the comprehensive economic valuation of the costs and benefits of vertical greening systems?*

3. *Based on a case study, what results can be obtained from the developed economic valuation tool and how can these results be interpreted?*

4. *How can the final product be put into its context, given its relation and contribution to the current level of scientific knowledge and society as a whole?*

1.5 Research methodology

In this section, for each sub-question the methodology to provide it with answers is discussed. In the end, answering all sub-questions should lead to a viable and standardized economic valuation framework and model. This should enable the quantification and valuation of the costs and benefits of vertical greening systems. For a more detailed substantiation of intermediate/practical questions and considerations that should be answered for sub-question 1, reference is made to appendix A.

1.5.1 What is the state of the art regarding the effects of vertical greening systems and the economic valuation of these systems (for different stakeholders)?

The first sub-question is primarily related to the execution of an extensive and comprehensive literature review, which has to form a solid basis for the further research. Literature review regarding the cost and benefits of vertical greening systems and their economic valuation will primarily be elaborated in Part I (chapters 2 & 3) of this thesis report. However, the more generic backgrounds on Nature-based Solutions, ecosystem services, the importance of biodiversity and relevant stakeholders will be dealt with in appendices B, C and E.

Theoretic background and general knowledge with regards to VGS, NBS and ES
First, a basic understanding of the theoretic background and knowledge on the topic of the effects and implementation of vertical greening systems on buildings has to be acquired. Relevant topics/questions that will need to be assessed in this part of the review are extensively listed in appendix A, while they are answered and elaborated in chapter 2 and appendices B and C.

Quantitative/Monetary data
Aside from the more generic background information and qualitative effects of vertical greening systems, also more specified data and quantitative information has to be collected regarding their effects. These effects can have impact on economical, ecological and societal values. In later stages of the research, economic valuation of these effects is pursued. This entails that numerical and monetary values with regards to these effects have to be collected from previous measuring or valuation studies and then brought together in an orderly fashion.
Not only is a numerical or monetary value of the effects important. Also the year, the (boundary) conditions in which the study is performed or for which it is controlled and the type of system for which the study was performed, have to be accounted for in order to come to substantiated valuation results. Ultimately, the effects will be economically valuated for residential real estate. However in order to determine the magnitude of the effects that VGS can have, no differentiation in types of real estate will be made. Intermediate questions and necessary information/data for this part are again listed in appendix A and the answers will be provided in chapter 2, as well as gradually implemented throughout Part II, III and IV of this research.

Pricing techniques and valuation analysis methods
Simultaneously, literature research has to be performed with respect to feasible pricing techniques and valuation analysis methods for the ecosystem services and co-benefits provided by vertical greening systems. Appropriate pricing techniques and a valuation analysis method suited for the monetary valuation of economic, ecological and social values have to be considered, chosen and mastered.

With regards to pricing techniques, based on preliminary literature study it is assumed that the Benefit Transfer Method (BTM) will be used in order to come to monetary values for most known effects. This holds for cases where previous studies have been conducted, from which the obtained effects or values can be adequately transferred into a more comprehensive valuation framework. Qualitative substantiation for choosing or adjusting values is an important aspect of this technique.

Also, per valued effect that is transferred from previous studies, the valuation method or pricing technique used in those studies should be clearly elaborated to ensure scientific transparency and offer a comprehensive overview in this research.

Whenever previous studies are unavailable, it should be considered whether it is feasible and realistic to elaborate on values of effects based on other pricing methods, and if so, which one. The Cost Based Method (CBM) is assumed to be an adequate technique for valuing ecosystem services or delivered benefits that rely on market costs, avoided damages or benefits that would need provision of a (technical) substitute good or service to deliver the same effect.

For the analysis method, it is proposed that both a financial business case analysis or Life Cycle Cost Analysis (LCCA) and a comprehensive Social Cost-Benefit Analysis (SCBA) will be performed, containing economic, environmental or ecological and social values of vertical greening systems. Most important considerations for this part of the literature review are again given in appendix A and will primarily be elaborated in Part I & II.

Stakeholders

Finally, information should be gathered in the area of stakeholders' relation to (the costs and benefits of) vertical greening systems, in order to deliver a valuation model that incorporates the viewpoints of multiple stakeholders. Then, the final product can work as a conversational mechanism between stakeholders and as a tool to enable pragmatic decision-making with regards to wider implementation of vertical greening systems on buildings. Hence, it would be suited to increase understanding of these systems and potentially enhance their acceptance. This information will be elaborated in Part I (chapter 3) and more extensively in appendix E. Important considerations are provided in appendix A.

Sources for information

The literature review will be performed based on scientific papers, reports, (sections of) hand- or E-books and readers or presentation slides of courses followed previously during the curriculum at Delft University of Technology. In addition to papers related to vertical greening systems, also literature relating to ecosystem services and co-benefits delivered by green roof systems may be consulted. Since this field of research is more mature, potentially values can be translated between these different types of systems to make them applicable for vertical greening systems.

Also, by reaching out and interviewing or consulting specialists in these fields of expertise, knowledge can be gained. Interviewees can be found via personal contacts, by performing peer interviews with Sweco employees, or via contacts made through the TU Delft or Sweco network (both internal and external).

Finally, information can be retrieved from existing tools that already make an attempt to quantify the costs and benefits of vertical greening systems, green roofs, or other NBS.

1.5.2 *Which analysis method and valuation methods are proposed to enable the comprehensive economic valuation of the costs and benefits of vertical greening systems?*

Building on the information and knowledge obtained in the first phase of the research project, a generally applicable valuation framework should then be designed considering the various costs and benefits that are delivered. Collected monetary data and values can be directly used in the valuation method. For benefits where only quantitative/qualitative data regarding their effects is found rather than monetary data, it should be considered whether it is possible to apply one of the pricing techniques that follow from literature study (Part I) in order to obtain monetary values. Applied valuation methods for indicators will also be elaborated in this part.

The employed economic analysis method will be based on literature regarding ecosystem services valuation and will be inspired by methods used for other NBS. Also the utilization perspective of the tool and costs and benefits distribution over stakeholders will be taken into account.

It is expected that the calculation model for the valuation framework will be produced in Excel, initially at least. This allows for a process for further optimisation and implementation of new knowledge on monetary values for costs and benefits in the future. Hence, the product can be redeveloped and expanded whenever new insights become available, allowing for more adequate and complete economic valuation of vertical greening systems. Furthermore, the most important goal for this thesis is to demonstrate the functioning of the valuation framework and to deliver viable results with the valuation model, based on a case study. Only whenever the product is more mature, an effort could be made to redevelop this valuation model into a more high-end software tool.

1.5.3 Based on a case study, what results can be obtained from the developed economic valuation tool and how can these results be interpreted?

Once the valuation framework has been developed and the required information with regards to the economically valuated effects of the vertical greening systems has been gathered, this sub-question is dedicated to showing the final composition, workflow and retrievable results of the valuation model.

Moreover, this sub-question will address a case study performed for a Sweco client organisation, hereby showing the intended use of the valuation model and generating quantitative output. The case study should provide additional location- or case specific input for the model, hence demonstrating a practical and societal application of the valuation framework. Therefore, in collaboration with Sweco and a client organisation, data has to be collected regarding the current conditions of the real estate object and its direct vicinity. The results will be analysed to enable a discussion and draw conclusions, also with regards to costs and benefits distribution over stakeholders.

For costs and benefits where no quantitative or monetary results can be generated yet, a qualitative elaboration/discussion of the added values will be given. Also, it will be touched upon how numerical values for these effects might be incorporated in the valuation model in the future.

Finally, the validity of the framework and calculation tool will be discussed. This is pursued by the validation through expert judgement and via a user experiment. The test panel for this user experiment will consist of anticipated users (primarily consultants) of the tool.

1.5.4 How can the final product be put into its context, given its relation and contribution to the current level of scientific knowledge and society as a whole?

This final sub-question will reflect on the final deliverable and its added value to the current level of scientific knowledge and society. It forms a discussion and concluding remark on the previously elaborated work. Also, it will evaluate what the consequences could be of the use of this model and how it can be implemented in decision-making. Furthermore, limitations and from this recommendations for further research are established. These should lead to an even more complete and comprehensive valuation model in the future.

1.6 Scope limitations and initial assumptions

The aim of this thesis work is to provide academia and industry with an initial impulse for a generally applicable and transparent valuation framework and tool, enabling the valuation of the costs and benefits relating to vertical greening systems. This research should therefore clearly describe these systems' costs and benefits, the pricing techniques available for economic valuation, and inputs, calculations and outputs that are taken into consideration for the development of this framework. This, in order to apply these successfully in a valuation tool.

The ultimate objective with this valuation framework is to integrate the quantifiable costs and benefits and to pave the way for integration of those which are more abstract and nowadays still considered intangible. The proposed framework should therefore be applicable for a choice in all types of vertical greening systems, all types of real estate objects and all locations in the Netherlands. Moreover, the stakeholders included in the framework should be diversifiable in future expansions.

For the sake of feasibility and given the limited total equivalent timeframe for the thesis of 40 ECTS, it is important to limit and demarcate the scope of the graduation work. To illustrate the presence of a good level of academic skills, a sufficient level of detail should be obtained. Therefore, in addition to the presented research methodology in the previous section, the scope of the thesis will be limited with regards to the aspects denoted in Table 1.1.

Table 1.1: Scope limitations and initial assumptions

Scope limitations	Elaboration
Vertical greening system type	As for vertical greening systems, in this thesis and for the development of the valuation framework and model it is chosen to limit the study to living wall systems (LWS). Hence, in its basis, after this thesis the valuation model will be designed for and focussed on LWS, with the opportunity to diversify and implement other types of systems. See section 2.4 for further elaboration.
Real estate type	As for the type of real estate, in this thesis a case study will be performed for a residential real estate object in the Netherlands (chapter 6). Hence, in its basis, after this thesis the valuation model will be designed for and focussed on the implementation of vertical greening systems on residential real estate. Considering the data sources and references used for input during the development of the model, it will be focussed on and applicable for the Netherlands. However, it is assumed that quantitative data and numerical values regarding the effects of vertical greening systems can be obtained from any real estate object.
Stakeholders	The stakeholder groups that will be accounted for during this thesis are real estate investors/owners and society at large. Implementation of multiple stakeholder groups should be possible in later stages, based on the proposed valuation framework. See section 3.6 and appendix E for further elaboration.
Economic analysis methods	CBA have been performed earlier to determine the value of different types of NBS, however in the field of vertical greening systems this is still rare and upcoming. The same goes for LCCA. This research will investigate existing knowledge and measurement studies which are performed in order to determine the effects of vertical greening system. Based on this, ultimately the translation towards a more comprehensive and complete valuation framework and model can be made.

	See sections 3.4 and 4.2 and appendix D for further elaboration.
Baseline situation	The research investigates costs and benefits of vertical greening systems, with as baseline an existing standard bare brick wall in the Netherlands. For the case study of this thesis, technical and structural feasibility of VGS implementation is assumed.
Anticipated end-users	The anticipated end-users of the valuation tool which is developed during this research are consultants working in environmental and climate consultancy, ecology and urban planning, as well as other experts in the field of VGS. The tool should facilitate in gaining insights regarding the quantitative and monetised values of costs and benefits of VGS. Ultimately, the tool should enable them to give well substantiated and transparent advice to their clients and other policy-makers. This in order to make rational decisions regarding the potential implementation of VGS in projects.
Background knowledge	The thesis requires the acquisition of knowledge regarding SCBA, LCCA, potentially Financial Engineering and benefits and Ecosystem Services Valuation of benefits of VGS. Note that this knowledge is not necessarily new in literature, hence it is not the innovating part of the scope of this thesis work. This knowledge should be acquired to an appropriate level, in order to answer the main research question and deliver an initial version of the VGS Valuation Tool.

1.7 Reading guide

The report is divided into four different parts, all containing one or more chapters (see Figure 1.1). The parts relate to the four sub-questions of the thesis and are connected to the research methodology and a development cycle for the tool. This development cycle consist of an analysis, synthesis, simulation and evaluation phase.

Part I contains the analysis phase, presenting the findings from literature research and elaborating the theoretical background for this thesis work. In Part II, the valuation framework and tool are developed and substantiated (synthesis), leading to a generally applicable framework and distinct methods for assessing the costs and benefits relating to vertical greening systems. Part III (simulation) dives into a case study, displays the outcomes & results from the valuation tool for the specific project and provides the validation of the work. Finally, Part IV (evaluation) concludes the report with a general discussion and conclusions, also containing an extensive future outlook with recommendations for further research.

The chapters within the parts treat different topics that are relevant in order to answer the corresponding sub-questions. Generally, each chapter contains a brief introduction and conclusion of its most important findings.

This thesis report is supplemented with a MS-Excel file, named *'VGS_Valuation_Tool_V.1.01'*.

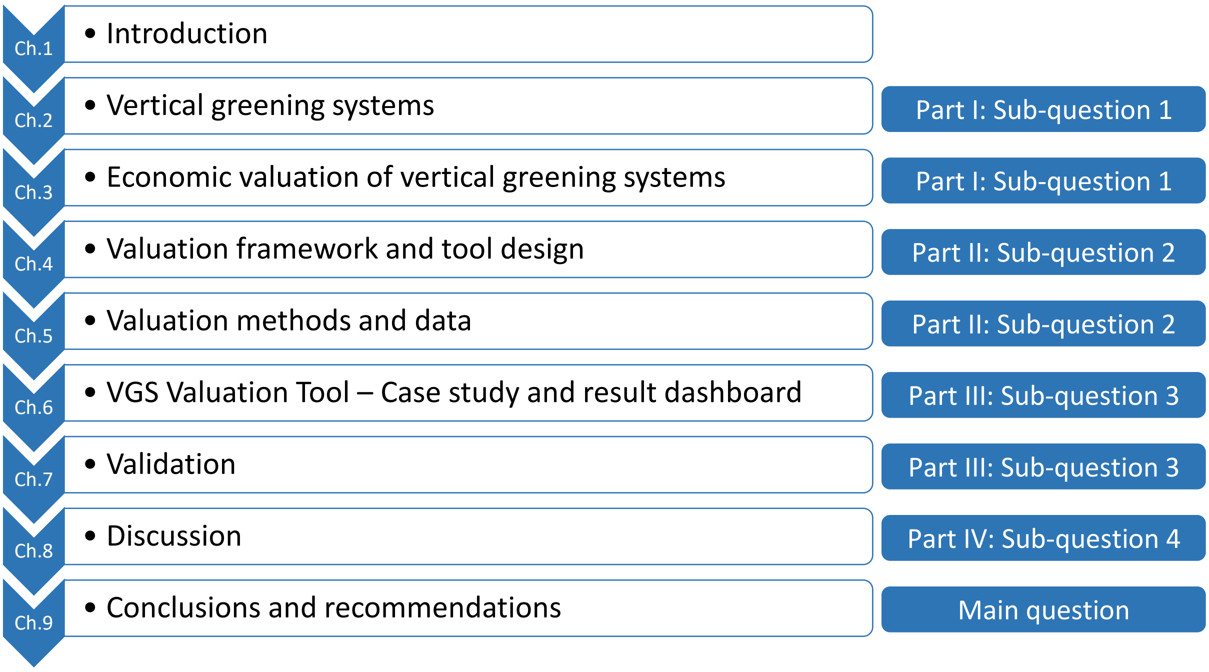
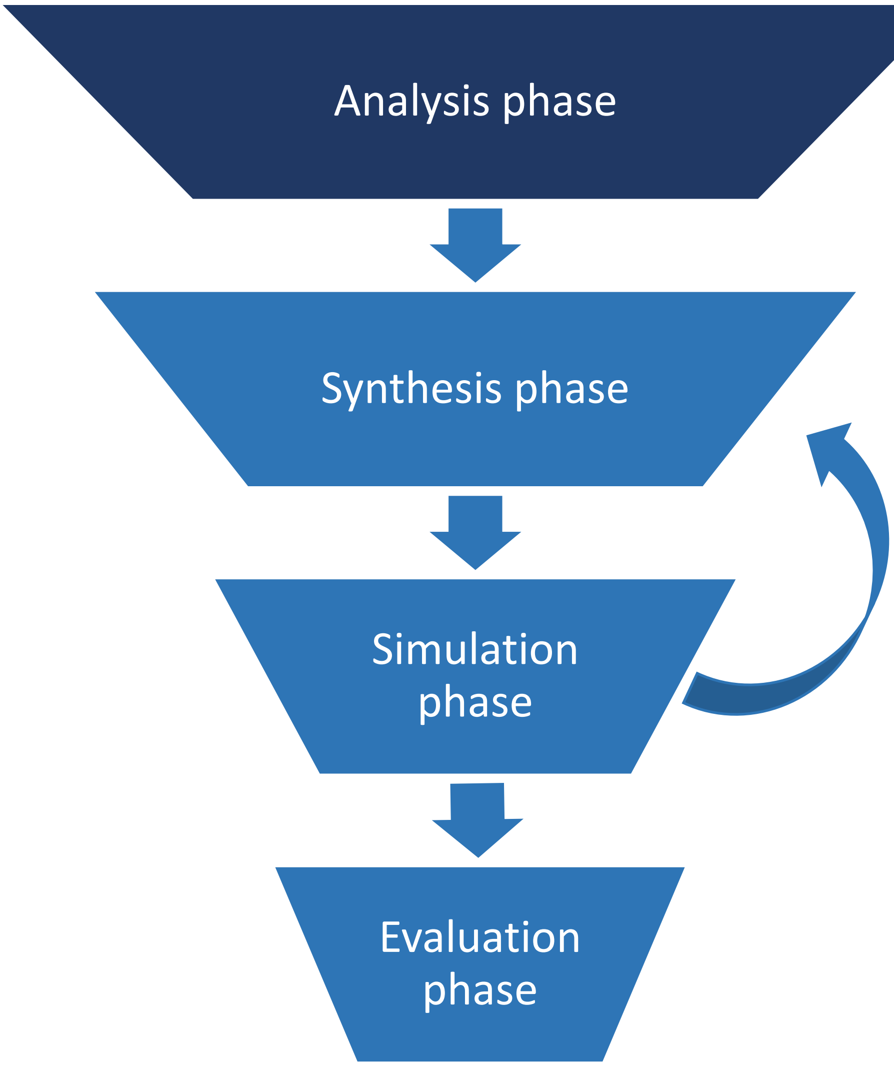


Figure 1.1: Outline of the report

Part I

-

Literature study & theoretical background



2

Vertical greening systems

2.1 Introduction

The analysis phase (Part I – Literature study & theoretical background) is the starting point for the research. It contains the chapters 2 & 3, which set out the literature review and provide the current state of the art of the main thesis topics. Furthermore, some of the scope limitations for the research are defined and elaborated in these chapters. In section 3.7, a conclusion of Part I is provided which should answer the first sub-research question:

"What is the state of the art regarding the effects of vertical greening systems and the economic valuation of these systems (for different stakeholders)?"

Chapter 2 presents the state of the art regarding vertical greening systems, the main subject of the thesis. The research is an attempt to expand the scientific knowledge regarding economic valuation of the costs and benefits associated with the implementation of vertical greening systems on buildings. This thesis proposes an interactive framework which enables the monetarization of these costs and benefits, applicable for distinct vertical greening systems. Therefore, it's important to create a general overview of the backgrounds of these systems.

First, a brief history and context of vertical greening systems is given. Then, the distinct vertical greening systems are presented which are currently available for the construction industry. The final section of this chapter provides an explanation, clarifying the choice to focus on living wall systems throughout the remainder of the work, in order to develop the valuation framework and tool.

2.2 Context and brief history of vertical greening systems

The increase of the world's urbanisation over the last century has resulted in destruction of (urban) green spaces, by replacement of vegetated land surfaces by built surfaces. These built surfaces consist of different forms of paved roads and buildings, usually with high albedo. This development and the destruction of green spaces has negative impacts on the quality of the city's living environment, its micro-climate and ecosystem functioning (Besir & Cuce, 2018; Bustami, Belusko, Ward, & Beecham, 2018; El Menshawy, Mohamed, & Fathy, 2022).

Furthermore, the construction industry as a whole is contributing to rapid changes in the global climate, while also having other catastrophic impacts on the (urban) environment. These entail the increase of carbon footprints and greenhouse gases, increase of the urban heat island effect, bad thermal performance and increasing albedo, the loss of vegetation and biodiversity, high energy consumption, reduced visual and sensual experience, increase in air and noise pollution, unhealthy life and increased stress rates, which overall lead to a reduced quality of life (El Menshawy et al., 2022).

In recent years, environmental awareness is increasing and the urgent need for urban green spaces becomes more apparent, leading to research with regards to ecological solutions in order to deal with or adapt to the problems mentioned before and restore environmental integrity of urban spaces.

Hence, a growing amount of studies are conducted with regards to the benefits of implementing so-called Nature-based Solutions in the built environment. The scarcity of horizontal area combined with its high land values, as well as their ability to provide multiple ecosystem services at once, make that solutions like green roofs and vertical greening systems are often favoured over other Nature-based Solutions in densely urban areas (Shafique et al., 2018). Empty roofs and façade surfaces are still present in abundance and offer great potential for nature-inclusive urban design (Apfelbeck et al., 2020). According to Brković Dodig, Radic, and Auer (2019), the surface area appropriate for vertical greening systems can be up to 20 times more than the roof area. They further state that these systems can therefore have more potential impact on a building's surroundings than green roofs.

For those interested in how vertical greening systems are positioned within the realm of Nature-based Solutions (NBS), reference is made to Appendix B. In summary, they are a type of urban NBS, a concept that brings nature into cities and in many cases relies on ideas for urban design that are derived or inspired from nature (Langergraber et al., 2020). Simply stated, NBS can be viewed upon as an umbrella term for solutions to societal challenges that are based on an ecosystem-related approach, and which address these challenges through delivery of 'ecosystem services'. A background on ecosystem services (ES) can be retrieved from Appendix C.

As for vertical greening systems (in the remainder of this work referred to as VGS), different terminologies and definitions are used in literature. Other applied terms are e.g. 'Vertical Greenery System', 'Green Vertical System', 'Green Wall System' and 'Vertical Garden'. To be accurate, in this thesis the definition as provided by El Menshawy et al. (2022) is adopted: "It is a system that attaches plants to structures or walls of buildings in order to be partially or completely covered with vegetation".

The concept of vertical gardens and VGS can be traced back to the Egyptians (3000 BC) and the hanging gardens of Babylon (600-800 BC). Also the Roman and Greek empires purposely integrated VGS into their built areas, in order to prevent the excessive heating of their building's envelopes. In later times, Mediterranean cultures, rulers, builders and artists added greenery in their settlement designs as well. In Central Europa and the UK, integration of plants (climbers) to building envelopes took a major flight in the 17th and 18th century. Although scientific studies and research towards the benefits of vegetation started in the 1970's (Perini, Ottelé, Haas, & Raiteri, 2011), due to difficulties with retrofitting, for a time consensus prevailed that the urban greenery systems were not compatible with modern architecture (Besir & Cuce, 2018).

However, according to El Menshawy et al. (2022), in contemporary society, implementation of VGS within the urban fabric is deemed a rational solution to enhance the built environment and offer benefits to e.g. psychological and physical health. Technological developments and social awareness of environmental and urban comfort issues initiated a research agenda for VGS and interest grows year after year (Besir & Cuce, 2018).

The applied vegetation in VGS as ecological design element is viewed upon as an additive building material, increasing the multi-functionality of building envelopes. This can have significant beneficial impacts, both on the building itself as well as its direct surroundings and urban scales. Through VGS, an abundance of benefits can be provided in the private and public domain, which are nowadays well-documented in literature. According to numerous studies that were found, VGS can contribute to the benefits as denoted in Table 2.1 (Besir & Cuce, 2018; Brković Dodig et al., 2019; Bustami et al., 2018; El Menshawy et al., 2022; Manso, Teotónio, Silva, & Cruz, 2021; Riley, 2017; Teotónio et al., 2021).

Table 2.1: Comprehensive overview of benefits delivered by VGS in urban areas

Nr.	Description of benefit
1	Improved thermal performance and energy efficiency
2	Reduction of energy consumption and overall high energy costs
3	Mitigation of urban heat island (UHI) effect
4	Enhanced microclimate both in summer and in winter
5	Sequestration of greenhouse gases (GHG)
6	Improved storm water management
7	Enhanced biodiversity and natural animal habitat
8	Enhanced visual experience and aesthetic appeal
9	Creation of a distinctive sense of place
10	Reduced noise disturbance and enhanced acoustic insulation
11	Protection of building envelope
12	Increased property values
13	Food production and urban agriculture
14	Improved air quality
15	Improved physical and mental health
16	Improved psychological well-being
17	A variety of social effects
18	Educational value
19	Receiving sustainability rating credits

2.3 Different types of vertical greening systems and their characteristics

Following the definition from El Menshawy et al. (2022), VGS are described as: “Systems in which plants are attached to structures or building walls, covering them completely or partially with vegetation”. Essentially, VGS are living cladding systems for buildings. Given the growing interest into VGS in recent years, numerous distinct concepts, types and configurations of VGS were developed and brought to the market by producers and suppliers. Hence, the collection of different (sub-) types of VGS that can be implemented in projects keeps expanding year after year. These different configurations range from simple and basic implementation of plants and shrubs, to highly complex and engineered designs. This variation in types can lead to distinct approaches for design, installation and maintenance. Since there are multiple ways to apply VGS, they are feasible both as an additional façade in front of existing walls and renovation projects, or contradictory as a fully integrated exterior façade skin in new developments. Many lightweight systems are available on the market, making even lightweight sandwich panels suitable as mounting surface. Scientific research and knowledge gradually provides improved insights into the functioning and sustainability aspects of VGS, therefore the systems can and should be optimized with new future developments.

A widely adopted VGS categorisation is the one from Perini et al. (2011). Many different variations are present to this categorisation and naturally they can be broken down further, however they all stem from the same basis. They stated that vertical greening concepts can be divided into two main categories, based on the supporting structures used and the vegetation types with their corresponding growing method. These categories are green façade systems and living wall systems (also referred to as green wall systems) (see Figure 2.1). A useful and compact table containing the basic system components and characteristics was created by Medl, Stangl, and Florineth (2017) (see Table 2.1), while their main advantages and disadvantages are displayed in Table 2.2. Further breakdown of these main categories is given in the subsequent sub-sections.

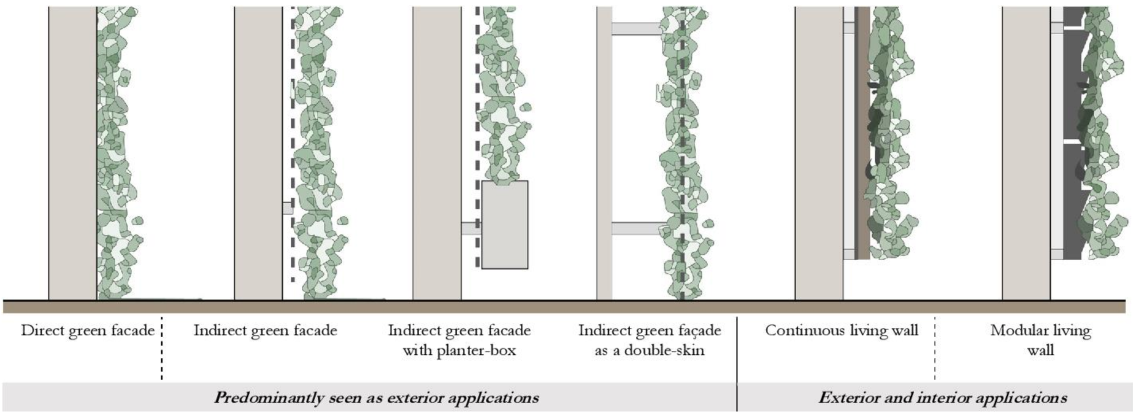


Figure 2.1: Different typologies of vertical greening systems (Gunawardena & Steemers, 2019)

Table 2.2: VGS types basic system components and characteristics, adopted from Medl et al. (2017)

Type	Sub-categories	System components	Characteristics
Direct GFs	• Ground-based planting	• No structural system components • Irrigation optional	• Climbing plants with adhesive pads or clinging roots are directly attached to the building surface and planted in the open ground at the building base.
	• Planter box-based planting	• Planter boxes • Irrigation optional	• Climbing plants with adhesive pads or clinging roots are directly attached to the building surface and planted in soil-filled planter boxes.
Double skin GFs	• Ground-based planting • Planter box-based planting	*Both categories:* • Structural frame of cables, meshes, trellis or nets • Irrigation optional	*Both categories:* • Twinning plants or plants with tendrils are supported by structure, creating an air cavity between building surface vegetation, and are planted on the base of the building in the open ground water or planter boxes.
Continuous GWs	• No sub-categories	• Structural frame • Base panel • Fabric layers • Drainage • Waterproof membrane • Irrigation system	• Most commonly no requirement for substrate, since fabric layers serve as substrate. • Hydroponic technology provides supply to water and nutrients.
Modular GWs	• Pocket-typed planter • Vertical panel • Grid panel	*For all three categories:* • Modular components • Structural frame • Substrate • Drainage • Waterproof membrane • Irrigation system	• Modules are filled with organic or inorganic substrate. • Simple replacement of panels in case of damage is given/required.

Table 2.3: Comparison of VGS advantages and disadvantages, adopted from Manso and Castro-Gomes (2015)

System	Category	Sub-category	Advantages	Disadvantages
Green façades	• Direct greening	• Traditional green façades	• No materials involved (support, growing media, irrigation) • Low environmental burden • Low costs	• Limited plant selection/climate adaptability • Spontaneous vegetation development • Slow surface coverage • Scattered growth along the surface • Surface deterioration/Plants detachment • Maintenance problems
	• Indirect greening	• Continuous guides	• Vegetation development guidance • Low water consumption	• Limited plant selection/climate adaptability • Slow surface coverage • Scattered growth along the surface • High environmental burden of some materials
		• Modular trellis	• Lightweight support • Vegetation development guidance • Controlled irrigation/drainage • Easiness to assemble and disassemble for maintenance • Plants replacement	• Limited plant selection/climate adaptability • High environmental burden of some materials • High installation cost

Living walls	• Continuous systems	• Felt pockets vertical gardens	• Uniform growth • Flexible and lightweight • Increased variety of plants/aesthetic potential • Uniform water and nutrients distribution	• Complex implementation • High water and nutrients consumption • Frequent maintenance Limited space for root development • High installation costs
	• Modular systems	• Trays	• Easily disassembled for maintenance • Increased variety of plants/aesthetic potential • Controlled irrigation/drainage	• Complex implementation • Heavier solutions • Surface forms limited to trays dimensions • High environmental burden of some materials • High installation costs
		• Planter tiles	• Increased variety of plants/aesthetic potential • Attractive design of modules	• Complex implementation • Limited space for root development • Surface forms limited to tiles dimensions • High installation costs
		• Flexible bags	• Adaptable to sloped surfaces • Increased variety of plants/aesthetic potential	• Complex implementation • Heavier solutions due to growing media/limited to buildings maximum load • High installation cost

In addition to these system categories, nowadays also the research into bio-receptive surfaces is starting to take its flight. This new typology of VGS is made possible due to technological advancements in the field of development of bio-receptive materials, however it is still early days with scientific research being carried out. Till date no commercial projects have been initiated yet. However the ground-breaking construction materials and technology show great potential to apply mosses on receptive concrete, thereby contributing to liveable and healthier cities in a cost-effective, structural efficient manner without the need for additional technical systems or maintenance (Riley et al., 2019; Veeger, Prieto, & Ottelé, 2021). For now, these systems are beyond the scope of this thesis.

2.3.1 Green façade systems

In green façade systems, the vegetation is based on the use of climbing or hanging plants that grow across the wall. Since the plants still have to grow among the wall surface, initially the façade will only be partially covered with vegetation. The vegetation used (evergreen, e.g. ivy/hedera helix, or deciduous) can either have adhesive properties, or be supported by a cable system. Whenever the climbers are rooted in the subsoil, they might be self-supporting with regards to water and nutrition for growth (El Menshawy et al., 2022; Perini et al., 2011). Green façade systems have a lifespan of more than 50 years (Bustami et al., 2018).

Direct green façade

In case when the vegetation is rooted in the subsoil or in strategically placed planter-boxes and are attached directly to the surface of the building’s façade, one speaks of a direct green façade. No additional structural or guiding system is required due to the adhesive property of the plant type. These types of VGS usually provide for a cheap solution, however they might impose implications for maintenance and repair works to the façade. Dependent on the plants used, research showed that within the first 4 years the greening can grow to 3-10 meters (Bustami et al., 2018), with an ultimate capacity to reach a maximum height of around 25-30 meters.

Indirect green façade

An engineered variant of the direct green façade is the indirect green façade. In case when desired plants do not have adhesive properties, or when it is not favoured to attach the vegetation directly to the building's surface, an additional supporting system is installed. This will facilitate and guide the plants' growth and coverage of the façade area and can consist of steel cables with wire rope nets, metal mesh systems or modular trellis panel systems. As illustrated in Figure 2.1, several variants are possible which all create an air gap between the façade and the vegetation: supporting system attached closely to the façade surface, rooted either in subsoil or in planter-boxes and acting as a double-skin at certain distance from the building. Whenever planter-boxes are used, these can also be installed at an interval over the height of the façade, enabling faster total wall coverage and a more uniform appearance.

2.3.2 Living wall systems

Unlike green façade systems, living wall systems (LWS) are developed to rapidly cover the entire façade surface with pre vegetated substrate media or through hydroponic culture. These LWS are attached to the wall via a secondary support system allowing for a uniform distribution of vegetation, rather than climbers being rooted in or near the subsoil. LWS are generally more engineered and high-tech variants of VGS and these systems form a more recent development and an emerging field of expertise. The secondary support system is equipped with an integrated irrigation and nutrition system in order to facilitate a part or all of the water and food, required for the growth and maintenance of healthy vegetation.

LWS can be composed from a wide variety of (ground cover) plant species, grasses, herbs, bushes and shrubs, enabling aesthetically pleasing and visually contrasting designs with different textures and colours all over the façade. Generally, plants used for intensive green roofs are also suitable for LWS and dense façade covers can be obtained (Perini et al., 2011). This property further enables the potential to meet specific ecological demands from the surroundings, which ultimately might result in a higher biodiversity level. Like green façade systems, also LWS can be distributed into two sub-categories (El Menshawy et al., 2022; Marc Ottelé, Perini, Fraaij, Haas, & Raiteri, 2011).

Continuous living walls

Continuous living walls consist of two layers of (synthetic) fabric containing pockets, which act as a growing medium containing plants. The fabric can be produced from e.g. felt or plastic fibres and is attached to the façade via the secondary support system, while a waterproof membrane protects the underlying building façade against high moisture content. This is necessary since the vegetated fibre mats operate as hydroponic systems, where the irrigation system delivers water and nutrients top-down. In hydroponic culture and systems, plants grow based on water containing nutrients, rather than being rooted in a substrate. These type of systems often have a limited lifespan of around 10 years (Bustami et al., 2018).

Modular living walls

Modular living walls have a different composition. These systems consist of modular containers (e.g. high-density polyethylene, HDPE) or panels, which are also attached to the façade using a secondary support system. These modular containers can be composed from vessels, trays, flexible bags, planter tiles, wire cages, framed boxes, solid planter boxes with pre-cut holes, or foam/mineral wool panels (El Menshawy et al., 2022). The containers hold the growing media (substrate) for the plants and since these are pre-vegetated, the LWS already has a visual effect upon installation. The irrigation system is installed at different levels, gradually distributing water and fertilizers (nutrition) over the substrates in the modular containers with help of gravity. Depending on the exact system, these are designed to reach lifespans up to 30-50 years (Bustami et al., 2018; Huang et al., 2021; Marc Ottelé et al., 2011). Regular maintenance of both the vegetation and the irrigation system is required for LWS in general.

2.3.3 Characteristics of vertical greening systems

In order to provide a general insight into the different types of VGS that were discussed, Table 2.4 gives an overview into their characteristics. Moreover, Table 2.5 provides an initial outlook into the qualitative advantages and disadvantages of these VGS types.

Table 2.4: Overview of different types of VGS and their characteristics, adopted from El Menshawy et al. (2022) and adapted from Mir (2011)

Type of VGS	Green façade systems				Living wall systems			
	Direct greening		Indirect greening		Continuous system	Modular system		
							Panel system	
	Planted into the soil	Planted into planter-box	Planted into the soil	Planted into planter-box	Felt system	Planter-box system	Foam system	Mineral wool system
Rooting space	*Ground*	*Planter-box*	*Ground*	*Planter-box*	*Pocket*	*Planter-box*	*Box*	*Plate*
Substrate	*Soil*	*Soil*	*Soil*	*Soil*	*Felt*	*Soil*	*Foam*	*Mineral wool*
Supporting system	*N/A*	*N/A*	*For plants*	*For plants*	*For module*	*For module*	*For module*	*For module*
Air cavity (mm)	*0*	*0*	*≥ 50*	*≥ 50*	*~ 50*	*~ 50*	*~ 50*	*~ 50*
Total thickness (mm)	*200*	*200*	*100*	*100*	*≤ 350*	*≤ 450*	*≤ 500*	*≤ 400*
Maximum greening height (m)	*30*	*30*	*30*	*30*	*Unlimited*	*Unlimited*	*Unlimited*	*Unlimited*
System weight (kg/m²)	*≥ 5,5*	*≥ 5,5*	*≥ 4,3*	*≥ 4,3*	*100*	*≥ 150*	*100-120*	*40-60*
Plant species	*Climbers*	*Climbers*	*Climbers*	*Climbers*	*Various*	*Various*	*Various*	*Various*
Watering	*Rain water*	*Irrigation system*	*Rain water*	*Irrigation system*	*Irrigation system*	*Irrigation system*	*Irrigation system*	*Irrigation system*
Fabrication	*In situ*	*Prefab. / In situ*	*In situ*	*Prefab. / In situ*	*Prefab. / In situ*	*Prefab.*	*Prefab.*	*Prefab.*
Plant life expectation (years)	*50*	*50*	*50*	*50*	*3,5*	*10*	*3,5*	*3,5*
Growing time (years)	*~ 30*	*~ 2-3*	*~ 30*	*~ 2-3*	*≤ 1*	*≤ 1*	*≤ 1*	*≤ 1*
Maintenance	*Pruning*	*Pruning*	*Pruning*	*Pruning*	*Pruning / replacement*	*Pruning / replacement*	*Pruning / replacement*	*Pruning / replacement*
Estimated cost (€/m²)	*30-45*	*~ 200*	*40-75*	*100-800*	*350-750*	*400-600*	*750-1200*	*500-750*

Table 2.5: Qualitative advantages and disadvantages of VGS, adopted from (El Menshawy et al., 2022) and adapted from (Mir, 2011)

Type of VGS	Green façade systems				Living wall systems			
	Direct greening		Indirect greening		Continuous system	Modular system		
							Panel system	
	Planted into the soil	Planted into planter-box	Planted into the soil	Planted into planter-box	Felt system	Planter-box system	Foam system	Mineral wool system
Reducing urban heat island (UHI) effect	*xx*	*xx*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Absorbing fine dust particles	*xx*	*xx*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Increasing biodiversity	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*
Moderating building's internal temperature via external shading	*xx*	*xx*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Sound insulation	*xx*	*xx*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Creating microclimate	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*
Improving aesthetic value	*xx*	*xx*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Visual experience in absence of plants	*N/A*	*N/A*	*xx*	*xx*	*x*	*x*	*x*	*x*
Improving the insulation property	*x*	*x*	*x*	*x*	*xx*	*xx*	*xx*	*xx*
Greening system cost	*x*	*x*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Maintenance cost	*x*	*x*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Irrigation system requirement	*N/A*	*x*	*N/A*	*x*	*xx*	*xx*	*xx*	*xx*
Short coverage period	*N/A*	*x*	*N/A*	*x*	*xxx*	*xxx*	*xxx*	*xxx*
Façade's full coverage	*x*	*x*	*x*	*x*	*xxx*	*xxx*	*xxx*	*xxx*
Moisture problems on solid walls	*xx*	*xx*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Penetration of roots to the wall	*xx*	*xx*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Indoor application	*N/A*	*N/A*	*x*	*x*	*xx*	*xx*	*xx*	*xx*
Technical expertise need	*N/A*	*x*	*xx*	*xx*	*xxx*	*xxx*	*xxx*	*xxx*
Replacement of panels	*N/A*	*N/A*	*N/A*	*x*	*xx*	*x*	*xx*	*xx*
Replacement of dead plants	*N/A*	*x*	*N/A*	*x*	*xx*	*xx*	*xx*	*xx*
Legend: *x*: Low *xx*: Moderate *xxx*: High *N/A*: Non applicable								

2.4 Elaboration of choice for LWS

Despite the aforementioned benefits (section 2.2), the implementation of VGS has not been immune to criticism. For instance, some argue that main advantages of horizontal greening in cities (shading or water drainage) are lost by raising greening from the ground into a vertical solution. Also, specifically aimed at LWS, criticism entails them being too expensive and unsustainable, too complicated and prone to failure and lastly too decorative and superficial to the buildings they serve (Riley, 2017). The excessive resource consumption (construction materials, water and energy) is a major driver of these arguments.

These challenges and doubts do not directly mean that these VGS should not be applied or encouraged. Even though they cannot completely replace the benefits of horizontal greenery, they can be a valuable addition to the urban natural landscape, promoting greener and healthier cities. Most certainly so in dense urban centres, as addressed by Shafique et al. (2018). However, Collins, Schaafsma, and Hudson (2017) and Ojala and Campbell (2020) among others, state that VGS are only a single element of a green infrastructure network. It is also expressed that: “Their design and implementation complements existing green infrastructure to create a functional and stable network of biodiversity, at both a site and landscape scale, essential for the long-term provision of ecosystem services” (Collins et al., 2017). This statement is further backed by the literature study on the importance of biodiversity in the second part of Appendix C.

In order to enable further legitimacy for VGS and LWS in specific, it is important to reflect on this, learn lessons from the criticism and act on these lessons learned by further (sustainable) development of the systems. When dealt with correctly (e.g. through optimized design), the lack of consensus regarding sustainability might be reduced. That is, when answers can be formulated to these frequently cited criticisms at least. In line with this, according to Riley (2017) one of the methods that is proposed to make better informed decisions regarding VGS, is performing economic valuation of these systems.

2.4.1 Elaboration of choice for (modular) LWS

Hence, in order to demarcate the scope, but still aim at the development of a generic and comprehensive framework and tool for economic valuation of all VGS, in this thesis it was proposed to focus on studying the effects of LWS. Yet, in the future multiple categories and types of VGS could be included in order to further expand the developed tool. In addition to the points of criticism mentioned above, this choice for (modular) LWS was based on several other arguments, namely:

1. This study takes biodiversity in VGS design as priority, in order to ensure delivery of a multitude of Ecosystem Services and derived benefits for humans. For backgrounds and elaboration of this starting point, reference is made to Appendix C. In this regard, LWS can be composed from a wide range of different (native) plant species, while green façades usually contain only few species and can merely be equipped with 1 plant type over the entire façade height. Hence, LWS are expected to have higher potential for stimulation and contribution to biodiversity for the same façade area as compared to green façade systems.
   Although nowadays mostly exotic species are used for LWS in the Netherlands, there are no indications that native species could not be integrated in these systems. The exotic species are predominantly decorative or provide nectar and/or pollen for generalist pollinators. But besides pollinators, there are of course all kinds of other things that are important for biodiversity. For instance nesting and feeding places for birds, plants for caterpillars (without caterpillars no butterflies) and other critters and so on. Local species at multiple trophic levels are mostly attracted by native species. Important notion or remark therefore is that future integration of native species is crucial for enhanced contribution to local biodiversity. (Sweco expert knowledge, 2022)

2. In accordance to the points of criticism, (modular) LWS contain a more elaborate secondary support system that exists of a multitude of building materials. Hence, this allows for the extensive elaboration and setup of environmental 'shadow costs' in this first framework proposal already, enabling the development of a more comprehensive valuation tool. In the future, other VGS categories should therefore be integrated in the framework more easily.
3. LWS are usually way more costly than green façade systems, complicating the development of a viable (financial) business case (Riley et al., 2019). With this thesis work, it is aimed to initiate the bridging of this value gap and facilitate an (economic) discussion relating the implementation of these urban greening systems. As stated earlier by Riley (2017), evolution of LWS economic valuation (more specifically Cost-Benefit Analysis) could therefore help. In turn, this should eventually allow for rational decision-making based on scientifically substantiated values.
4. LWS can be installed at higher altitudes since they do not rely on implant in the subsoil, while green façades with climbers are restricted to a height of around 25-30 meters. Moreover, LWS systems can cover the entire façade area with vegetation within one year of installation and are more constant, while green façade systems take years or decades to grow, densify, mature and cover full façades. (Rotteveel, 2022)
5. LWS have the tendency to appeal to the eyes of the public at large, due to their artistic and decorative appearance.

Unless specifically stated otherwise, from this point onwards in the report, the information provided regarding costs, benefits and potential other effects of VGS is applicable to LWS. Appendix H provides the reader with several impressions of two LWS projects in the Netherlands.

2.4.2 Sustainability aspects and design criteria of LWS

With the scope narrowed down to LWS, it should be noted that whenever these systems are integrated within the urban environment, they should be properly studied and designed. This in order to ensure sufficient considerations of sustainability aspects and integration of climate-smart technologies, aside from solely accounting for biodiversity standards and assumptions. For more backgrounds on biodiversity and its requirements, reference is made to Appendix C.2.

This sub-section therefore addresses considerations that should be kept in mind when designing not only a biodiverse, but also a sustainable LWS, that does not significantly harm other climate goals and challenges. In the following, a comprehensive list with qualitative design criteria, starting points, requirements and boundary conditions is presented that have to be accounted for, in order to obtain a LWS with a maximum level of sustainability. This list is created based on scientific documents (Bustami et al., 2018; Gemeente Amsterdam, 2021; Montjoy, 2022; Riley, 2017), as well as peer interviews with Sweco experts and ecologists (Sweco expert knowledge, 2022).

1. One should study all the local conditions for the desired orientation, such as wind and air currents, sun and light exposure, temperature and humidity over the entire surface of the LWS;
2. The system that is most suitable for a successful project should be chosen. This starts by understanding the different LWS solutions. In this light, several factors can be of importance:
    - An integral and holistic building design approach from the start of the development process, leading to deliberate decisions with regards to system integration and material use tailored to the building’s functioning. For instance, integration of rainwater storage tanks into building’s design in order use this for LWS irrigation;
    - Choosing for durable, circular and recyclable materials with the least environmental impact. E.g. the implementation of a Cradle-to-Cradle (C2C) certified LWS and alignment of the VGS service life and remaining façade lifetime;
    - Minimizing and compensating for the environmental damages as a result of raw material extraction, production and installation of the LWS;

3. Selection of sufficient, adequate (native) plant species to ensure a vital, healthy and long-lasting growth. Local climate settings and system orientation play a key role in this selection, meaning plant design is as important as plant selection. Proper plant species selection also influences potential energy savings;
4. Incorporate efficient irrigation and management systems, in order to avoid manual and excessive supply (over-watering) of water and nutrients. These systems can be in the form of drip irrigation, tank systems or monitored and automatic irrigation. Preferably, circular use of water for the irrigation system is enabled through the use of locally collected rainwater (grey water) rather than fresh tap water. This topic is only occasionally addressed in studies, however transparent reporting is needed for LWS to become (accepted) sustainable systems;
5. Integration of technological innovations in order to increase LWS efficiency, automation and monitoring. including air circulation methods and effective growth mediums that can create smart, active and more sustainable structures;
6. Proper plant maintenance, such as cleaning, trimming and irrigating is crucial for plants to stay vital and alive. Moreover, prevention and management of the use of chemical pesticides should occur, utilizing natural fertilizers instead. A well-designed LWS with adequately selected plants still relies heavily on maintenance for success.

3

Economic valuation of vertical greening systems

3.1 Introduction

In order to identify a basic set of analyses and methods that can be applied when valuing VGS, this chapter provides the state of the art regarding economic valuation of these systems. First, a definition of natural value is given and it is covered why one would try to value nature anyway. Then, an introduction into Ecosystem Services Valuation is given. In section 3.4 previous conducted studies into, and developed tools for, the economic valuation of VGS are reviewed. Generic backgrounds on these topics, i.e. economic analysis methods and valuation techniques to assess both costs and benefits of VGS, are covered in Appendix D. Hereafter, the proposal for the establishment of valuation themes that will be used throughout the thesis is given. Finally, a brief section is dedicated to different stakeholders accounted for in this thesis work, with an extensive elaboration to be found in Appendix E. Section 3.7 forms the concluding remark of Part I, answering the first research question.

3.2 Natural value and why we try to value nature

Nature is one of our greatest goods. All things we extract, produce, consume, trade and adore have their origins in nature. Without nature, life as we know it would not be possible on our planet. For the author himself, the value of nature and NBS is both in the field of aesthetics as well as in the area of its provision of ES for society. With the help of the implementation of NBS in urban areas, the living environment of citizens and visitors can be enhanced, leading to a reduction of environmental burden and societal costs (e.g. health costs, energy savings, extended lifetime of constructions) and hence, an increase of values (see Table 2.1 and Table C.1) (Perini & Rosasco, 2013).

3.2.1 Three value perspective of how people relate to nature

Nowadays, we understand and value nature in multiple ways. Our perspective on nature and thus the everyday practices are influenced by different values and interests. However, this value spectrum is seldom acknowledged, hampering the conservation and sustainable use of nature (WUR, 2022).

In a recent study, L. M. Pereira et al. (2020) demonstrated that at least 3 value perspectives of how people relate to nature are present (Figure 3.1). These perspectives are the following:

- *Nature for Nature,* where nature has value in and of itself (intrinsic value) and the primary importance is to preserve nature's diversity and functions;
- *Nature for Culture,* where humans are viewed upon as being an integral part of nature and here the people-nature relationship is valued;
- *Nature for Society,* where nature is primarily valued for its ES and the benefits derived by it from people, and which could lead to optimization of multiple uses of nature.

In order for nature (through NBS) to contribute to nature-inclusive and climate resilient real estate, in this thesis the main focus will be on the last perspective, *Nature for Society*. Hence, value is created through the delivery of ES and their derived benefits in urban areas (Table 2.1, Table C.1 and Table C.2). However, by implementing NBS that contribute to an enhanced level of biodiversity in urban context, also the intrinsic value of nature is stimulated. Besides, bringing nature back to urban areas requires people to live in harmony with nature. This showcases how the different value perspectives are interwoven. This is further acknowledged in section 3.2.3 on 'Doughnut Economics'.

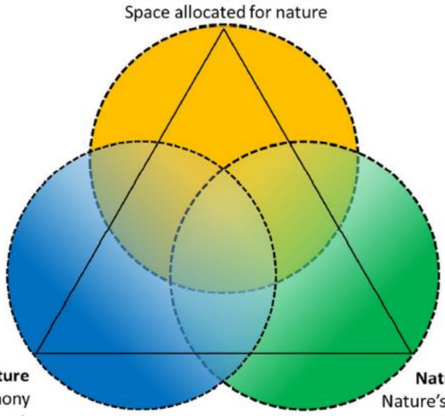


Figure 3.1: Three interwoven value perspectives of how people relate to nature (L. M. Pereira et al., 2020)

3.2.2 Reasons for valuing nature economically

The earth's system, biosphere and several planetary boundaries (Figure 3.2) are pushed beyond their limits by the human species. Severe economic, environmental, ecological and social impacts result from this, leading to ecological conflicts around the world. (Jacobs et al., 2016)

With regards as to why we would try to economically value nature, there are debates whether nature itself should be conserved for its intrinsic value (*Nature for Nature*), or that it indeed should be monetised. Long standing arguments emphasise that ecosystems have intrinsic value and that Mother Nature shouldn't get a price tag (McCauley, 2006). Sharing the viewpoint of Rea and Munns Jr (2017), the author of this work doesn't think all beauty that is present in nature itself should be expressed in numbers: when acknowledging intrinsic value and protecting/expanding ecosystems for their own sake, naturally human welfare and well-being will increase. However, as they and others also state, there are some good arguments present that advocate for the monetising of value brought by nature, NBS and thus VGS. As mentioned, this is mainly in the domain of *Nature for Society*.

- Firstly, NBS are implemented by humans through design and actions that strive towards a more nature-inclusive and climate adaptive society (Hobbie & Grimm, 2020). Indeed, once these NBS are installed, nature itself will take care of the growing process and delivery of ES, automatically contributing to intrinsic value of nature. However the initiative for implementation comes from human action, meaning there will be a monetary investment involved. Apart from adding natural beauty (intrinsic value) to the built environment, the implementation of NBS are thus mainly initiated from the viewpoint of *Nature for society*. Aside from the values the ES and derived benefits provide, people also engage with the nature through their actions. Therefore, from a pragmatist's viewpoint, it makes sense to value the benefits, although also the activities through which people come to value natural elements in their everyday life are important (Peltola & Arpin, 2017);
- Secondly, sound science is at the basis of environmental management and decision-making. To strengthen the justification of these decisions and allow for adequate and rational decision-

making based on facts and figures, Rea and Munns Jr (2017) state that “economic valuation has been used to show how human-induced changes in nature’s services impact human well-being… This information fosters systems thinking and sustainability, allowing decision-makers to better understand the consequences of their decisions”. Also Laurans and Mermet (2014), among others, advocate that valuation studies are believed to draw the attention of policymakers to the goods and services provided by natural processes. By appending monetary terms to nature, more awareness is created and it can make nature’s value really count. Not to make nature a tradable good, but to make it stronger in the face of the current economic system (van 't Hoff, Siebers, van Vliet, Broer, & de Groot, 2022);

- “From a valuation perspective, environmental problems and conflicts are the consequence of trade-offs between values held by different groups of stakeholders, which in many cases are not well represented in the decision-making process” (Jacobs et al., 2016). The rationalization in decision-making can be improved by taking into account the costs and benefits of groups that are absent from the decision-making process as well. Economic valuation and cost-benefit analysis can give consideration to all preferences, also those of the absentees (Laurans & Mermet, 2014);
- In line with the previous arguments, monetising ES and benefits of NBS can provide additional incentives for conservation and expansion of (urban) nature (WUR, 2022). Valuing nature can form a part of many decisions and with an open mind it can be regarded as assigning importance (Jacobs et al., 2016). The European Commission supports this view through their TEEB initiative (The Economics of Ecosystems and Biodiversity), stating: “Setting a price on natural capital may appear callous. But nature and its services escape pricing and are therefore ignored or undetected by markets. In our economic system, this lack of monetary valuation is a root of the problem”. Demonstrating (in economic terms) that NBS are not only a cost item in projects but provide beneficial values as well, the monetization can work as an advocacy or justification measure for the sake of further implementation of NBS in the built environment (European Commission, 2022). Laurans and Mermet (2014) denote this argument as “speaking from the outside of the process, bringing in science-based evidence, and thus influencing the value systems of decision-makers, with a view to achieving a better preservation of ecosystem services.” Hence, by executing economic valuation of NBS (and thus VGS), the methods or tools used provide nature with a voice as to explain why it can contribute to an enhanced living environment;
- When addressing a larger spectrum of stakeholders, i.e. not solely decision- or policy-makers, but also including the likes of real estate investors and developers, engineering and consultancy firms, builders and (sub-)contractors, citizens and the general public, the monetised values of nature and NBS can act as a conversational mechanism or subject of debate. Monetised values are economic terms most people in society can relate to, making the potential contributions of NBS to a healthier and better liveable built environment tangible for all stakeholder groups (Laurans & Mermet, 2014).
- Although some argue that extrinsic motivations (payment for ecosystems) could negatively affect intrinsic motivations to implement nature, Maca-Millán, Arias-Arévalo, and Restrepo-Plaza (2021) did not find strong evidence that supports this in their field experiment. They concluded that extrinsic motivations and equity-related outcomes could be fostered and co-exist with intrinsic motivations, by integrating multiple ways of relating and caring for nature.

In conclusion, economic valuation of NBS might contribute to a more widely support for a green economy and justification of these measures. Like stated by Mabon (2021), “A green economy is an economy that improves human well-being and builds social equity whilst reducing environmental degradation”. In a green economy, growth in employment and income are driven by public and private investment in economic infrastructure and assets, which reduce emissions and pollution as well as protecting and enhancing biodiversity. In addition, a green economy sets high standards for equality and well-being aspects (Mabon, 2021).

3.2.3 Doughnut Economics

Although not within the scope of this research, as a future outlook it might be interesting to link NBS and TEEB to Doughnut Economics, firstly proposed in 2012 by Kate Raworth. The model conceptualizes the inadequacy of the 20th century economic system with regards to our current 21st century climate and biodiversity crisis. A main idea is that Gross Domestic Product (GDP) is not an acceptable measure of success, since the planetary resources are finite and GDP cannot increase forever. Doughnut Economics is a progressive approach to Green Economy thinking. (Mabon, 2021)

Raworth describes the doughnut as being the sweet spot between two concentric circles. The inner circle consists of 11 welfare dimensions based on the United Nations' (UN) world goals, also known as life essentials, while the outer circle is based on 9 key supporting systems (planetary boundaries) of ecological and climate dimensions. Between social and planetary boundaries, so within these 2 circles, lies an environmentally safe and socially just space in which humanity can thrive (Figure 3.2). According to Doughnut Economics, we should not be pushing for endless growth, but instead focus on thriving, resilience and well-being within communities. This places GDP at the side lines.

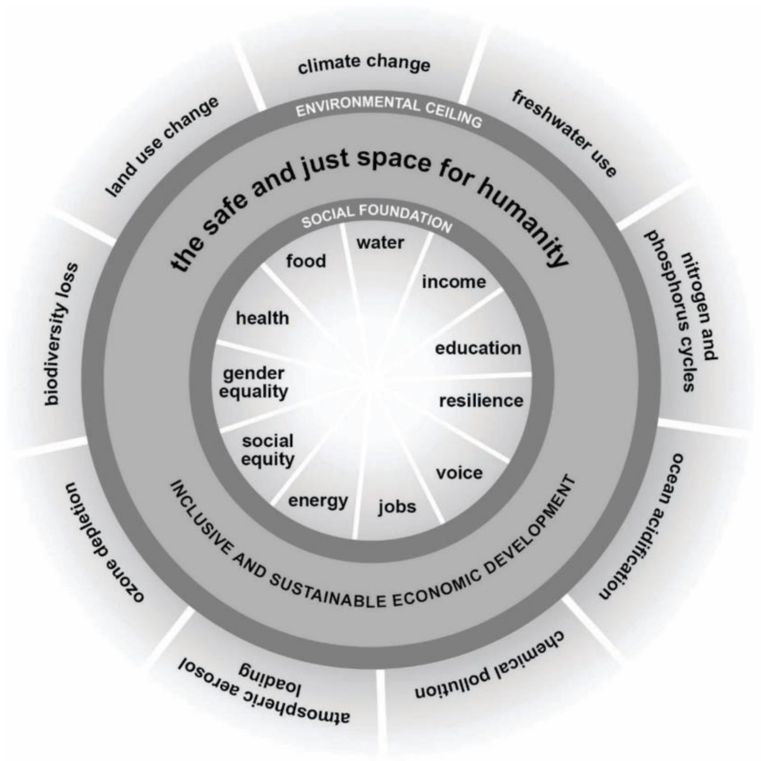


Figure 3.2: The Doughnut Model (Raworth, 2017)

As long as monetary gains and values are the main economic terms and GDP is the measure for a country's success, economic valuation of NBS will have to remain in order to advocate for their implementation and stress the values and benefits they can deliver. However, in light of Doughnut Economics, NBS also have the potential to help transforming towards an economy within the 2 boundaries of the model, while not focussing solely on their 'Nature for society' values in terms of contribution to GDP. Nature does not only possess material value, but also intrinsic and existential value. Thinking like in the doughnut model is considered to be a powerful catalyst for a shift towards both a circular and nature-inclusive economy (Mabon, 2021; Raworth, 2017).

3.3 Ecosystem Services Valuation for VGS

Although human's technological progress created the conception that urban society can function decoupled from ecosystems, the demand for urban ecosystem services gradually keeps increasing. Researchers state that further conservation and restoration of ecosystem functioning in an urban context has the potential to reduce ecological footprints of densely populated areas, while at the same time it offers enhanced climate resilience, human health and quality of life (Gómez-Baggethun & Barton, 2013). At the basis of ecosystem functioning and through this, delivery of ecosystem services and derived benefits for humans, is the presence of rich and abundant biodiversity in multiple trophic levels (Soliveres et al., 2016). This notion is extensively elaborated in appendix C.

Ecosystem Services Valuation (ESV) can inform urban planning in different decision-making contexts. According to Gómez-Baggethun and Barton (2013), these include: "awareness raising, economic accounting, priority-setting, incentive design and litigation". However, there is little understanding of economic valuation of urban ecosystems and the topic is challenging due to high complexity, heterogeneity and fragmentation. This is further hampered by the fact that, although a relative abundance of biophysical and economic studies are performed (however not for VGS unfortunately), only a scarce number of studies address non-economic values, these being in the domain of environmental, social, cultural, and insurance values. Although recognized in ES literature, at an operational level these values are lacking behind and from an applied point of view it should be investigated how these values could be incorporated in urban planning (Gómez-Baggethun & Barton, 2013).

3.3.1 Ecosystem Services Cascade framework

The Ecosystem Services Cascade (ESC) framework explains the relationship between the ecosystem structure-process and human welfare benefits. Thereby it provides a research paradigm for ES, as well as a theoretical basis for ES value accounting and regional sustainable development (Zhang, Li, & Zhou, 2022). The current form of the framework was established by de Groot, Alkemade, Braat, Hein, and Willemen (2010), who argued a separation of benefits and values. Later it was reviewed and redeveloped on numerous occasions, ending up with a cascading scheme as displayed in Figure 3.3.

The scheme illustrates the pathway from ecosystem structure and biodiversity, through ecosystem functions and ES towards benefits and ultimately values for humans in a socio-cultural context. This is at the basis of ESV, which entails the quantification of values attached to the benefits for humans that are directly or indirectly delivered by ES (Fisher, Turner, & Morling, 2009). Also, the framework urges one to link complex ecosystem processes and intermediate ES to final benefits perceived to be important by specific stakeholders of ESV. From the list of final benefits generated by VGS, it should be decided for which benefits it is appropriate and meaningful to apply economic valuation (Fisher et al., 2009).

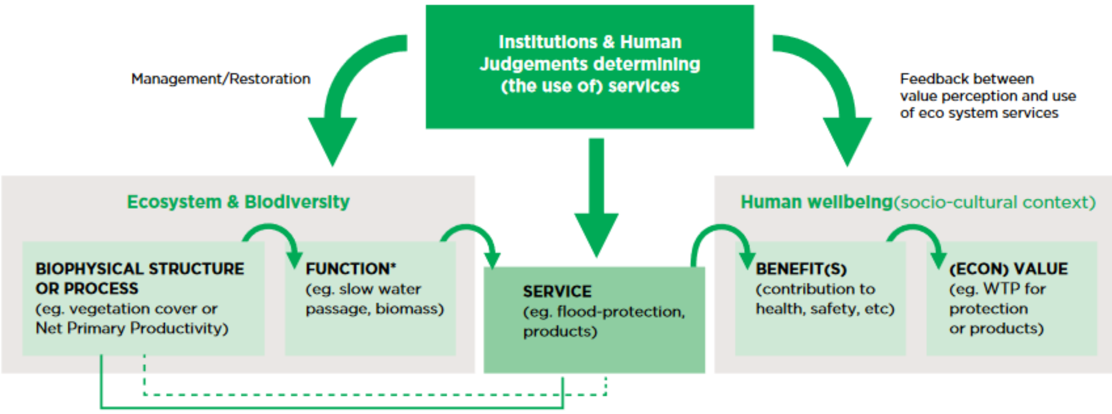


Figure 3.3: Ecosystem Services Cascade framework - Pathway from ecosystem structure or process to ecosystem function, ecosystem service, human well-being benefits and finally economic value (de Groot et al., 2010; Victoria University and University of Melbourne, 2018)

Hence, the (economic) values of benefits, derived from the provision of ES to urban society, are identified through studies which apply environmental economics. In their report quantifying the benefits of green infrastructures in Melbourne, researchers from the Victoria University and University of Melbourne (2018) stated that: “Conventional economic analysis has a limited role in valuing such diverse benefits; instead, a range of valuation methods is required. This is often referred to as a heterodox economic approach, as contrasted with an orthodox approach.”

3.3.2 Integrated valuation of Ecosystem Services

Jacobs et al. (2016) already acknowledged that there is increasing recognition that, from an application oriented perspective, multiple disciplines and methods should be combined in order to represent the diverse set of benefits and coherent values delivered by nature (Figure 3.4). They stated: “A growing number of scientists and practitioners subscribe the ambition to further explore how combining ecological, socio-cultural and economic valuation tools can support resource and land use decision-making. The applied school of ‘Integrated valuation’ is building on earlier traditions in sustainability science. However, integrated valuation explicitly aims at including the multiple values and worldviews in a coherent and operational framework aiming at societal rather than (only) academic impact” and “Different value dimensions (economic, environmental, ecological, social, cultural, self-interest, electoral, or ethical) are implicitly or explicitly part of decision making and its justification” (Jacobs et al., 2016). Exactly this is reflected in the main goal of this thesis work: to develop an interactive and inclusive framework and tool for VGS valuation, in which ultimately a comprehensive set of costs and benefits are quantified and in which these can be weighed with one another.

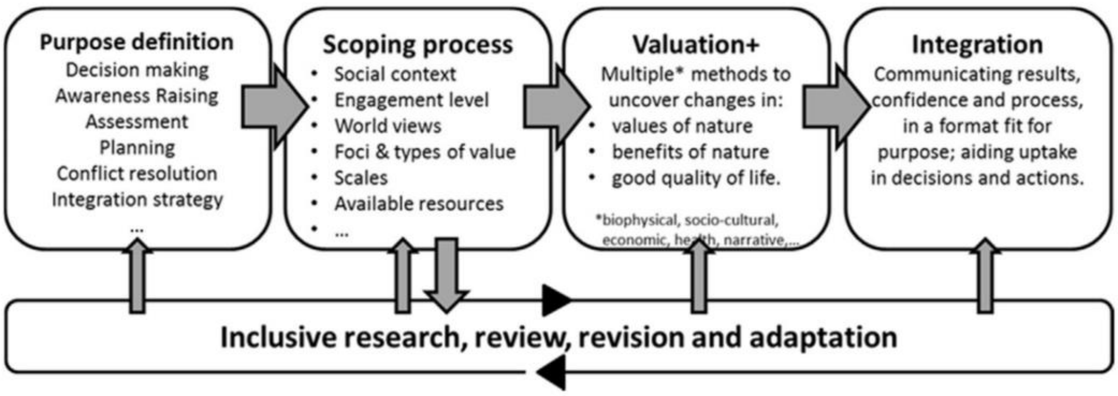


Figure 3.4: Schematisation of the approach for ‘Integrated valuation of Ecosystem Services’ and its main components, adopted from Jacobs et al. (2016)

As can be observed from the figure above, valuation decisions span over multiple stages during the assessment of ES. For example: “The choice of the types of values to elicit or the value language to use, the selection of social actors to engage in the process, the decision of which methodological tools and measurement units to use, or even the choice of which ecosystem services or benefits to include, are steps of the assessment that determine the construction of values and, therefore, the outcome of assessment. In fact, to broaden the action of valuation beyond the mere act of estimating values has severe implications for the conceptualization of valuation, the valuation practice itself, and the role taken by scholars who perform the valuation.”(Jacobs et al., 2016).

In their special issue research paper, Jacobs et al. (2016) (consisting of a broad group from different disciplines) identified a number of key challenges for the field of integrated valuation. Thereby they also demonstrated the broader relevance for ESV and applied (social-) ecological research. However, instead of ignoring or avoiding these challenges during applied valuation research, they should guide as conditional requirements to be addressed and resolved:

1. Scientists studying the different values often keep operating in their own mono-disciplinary fields (e.g. ecology, economy, geography, political ecology, environmental anthropology), preventing interdisciplinary experience and results;
2. Since each valuation method copes with its own complexities and shortcomings, combining methodologies is difficult;
3. There is a lack of reflection in ESV research, meaning assessment of actual societal impact of research outcomes is hard and rarely done;
4. There is a diverse spectrum of policy and governance fields that should be targeted, each including their own specific (and opposing) stakes;
5. Value complexity and uncertainty, e.g. due to limited validated input or sufficient previous research, can hardly be made tangible or communicated in a comprehensive yet compact manner. This limited compactness could hamper correct digestion and use by decision-makers;
6. Limiting the number of methods used can affect the valuation results, emitting potential important values that are not included in these methods. However, selecting an appropriate (complete) set of methods can be perceived difficult and elaborate;
7. It can be hard to make choices regarding whose values should be included in the valuation research in order to obtain purposeful yet realistic outcomes. If certain stakeholders’ interests are not represented in the study, power imbalances may arise or their concerns and perspectives might be forgotten completely;
8. The practice of integrated valuation appears to be more costly in time, resources and data needed. Therefore it seems to be less efficient, at least this notion might be inflicted.

3.4 Studies and tools regarding economic valuation of VGS

Based on a literature review into economics of green roofs and walls, Teotónio et al. (2021) stated that although mere financial performance of these systems is typically low, or sometimes negative even, the return of economic evaluation improves when ecological and social benefits are taken into consideration. Therefore, in order to obtain a full insight into the socio-economic feasibility of NBS (and thus VGS), it is recommended to perform an additional Social Cost-Benefit Analysis (SCBA) rather than performing solely a Life Cycle Cost Analysis (LCCA) (Riley, 2017; Rosasco & Perini, 2018). According to researcher of the Victoria University and University of Melbourne (2018), who performed an analysis into quantification of benefits of green roofs, façades and walls: "The so-called 'gold standard' for economic analysis is to undertake a cost and benefit analysis using the whole-of-life cycle for green infrastructure. The total economic value of the ecosystem services provided and any co-benefits such as extended structure life will provide the benefits, and total life cycle investment including maintenance provides the costs. To our knowledge, there is nothing in the literature that comes anywhere near reaching this standard."

In the following, previous scientific studies conducted by researchers regarding economic valuation and ESV of VGS are identified. These studies will be at the basis of the design and substantive infill of the VGS Valuation Tool, which will be covered later in this report (chapters 4 & 5). It is covered which values are monetized. Reference is made to appendix D as well, which provides a generic background of financial engineering principles, analysis methods, valuation techniques and indicators for economic feasibility.

3.4.1 Studies regarding economic valuation of VGS

From literature study, it was observed that only very little research has been conducted towards the total life-cycle costs and benefits of VGS. Only two elaborate studies were found on this exact topic.

Huang et al. (2019) executed a LCCA of 3 different vertical greening systems in Singapore (tropical climate), where the main goal was to identify and account for all financial costs. These included cost with regards to initialisation, installation, operation and maintenance and disposal of the different VGS types. Hence, the whole life cycle of the systems was indeed covered. Also, a basic description of the types of costs involved in each life-cycle stage was provided, however no specific input data or transparent calculations for these cost components were given.

Furthermore, only Perini and Rosasco (2013) executed a proper CBA for VGS in Genoa (Mediterranean climate). For the costs, only personal financial costs for the funding party were analysed: 1) initial costs; 2) (limited) maintenance costs; 3) disposal costs. Also, some benefits were identified, but due to methodological difficulties and complexity of valuation even less of these were regarded tangible benefits and thus monetised: 1) energy savings due to reduced heating; 2) energy savings due to reduced cooling; 3) increase of cladding durability; 4) increase of property value; 5) carbon dioxide reduction; 6) NO_2, PM_{10} and SO_2 reduction. The CBA demonstrated that some of the VGS analysed can be economically sustainable, when well designed (Huang et al., 2021; Perini & Rosasco, 2013). Economic incentives, for instance tax reduction, could reduce personal initial costs. Subsequently, this could potentially lead to a wider diffusion of VGS to reduce environmental issues in dense urban areas, such as the urban heat island (UHI) effect and other air pollution.

No extensive review or framework for the values of a more inclusive perspective on cost and benefit of VGS were included in both of these studies however. Also, for the temperate climate governing in the Netherlands, no CBA or LCCA for VGS is performed till date. To the author's knowledge, till date no extensive efforts have been made to conduct a research to integrating a comprehensive number of values for (social) costs and benefits and potential distribution or allocation of perceived values over multiple stakeholders.

Some more papers were found elaborating on economics, costs and benefits of VGS, yet also these mostly had a clear focus towards pure financials or were review papers. Hence, they did not provide a true cost-benefit analysis. The list below gives a number of papers that were reviewed and from which can be drawn:

- Perini and Rosasco (2013): Cost-Benefit analysis for green facades and living wall systems
- Perini and Rosasco (2016): Is greening the building envelope economically sustainable?
- Riley (2017): The state of the art of livings walls – lessons learned
- Medl et al. (2017): Vertical greening systems – A review on recent technologies and research advancement
- Kotzen (2018): Economic benefits and costs of green streets
- Rosasco (2018): Economic benefits and costs of vertical greening systems
- Rosasco and Perini (2018): Evaluating the economic sustainability of a vertical greening systems
- Bustami et al. (2018): Vertical greenery systems – A systematic review of research trends
- Brković Dodig et al. (2019): Green facades and living walls – A review establishing the classification of construction types and mapping the benefits
- Huang et al. (2019): The true cost of greening a building – Life cycle cost analysis of vertical greenery systems (VGS) in tropical climate
- Huang et al. (2021): Holistic analysis and prediction of life cycle cost for vertical greenery systems in Singapore
- Manso et al. (2021): Green roof and green wall benefits and costs – A review of the quantitative evidence
- Teotónio et al. (2021): Economics of green roofs and walls – A literature review
- Rowe, Poppe, Buyle, Belmans, and Audenaert (2022): Is the sustainability potential of vertical greening systems deeply rooted?
- Wang, Wong, Tan, Li, and Chong (2022): Vertical greening systems – Technological benefits, progresses and prospects

Moreover, no efforts have yet been made to integrate environmental costs and potential Ecosystem Disservices (EDS) in an all-encompassing valuation framework in order to obtain the true total costs of VGS for society. True pricing of VGS also entails internalising all environmental and social costs and benefits of these systems. Several LCA studies have been conducted in monodisciplinary studies though, which can be used as foundation for the environmental cost calculations (Chàfer, Pérez, Coma, & Cabeza, 2021; Feng & Hewage, 2014; Manso, Castro-Gomes, Paulo, Bentes, & Teixeira, 2018; Oquendo-Di Cosola, Olivieri, Ruiz-García, & Bacenetti, 2020; M. Ottelé, Perini, & Haas, 2014; Salah & Romanova, 2021). For Ecosystem Disservices research, reference is made to appendix C and Table C.3, where a number of these were identified by Gómez-Baggethun and Barton (2013) and von Döhren and Haase (2015).

These were the main reasons that contributed for this thesis work to focus on the initiation and development of a comprehensive, interactive valuation tool for VGS. Knowledge that is available from previous studies is to be combined and expanded further, integrating recent study results in order to arrive at a more comprehensive VGS valuation framework and tool. This framework and tool forms the impetus for future VGS research and gradual further integration and implementation of studies into the developed tool infrastructure, both for costs and benefits. Broader identification of benefits and their value indicators should therefore also occur in order to establish such framework.

3.4.2 Existing tools regarding economic valuation and Ecosystem Services Valuation

In this section, tools that are known to quantify or economically value costs and/or benefits following from ES of NBS and green in urban environments are listed. These can be both tools that are publically available as well as ones that are internally developed by Sweco. The tools in this list were evaluated to varying degrees in order to gain knowledge and insight about important valuing aspects of NBS in an urban context. Subsequently these can be used in order to develop a standardized framework and valuation model for VGS, which, to the best of the researcher's knowledge, is not incorporated in any of these tools yet and non-existent till date. Hence, decision-makers and other stakeholders cannot rely on valuable information regarding costs and benefits of VGS, nor can consultancy firms properly advice clients in this field of urban NBS.

- De Groene Batenplanner: application of the Dutch national institute for public health and environment (RIVM). In development by ESRI Urban Modeller and Tygron Engine (pilot phase)
- TEEB-Stadtool: initiated by the RIVM as a result of the European TEEB program
- i-Tree: a tool which focusses on the values of street trees
- LIFE@Urban Roofs (Arcadis): an economic valuation tool for multifunctional roofs (Posma, de Kort, & Warringa, 2018)
- De Groene MKBA-tool (Sweco): a SCBA tool based on 'De Groene Stad Challenge', which quantifies and monetizes effects of horizontal greening. Extensive data which is produced and gathered by the challenge is used and combined with literature research, in order to make substantiated value calculations of the horizontal NBS. This can be done for municipalities which take part in the challenge.
- SimaPro: world's leading LCA software chosen by industry, research institutes and consultants, to calculate environmental footprints of products and services

During this research, unwittingly a share of knowledge and inspiration was derived from these tools. This was used to form general ideas for a valuation framework for VGS and initiated the thought process regarding the valuation tool.

3.5 Thematic classification for the economic valuation tool

Based on previous conducted studies into the economic valuation of VGS, this section first dives into an appropriate thematic classification for the proposed tool. Then, it summarizes some of the obtained values of costs and benefits within these studies. Relevant conclusions and considerations from these studies are elaborated.

3.5.1 Classification schemes for economic valuation

In order to classify and distribute the costs and benefits of VGS, a classification scheme should be established. Costanza (2008) argued the following: “In the messy world we do inhabit, we need multiple classification systems for different purposes, and this is an opportunity to enrich our thinking about ecosystem services rather than a problem to be defined away”. Building on this, Fisher et al. (2009) noted that: “Any attempt to come up with a single or fundamental classification system should be approached with caution”. They argue for a classification of ES based both on the characteristics of the ecosystems of interest, as well as the decision context for which the concept of ES is called upon.

Specifically when applied for valuation purposes, it is further suggested to apply a classification which divides into intermediate services, final services and benefits. This implies that ecosystem processes and structure can be considered services or benefits, depending on the degree of contribution to human welfare. The same service can also be called upon multiple times, depending on the benefits of interest. This scheme recognises the complexity of ecosystems and instead of trying to understand this all in detail, it only has to be made clear which (final) benefits are accounted for (also see Figure 3.3). This avoids potential double counting since only final benefits are valued, meaning the method is fit for purpose in valuation affairs (Fisher et al., 2009).

Hence, in order to provide a legitimate setup or outline which can be used throughout the process of economic valuation of benefits (and costs) of VGS, a solid thematic classification scheme should be applied as its foundation. This should provide for a relevant, robust and insightful overview and compilation of costs and benefits, facilitating their comparison or weighing to one another. Developing a comprehensive yet functional and applicable VGS valuation tool, which keeps in mind the user perspective by decision-making or practitioners, in accordance to the abovementioned a classification into the full spectrum of individual ES is perceived too impractical, laborious and complex. Since the decision context for which the ES are being mobilised is to objectively inform decision-makers (often laymen in the field of VGS) in an early project process regarding the costs and benefits of VGS types, open and accessible valuation themes to which they can relate are preferable. In the search for an appropriate classification scheme for costs and benefits, literature and existing tools were reviewed.

3.5.2 Cost themes

In order to fulfil the objective of developing a comprehensive cost-benefit tool that accounts for financial, environmental or ecological and social aspects, it was clear that for acquiring the true costs a distribution can be made regarding financial costs and environmental costs. Financial costs have been a subject of research by e.g. Perini and Rosasco (2013) and Huang et al. (2019), while for the environmental aspects shadow costs can be calculated through the Environmental Cost Indicator (ECI) with a Life Cycle Assessment (LCA) study (Chàfer et al., 2021; Oquendo-Di Cosola et al., 2020; M. Ottelé et al., 2014). Additionally for the cost components of the analysis, potential Ecosystem Disservices (EDS) could be identified as a theme in the social domain. This holds that 3 distinct cost themes could be integrated into the VGS valuation tool:

- Financial costs
- Environmental costs
- Potential Ecosystem Disservices

3.5.3 Benefit themes

As illustrated in 3.3 and 3.5.1, the thematic classification for the values of final benefits resulting from ES can be a delicate process. In order to comply with the statements made earlier on by Costanza (2008) and (Fisher et al., 2009), noting that the classification scheme should meet decision context and possess open and accessible valuation themes to which the target group can relate, the thematic classification for this thesis is established based on the categories as acquired from TEEB-Stadtool. TEEB (The Economics of Ecosystems and Biodiversity) is a leading worldwide initiative dating from 2007, facilitated by the United Nations (UN), which strives to acknowledge and recognise the values of ES and biodiversity. To account for these values, in the Netherlands the TEEB-Stadtool was initiated in 2013, which since 2016 is managed and developed by the Dutch national institute for public health and environment (RIVM). Since 2019, after extensive review by 'Planbureau voor de Leefomgeving' (PBL) (van der Heide, 2015) and further development, hereby taking into account interviews with stakeholders, the tool comprises the following themes: health, climate adaptation, real estate, recreation & leisure (Does, Remme, & de Nijs, 2019). Further recommendation was to include values for biodiversity in the future.

- Health & well-being
- Climate adaptation & mitigation
- Real estate
- Social & recreational & commercial
- Biodiversity

Formal reason for the thematization as provided by TEEB-Stad was 'to keep it as simple and accessible as possible'. Although this might seem as an arbitrary argument for classification which is not scientifically sustained, in accordance to the statements made by Costanza (2008) and Fisher et al. (2009) in section 3.5.1, this does meet the decision context for which the concept of ES valuation is called upon.

Furthermore, Climate Adaptation Services (CAS) developed the 'NAS-adaptatietool' for the Netherlands. This tool visualises impacts of climate change on several themes, which are by and large established in a similar fashion as was done for this thesis work (CAS, 2022). Impacts are distributed over sectors and themes, e.g. health, built environment and urban planning or infrastructure, nature, recreation & tourism. In a study conducted at Victoria University and University of Melbourne (2018), similar themes were applied to group benefits.

Finally, during constructive conversations with experts in this field of study (Marc Ottelé, 2022; Rotteveel, 2022; Sweco expert knowledge, 2022), the abovementioned thematization was presented (and validated). They acknowledged that these were recurring themes in scientific studies and projects within the field of VGS, NBS and urban planning, and that they touch upon urgent issues at play in contemporary society. Also, aside from expansion of current scientific knowledge, the objective for the tool is to inform decision-makers in real estate companies or politics (usually laymen in this scientific field) and to engage with other stakeholders where the tool acts as a conversational mechanism. Especially with the proposed objective and the target group in mind, compilation of the distinct benefits into these themes (to which they can relate and which capture their imagination) can help to meet this goal, rather than a classification into the abstract and more complex ES. Hereby, it should be noted that the proposed thematization is one way of classifying and pooling the benefits delivered, and not necessarily the only correct way.

A sub-division of the distinct benefits and their value indicators over the themes as established in this section, will occur in chapter 4, where the proposed framework is further explained. Same goes for the cost indicators that will be used for valuation.

3.6 Stakeholders in economic valuation of VGS

Comprehensive and integrated economic valuation of VGS can per definition also be inclusive, by involving the viewpoints of different stakeholders that are concerned with and affected by costs and benefits resulting from these system's implementation. However, since valuation (in) directly affects everyone, this also imposes the challenge to consider these multiple social actors speaking different value languages. Distinct stakeholder groups or individuals can articulate or perceive different (values of) costs or benefits of VGS and the ES involved, at times these perceived differences can even be conflicting (Turner et al., 2003; Hein et al., 2006; (Jacobs et al., 2016)).

Fisher et al. (2009) illustrate this phenomenon with an example related to the different values of tropical rain forests. To global stakeholders predominantly the climate regulating ES of carbon sequestration may be valued. However, local inhabitants may also value the forest for its fuel wood or spiritual worship. These services are in economic terms rivals to one another. The fact that many intermediate and final ES are valuable impose further complications, since they might provide benefits to humans, even if the stakeholders themselves do not perceive these services. Climate regulation for instance, is a vital ES for human health and well-being, however it is probably not perceived nor is it valued appropriately by a major portion of the earth's population. Findings resulting from extensive literature research into VGS and their important stakeholders are included in Appendix E of this report.

3.6.1 Scope demarcation with regards to stakeholders

For the sake of feasibility and potential for social application of the results of this thesis, a demarcation in scope with regards to the stakeholders is proposed. In accordance to the LIFE@URBAN ROOFS tool by Posma et al. (2018), this research will distinguish between a mere financial business case, this in the Life Cycle Cost Analysis (LCCA), and a Social Cost-Benefit Analysis (SCBA). Therefore, appropriate and corresponding stakeholder groups for these analyses are suggested in Table 3.1. Huang et al. (2019) already acknowledged that LCCA are especially relevant for building owners or real estate investors, in order to make informed decisions regarding their financial investments. In SCBA, besides the financial costs and benefits (tangible costs), also an effort is made to quantify indirect or sometimes even intangible costs and benefits for society as a whole (Bonner, 2022).

Although research by van den Biesen (2018) also identified government bodies as crucial stakeholders for implementation of VGS, this group is not included in the current research. Reasoning behind it is that they are no direct investor or beneficiary of VGS, however they are ought to adopt a supporting and facilitating role.

Table 3.1: Demarcated list of stakeholders for thesis work

Economic analysis type	Nr.	Description of corresponding stakeholder
LCCA	1	Real estate investor (private)
SCBA	2	Society as a whole (public)

It should be noted that this scope demarcation is useful for the development of the valuation framework and tool for VGS. Distribution and allocation of costs and benefits over these stakeholders will occur during development of the VGS Valuation Tool. In subsequent research or tool versions, a more inclusive number of different stakeholders may be studied in order to gain insights into a more diverse palette of the distributions of costs and benefits of VGS. A study conducted by the Victoria University and University of Melbourne (2018), suggests that different groupings could be established like e.g. public and private, or individuals, communities and institutions. Another option is that the stakeholder groups, like displayed in Figure E.1, are to be studied and implemented in the valuation model on an individual basis. This would require a more detailed analysis of stakeholder attitudes, preferences and value perspectives, in order to make substantiated choices with regards to costs and value distributions of benefits provided by VGS.

3.7 Conclusion Part I – Analysis phase

In this analysis phase, literature research has provided interesting findings and insights into the concept of VGS and these systems' economic valuation. Chapter 2 reviewed the current state of the art regarding different types of VGS with their characteristics and qualitative (dis-) advantages, their context within the concept of (urban) NBS, their relation to ES and the importance of biodiversity integration and sustainability aspects and design criteria. Chapter 3 gave a deeper understanding of the different notions of natural value and why one would even try to value nature economically. Furthermore, the concept of ESV, the Ecosystem Services Cascade framework and the approach of 'Integrated Valuation of Ecosystem Services' were introduced. Then previous conducted studies into economic valuation of VGS were identified and existing valuation tools were reviewed. The literature study was concluded with specific information and valuation methods for different costs and benefits of VGS, and a demarcation of the stakeholders as accounted for in the remainder of the work was provided. Additionally, in-depth backgrounds and elaborations on these topics were further addressed in Appendices B, C, D, E and H. Combining these findings enabled the author to generate a sufficient understanding and background knowledge of the thesis topics and to answer the first sub-question of this research.

"What is the state of the art regarding the effects of vertical greening systems and the economic valuation of these systems for different stakeholders?"

Although the concept of VGS has a long history, these systems are an innovative field of scientific research in urban planning and the area of urban NBS. In contemporary society, implementation of VGS within the urban fabric is deemed a rational solution to enhance the built environment (building itself, direct surroundings and urban scales), which can offer numerous benefits to human society in the private and public domain. In Table 2.1, a comprehensive list of 19 distinct benefits was composed, however it cannot be ruled out that in the future even more benefits become apparent or scientifically sustained.

Upon identification of different VGS types, i.e. direct green façades, indirect green façades, continuous living walls and modular living walls, for several reasons (modular) LWS were deemed most feasible to use in order to develop a comprehensive valuation framework and tool. Among these reasons were the notion that biodiversity is a priority for ES delivery and the more elaborate secondary support system of LWS, which allows for the extensive elaboration and setup of environmental 'shadow costs' in this first framework already. For these systems, design criteria (minimum standards) regarding biodiversity and sustainability were acknowledged and established.

Then, a scientific introduction into natural value and the reasons to value these was given. Multiple value perspectives are present and in this work the perspective of 'Nature for society' is utilised in order to append values to Ecosystem Services (ES) that are delivered.

The concepts of Ecosystem Services (ES), Ecosystem Services Valuation (ESV) and Ecosystem Service Cascade (ESC) framework were studied. Healthy ecosystem functioning is at the basis of ES delivery. If this is ensured, ESV can inform urban planning in different decision-making contexts. The ESC framework explains the relationship between the ecosystem structure-process and human welfare benefits and urges one to link complex ecosystem processes and intermediate ES to final benefits perceived, which can then be valued. Also, there is increasing recognition that, from an application oriented perspective, multiple disciplines and methods should be combined in order to represent the diverse set of costs and benefits and coherent values imposed by nature. Integrated Valuation is therefore proposed, combining value dimensions in economic, environmental, ecological, social, cultural, self-interest, electoral, or ethical field.

Subsequently, merely two previously conducted studies could be identified in which (more or less) comprehensive CBA/LCCA were performed. The study by Perini and Rosasco (2013) accounted for personal and social costs and some benefits over the life cycle. In the LCCA of Huang et al. (2019), only an eye was cast upon the pure (direct) financial costs and from this the financial benefits were deducted. However, taking into account and including the remaining findings from literature review, the studies mentioned can form a solid basis for the development, design and setup of a more comprehensive VGS Valuation Tool elaborating on the true total costs and benefits.

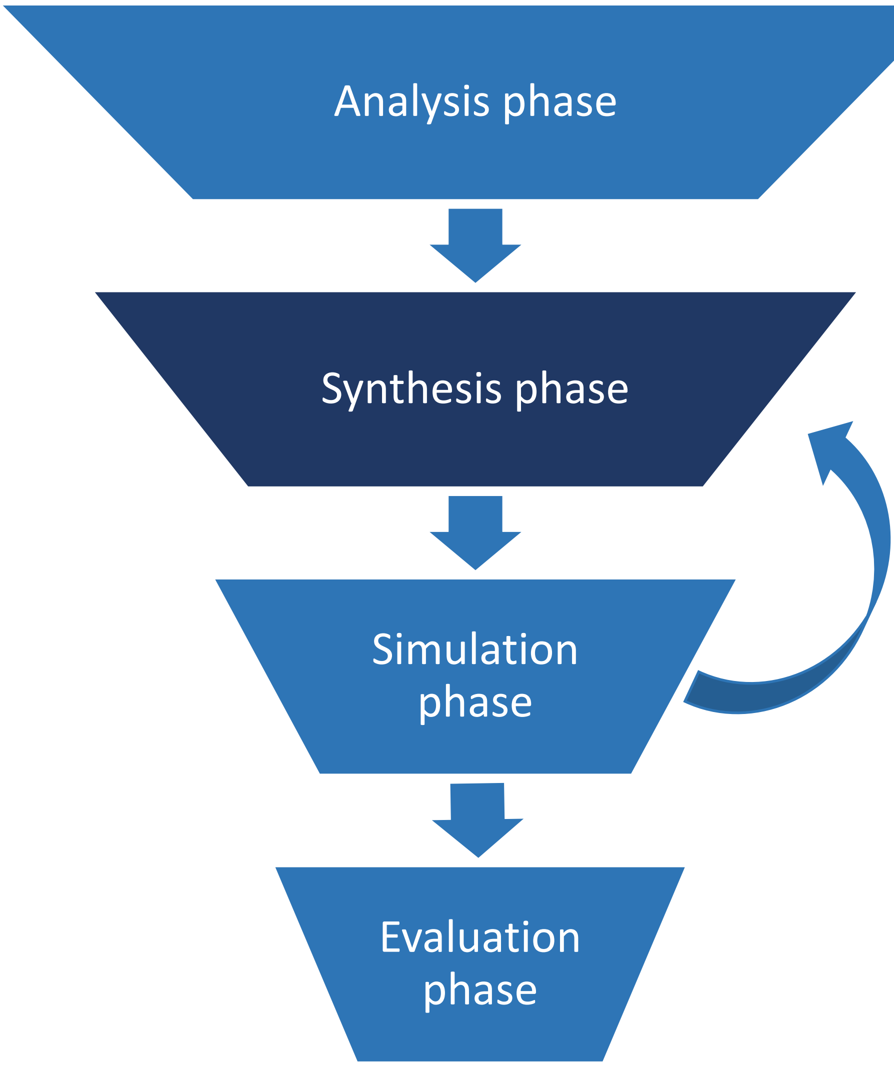
The possibilities regarding thematic classification of costs and benefits were reviewed based on literature. This led to the thematization for this research as per the following themes: financial costs, environmental costs, potential Ecosystem Disservices, health & well-being, climate mitigation & adaptation, real estate, social & recreational & commercial and biodiversity. However, this is merely one option of classifying and pooling the benefits delivered, fit for the intended purpose and suiting the decision context of the valuation tool. As set out by Costanza (2008) and Fisher et al. (2009), it is not necessarily the only correct way, since different classification systems should be "regarded as an opportunity to enrich our thinking about ecosystem services, rather than a problem to be defined away".

Looking at the stakeholder perspective, for the sake of feasibility and potential for social application of the results of this thesis, a demarcation in scope was proposed. In accordance to a previously developed tool for multifunctional urban roofs, this research will distinguish between a mere financial business case (LCCA) and a SCBA in order to show different perspectives of value for stakeholders (Posma et al., 2018). The stakeholder groups that were identified to fit to these analyses were 'real estate investors' (private) and 'society as a whole' (public) respectively.

Part II

-

Development of valuation framework



4

Valuation framework and tool design

4.1 Introduction

The synthesis phase (Part II – Development of valuation framework) translates the findings of the literature review into a framework fit to determine all costs and benefits of VGS. It contains the chapters 4 & 5, which cover the general analysis methodologies, framework and tool design, and some of the distinct valuation methods for cost and benefit indicators respectively. In the end (section 5.5), a conclusion of Part II formulates the answer to the second sub-research question:

Which analysis method and valuation methods are proposed to enable the comprehensive economic valuation of the costs and benefits of vertical greening systems?

This current chapter presents the general concept and the analysis methodologies that are used throughout this thesis work, in order to develop and establish a comprehensive VGS valuation framework and tool. The Social Cost-Benefit Analysis (SCBA) and Life Cycle Cost Analysis (LCCA) are elaborated, covering their most relevant aspects for use. Then, the framework for the valuation tool, containing general workflow and main contents, is given. Hereafter, a further breakdown of the design for the framework is provided, forming the infrastructure of the semi-automated tool.

4.2 Social Cost-Benefit Analysis and Life Cycle Cost Analysis

This section provides the overview for the economic analysis framework used to develop a scientifically sustained valuation tool, accounting for the different values of VGS that correspond with real estate investors and society as a whole. Sections 3.4 and 3.6, as well as appendices D and E, already elaborated on the backgrounds of economic valuation of VGS, appropriate economic analyses, valuation methods and the different stakeholders involved with their implementation.

4.2.1 Theory of Life Cycle Cost Analysis and Social Cost-Benefit Analysis

Both estimating the net resulting costs or benefits of a potential project, LCCA and SCBA possess similar features and procedures. Both methods are employed with calculating the Net Present Value (NPV) where present and future costs and benefits are discounted with appropriate (often distinct) discount factors. However, the most important difference between LCCA and SCBA is that SCBA takes account of all direct and indirect costs and benefits irrespective of who is the bearer of these (thus, society as a whole), whereas LCCA only considers direct financial cash flows or transactions attributable to a certain company or other stakeholder. SCBA is therefore considered an economic analysis, while LCCA is a financial analysis. To evaluate all financial, environmental and social costs and benefits in SCBA, valuation techniques similar to those found in financial analyses are applied for direct and indirect financial effects, however these can be complemented with distinct methods for valuating 'intangible' (non-monetary) aspects (Bonner, 2022). For instance, Life Cycle Assessment (LCA) can be integrated as a valuation method for calculating environmental shadow costs through the Environmental Cost

Indicator (ECI). Simply stated, SCBA expands LCCA by integrating environmental and social costs and benefits into the equation, rather than only assessing the pure financial, monetary impacts.

Since financial feasibility is strictly depending on profitability, it could be the case that a financially feasible project might not be economically viable when costs or impacts for society are negative. On the other hand, an economically viable project with lots of benefits for society, may not always be financially feasible or attractive for the funding party. In some cases, by tapping into additional funds that are made available by governments (tax incentives, subsidies, appealing loan structures) for instance, still positive societal impact can be realised (Imarticus Learning, 2019).

Studying both the financial feasibility as well as the economic feasibility of VGS can help develop further understanding of the distinct values for the investor and society as a whole, while the framework can act as a conversational mechanism and potentially encourage a more widespread acceptation of the systems considered. At least the framework could be applied to search for more sustainable business cases or broadly supported financing strategies (Bonner, 2022).

Steps in SCBA and LCCA

Generally, SCBA applies to policies, programs, projects, regulations and demonstrations. Previous research also concluded that CBA can provide guidance in evaluating costs and benefits of VGS (Huang et al., 2019; Perini & Rosasco, 2013). The procedure of SCBA can be performed by applying the nine steps as denoted below. These are covered throughout this report: steps one and two are reiterated in section 4.2.2, while chapter 5 is dedicated to the methodologies for steps three to seven. For LCCA the same steps can be followed, however since only financial effects are accounted for there is no need for step five. For now, sensitivity analysis is beyond the scope of this research, while conclusions on analysis results are drawn in chapter 6. The steps follow from Boardman, Greenberg, Vining, and Weimer (2011), who composed a book bundling the concepts and practice of cost-benefit analysis:

1. Specify the set of project alternatives or options;
2. Decide whose costs and benefits count;
3. Identify the impacts and select measurement indicators;
4. Predict the impacts over the life of the proposed regulation;
5. Monetise (attach monetary values to) impacts;
6. Discount future costs and benefits to obtain present values;
7. Compute the net present value of each option;
8. Perform sensitivity analysis;
9. Reach a conclusion.

Discount rate

In order to make all monetised costs and benefits directly comparable in both the SCBA as well as the LCCA, future values are converted into present values. Discounting of future values occurs by means of applying a discount rate to those (fictitious or monetised) future cash flows. The need for discounting future costs and benefits to present values, stems from two main arguments which both relate to the opportunity cost of capital (Boardman et al., 2011).

First, the general observation that individuals prefer a penny today to a penny in the future. This general preference for current consumption is also known as the ‘rate of time preference’, where society accounts greater weight to consumption closer to the present. This relates to all economic costs and benefits and is not limited to those of financial nature.

Second, the notion of alternative investment opportunities forgone. Funding of an investment imposes costs on the investor, either through interest that should be paid to the lender or the returns from an alternative investment made forgone. The money invested cannot be used for other purposes. Also a risk premium could be included in the discount rate, reflecting additional return for the risk of future payments not materialising (Boardman et al., 2011).

4.2.2 Application in VGS Valuation Tool

In the VGS Valuation Tool there is distinguished between two analysis frameworks in order to identify, quantify and monetize the costs and benefits related to vertical greening systems. The financial business case for the investor, is captured in the LCCA. The costs and benefits for residents (society) are analysed in the SCBA. In order to develop a first version of the tool, (modular) LWS are used as applicable option for the project case. Additional VGS types can be incorporated in later stages. The baseline alternative for the SCBA is no VGS, implying standard Dutch bare brick wall.

In the LCCA, the financial business case shows the pure financial costs and direct financial earnings for the real estate investor over the lifetime of the VGS, based on expected transactions and cash flows, or a potential reduction in the costs. Based on future research, it might be concluded that other stakeholders relate to this analysis framework as well. These might be integrated in subsequent versions of the VGS Valuation Tool.

In the SCBA, an effort is made to also quantify and subsequently monetize costs and benefits that do not have a true financial origin and were no direct cash flows are involved. These are the indirect or intangible costs and benefits. Here, values of the environmental and social costs and benefits are included, regardless of who pays or benefits. Hence, the stakeholder group for this analysis is society as a whole. Additionally, qualitative potential Ecosystem Disservices (implying costs) and benefits of VGS are included in the tool. These are deemed unquantifiable values or are not expressed and valued in monetary terms yet. However, they are scientifically proven to affect or benefit certain stakeholders or society at large. Future effort should be made to integrate and develop these within the tool.

Based on the various costs and benefits and the distinct discount rates per analysis, the projected future costs and benefits will be discounted to present values. Three discount rates are applied:

- As a baseline, for both LCCA and SCBA a 'Zero discount rate' analysis is performed. This entails the valuation of all costs and benefits corresponding to a case in which the time value of money would be neglected;
- For the LCCA, subsequently an analysis is performed with a certain governing 'investor discount rate' (to be determined in accordance between the consultant and client);
- For the SCBA, aside from the 'Zero discount rate' analysis, a ‘Social discount rate’ for green investments is applied. This rate is lower, since due to the long time horizon it is assumed these benefits start occurring at later moments in time, yet their importance should be manifested.

These different kind of analyses and applied discount rates generate insights into both the different costs and benefits taken into account for the framework, as well as the influence of the time value of money and other investment opportunities forgone for distinct stakeholders. For the development of the tool, it will be assumed that the implementation of and payment for the new VGS occurs immediately in the present year. Hence, the initial investment will not have to be discounted. Furthermore it is noted that in the tool the real discount rates are used for calculations. This means (assumed) inflation is already accounted for when implementing the nominal discount rate.

For the LCCA, the user of the tool will be free to insert an appropriate discount rate for the analysis. Usually, discount rates for investors in financial analyses are between 6-10%, depending on the opportunity cost of capital and the amount of risks imposed by the investment. Higher risks require higher rate of return, hence a higher discount rate should be applied.

For the SCBA fixed discount rates are applied based on research by ‘Planbureau voor de Leefomgeving’ (Koetse, Renes, Ruijs, & de Zeeuw, 2017). The discount rate for SCBA in which ES are valued, is proposed to be kept at 2,0% when these ES become relatively more scarce than regular consumption goods and are not substitutable, whereas it is at 3,0% when this is not the case. For this research, it is assumed that the growth of ES delivery will lag behind the growth of consumption goods, meaning they become relatively scarcer. Hence, a real discount rate of 2,0% is proposed for this SCBA.

4.3 General setup, design and infrastructure of the VGS Valuation Tool

The VGS Valuation Tool is developed to get an overview of the monetary values of lifetime costs and benefits associated with the implementation of VGS at building envelopes, based on substantive and scientific facts and figures. This is in order to generate valuable insights for the anticipated end-users of the tool, who can use it to inform, consult or steer clients and other decision-makers. The primary target group for the tool consists of consultants in environmental and climate consultancy, ecology and urban planning, as well as other experts in the field of VGS. The tool can specifically be used when real estate owners, investors or other decision-makers are exploring their options for implementing green measures in the urban environment, more specifically when they are potentially interested in applying VGS in their real estate projects.

During this thesis, the VGS Valuation Tool will be developed in MS-Excel, following the steps representing SCBA guidelines. The goal is to deliver a first running version of a valuation model, capable of calculating monetary values of costs and benefits automatically. To the best of the author's knowledge, this provisional version of the tool will be the first model capable of doing so, in a most comprehensive and interactive manner. Manual data input for a number of variables will remain necessary. Through changes in input data, hence the implementation of a number of governing input parameters, users can see the impact of certain cost and benefit values on the total outcome. These specific valuation methods will be elaborated in chapter 5, while inserting input data will be demonstrated by means of a case study in chapter 6. With this framework, an outline will be provided which also serves as reference work and impetus for future research into VGS valuation and tool extensions.

4.3.1 Framework functioning

User workflow and main tool contents

The VGS Valuation Tool should be a tool which ultimately allows for adequate and precise, and when applicable location specific, value calculations for costs and benefits of VGS implementation. Each type of cost and benefit will be calculated with a so-called cost or benefit indicator. Also the term value indicator could be used. For each value indicator that is monetised, calculations including several distinct input variables result in a monetary cost or benefit (chapter 5). This initial tool version was developed with help of input values following from executed literature review for LWS and a case study (chapter 6). However, in order to make the tool interactive and suitable for future modifications or extensions, thus allowing for project specific input, the input values can be changed when deemed appropriate.

Figure 4.1 illustrates the framework functioning by indicating the user workflow that is to be followed in order to utilise the tool. Also, main tool content is depicted. This workflow is based on proposed guidelines as established in several research papers, among others by Rowe et al. (2022), Huang et al. (2019) and Perini and Rosasco (2013). As shown, the analysis sequence consists of 3 main phases:

1. Selecting general principles and assigning distinct input parameters to established variables;
2. Valuation of the quantifiable costs and benefits, followed by clear and visual classification and presentation of these valuation outcomes;
3. Interpretation of results to allow for substantive consultation as basis for decision-making.

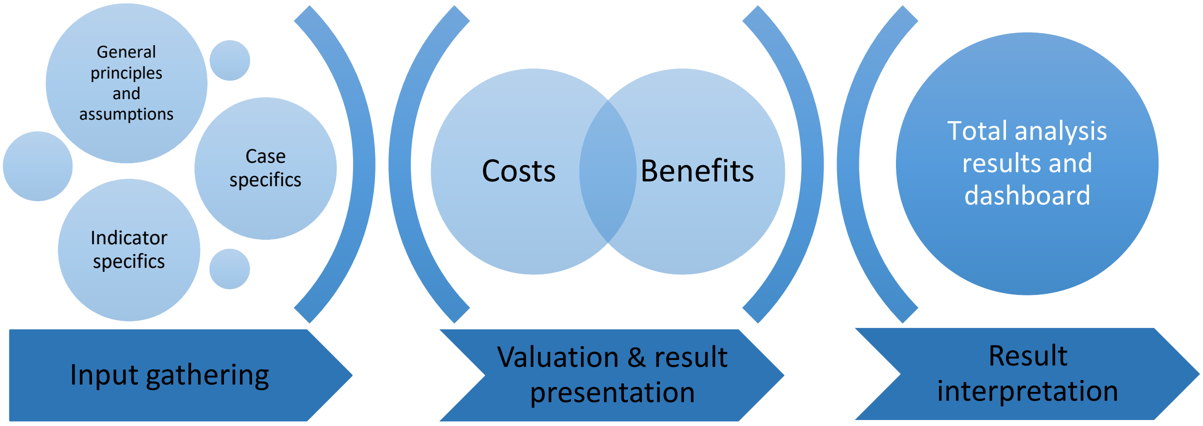


Figure 4.1: Framework functioning – User workflow and main tool contents

Automated valuation workflow in tool per monetised value indicator

The developed tool automates the second phase of the user workflow displayed above. This is done by exercising the valuation workflow for each value indicator that is to be monetised (Figure 4.2). In order to do so, the sources of each cost and benefit were analysed based on scientific papers and expert knowledge of VGS. Then, corresponding valuation methods and formulas were integrated in the model. Requisites and relations that led to these methods, provided the input variables that needed to be established. For these input variables, users can insert project specific input data based on locations, buildings, demographics and local climatic and environmental circumstances. References for data sources are provided in the tool. Once inserted in phase one of the user workflow, the input data is then transported, linked and when needed transformed throughout the model in order to fill the valuation formulas, ultimately delivering the results which can then be assessed and interpreted.

1. Linking, transporting and when needed transforming assigned input parameters for valuation formulas;
2. Conducting monetisation calculations, based on:
    a. Applied general principles and assumptions;
    b. Case specific input data;
    c. Indicator specific input data;
    d. Indicator specific valuation method;
    e. Post-processing of obtained yearly values by discounting to present value;
3. Classification and visual presentation of output in result dashboard, ready for interpretation.

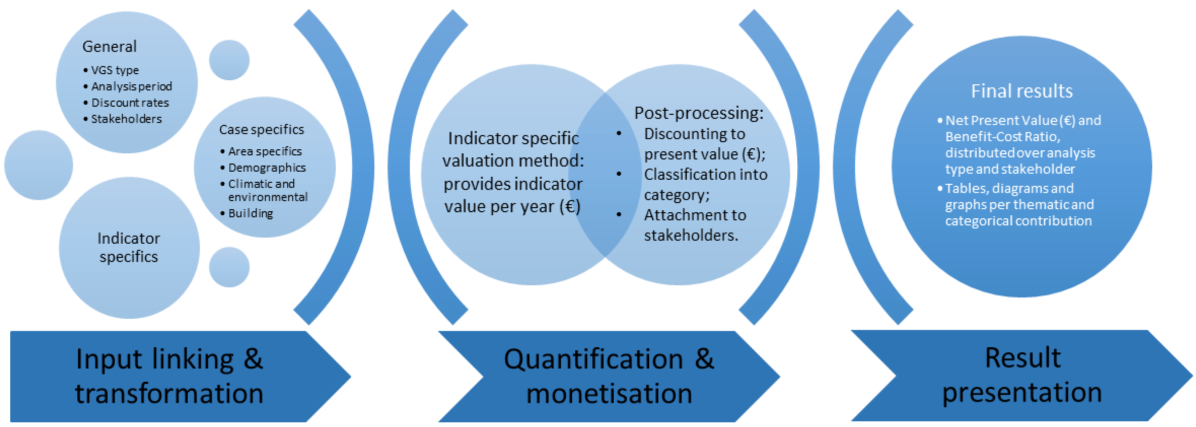


Figure 4.2: Framework functioning – Automated valuation workflow in tool per monetised value indicator

The functioning and background of the automated valuation workflow will be tailored to each monetised value indicator in chapter 5. In the following, a brief overview is given elaborating on the workflow employed by the tool and which is visualised in Figure 4.2:

1. **Input linking & transformation:** General principles & assumptions contain information with regards to the type of VGS, the total analysis period and the applied discount rates for calculation of the present value (PV). Also the stakeholders that are included in the analyses are displayed here. Case specific input relates to relevant project data regarding area specifics, local demographics, local climate and environmental conditions and the host building. Indicator specific input includes numerical data or monetary terms from literature, which is necessary to complement the general and case specifics, filling up the voids in value indicator formulas. For instance, additional unforeseen variables that follow from indicator's valuation methods or available monetary terms for translation of quantitative effects to monetary values, can be regarded indicator specific input. In order to limit the number of input variables that are to be adjusted by the end-user, some valuation methods will require transformation of certain input data. When this is the case, this data transformation is incorporated in the tool.
2. **Monetisation:** For the indicator specific calculation, input is linked to one another as per the valuation method that is described. For this, generally a link will have to be made between VGS specific data, case specifics, e.g. the number of people included in that indicator, and indicator specific input. This value calculation results in a monetary value for the indicator per year that this cost or benefit is applicable. During post-processing, discounting of all expected future costs and benefits for the duration of the analysis period is performed as per applied discount rate. This will result in the present value (PV) of each monetised cost and benefit indicator. Additionally, each cost and benefit indicator is classified to the overarching category it belongs to. Also, the indicators are attached to the analysis type and corresponding stakeholder for which they apply.
3. **Result presentation:** The output of a value indicator calculation will be a monetary term in Euros, accumulated as present value over the duration of the analysis period (for now assumed constant at 30 years). In the Excel tab where the respective indicator is calculated, the values are classified to their categories and attributed to the correct analysis and stakeholder, like mentioned above. However, this results in a relatively detailed elaboration and overview, which might not be interesting for all end-users. Therefore, the outputs of all value indicators are subsequently redirected and visualised in the 'Results section'. Here, the total Net Present Value (NPV) and Benefit-Cost Ratio (BCR) is given per analysis and corresponding stakeholder. Also, a more compact tabular overview is generated containing thematic totals. In the result dashboard, diagrams and pie charts present the total analyses outcomes. This provides further insight into the relative contribution of different cost and benefit themes and categories towards the final results.

As stated earlier in this report, for the development of the model a Living Wall System (LWS) is used. However, the opportunity to implement variable input parameters in later stages is accounted for. This indicates that the main deliverable of the research project is a valuation model in which a generally applicable method is incorporated, that should hold for all types of VGS. By changing and tweaking the input parameters, different scenarios can be modelled. In this case, different scenarios can be created by inserting input parameters related to specific locations, buildings or types of VGS, resulting in various outcomes with respect to the costs and benefits of distinct host projects.

4.3.2 Overview of the complete framework and tool design

Figure 4.3 displays a coarse level overview of the tool design, providing the general setup and infrastructure of the valuation model. The entire valuation tool exists of 15 accessible tabs. These tabs are distributed into five sections, each containing distinct aspects in the framework. These sections entail the introduction, input, results, costs and benefits. All sections contribute to performing the comprehensive LCCA and SCBA for VGS in their own way. Additionally, there are some tabs that are not to be used by the end-users of the tool, but act as data or calculation sheets, supporting the automated workflow mentioned in the previous sub-chapter. These supporting tabs are therefore to be hidden in the user-version of the tool and not incorporated in the framework overview. The remainder of this chapter offers more detailed insight into the tool sections. Especially the 'Costs' section and the 'Benefits' section, contain a further breakdown into the themes, categories and value indicators as identified for this framework.

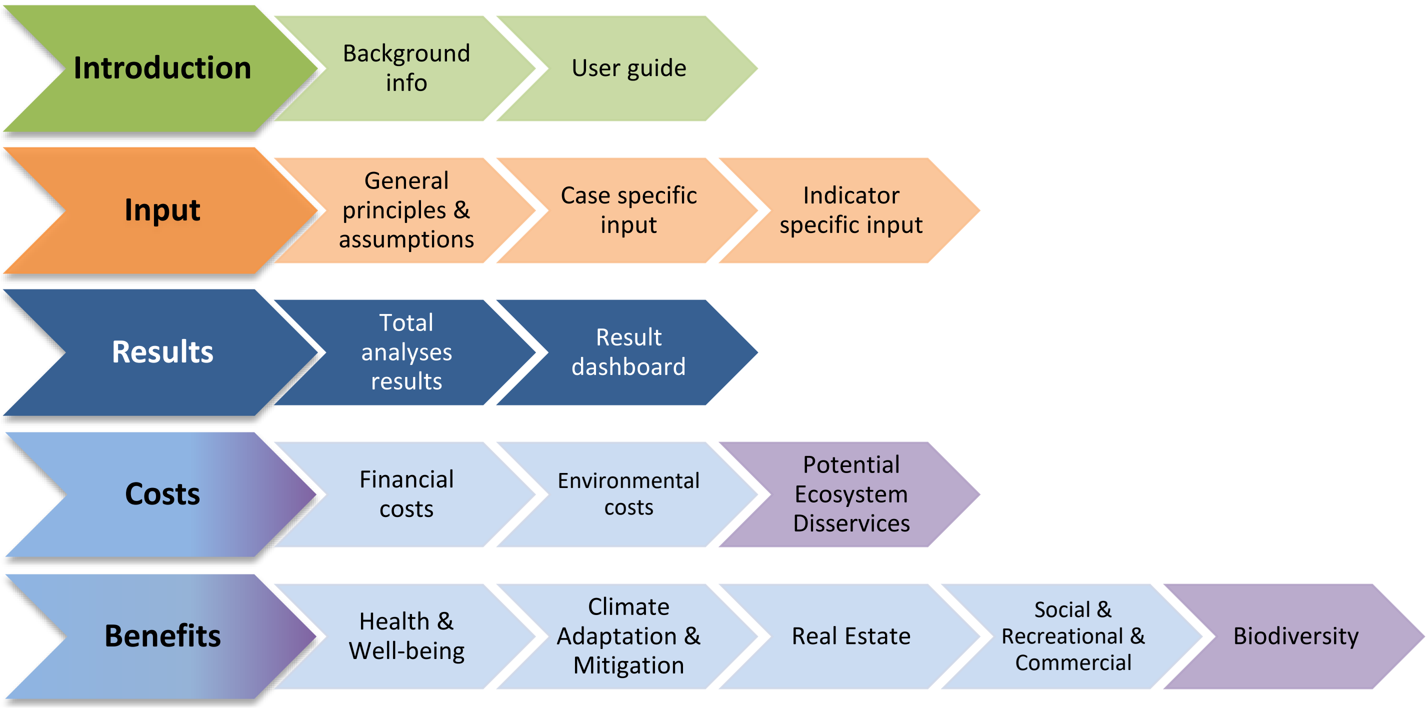


Figure 4.3: VGS Valuation Tool - Complete framework, design and infrastructure

4.3.3 'Introduction' section

Section 1 (Introduction, 2 tabs), firstly contains two explanatory tabs with text that introduce the tool to its users (Figure 4.4) and describe the intended procedure to acquire and interpret results, independent from this report (Figure 4.5). They provide some context and background for the tool as to why it was developed and by whom, for which scenarios and conditions it can be used, who the target group is for using the tool and what the current state of development is.

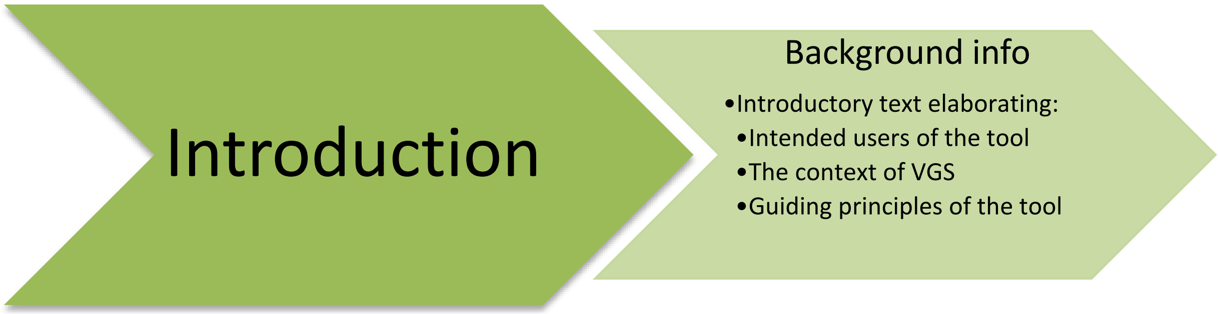


Figure 4.4: VGS Valuation Tool - 'Background info'

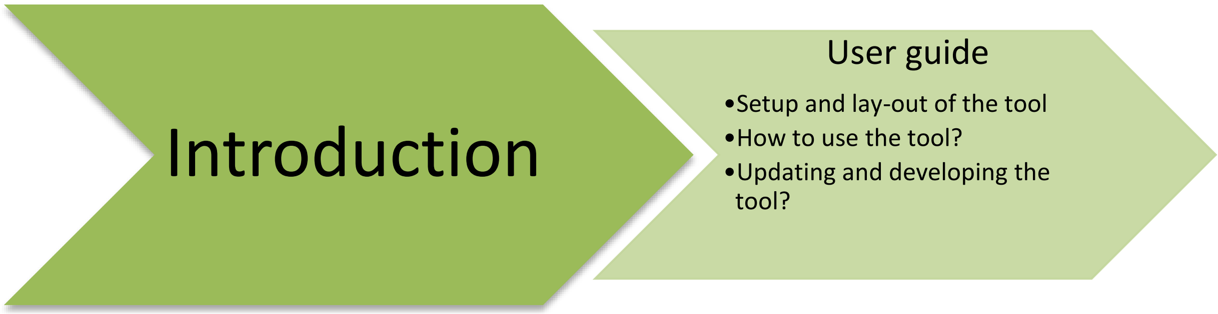


Figure 4.5: VGS Valuation Tool - 'User guide'

4.3.4 'Input' section

In section 2 (Input, 3 tabs), the 'General principles & assumptions' for the model are to be chosen and the 'Case specific input' and 'Indicator specific input' can be inserted. Generally, the user of the tool only has to fill in and make adjustments to the parameters in this input section. The remainder of the model then runs automatically and is incorporated for interpretation of the results and for the sake of methodological transparency. Clear substantiation of the calculation of costs and benefits is often lacking in reviewed literature, where usually only input and output values are provided.

'General principles & assumptions' (Figure 4.6) contains administrative information on the project case and principles with regards to the type of VGS, total analysis period and applied discount rates for calculation of present values. Also the stakeholders corresponding to the performed analyses are denoted.

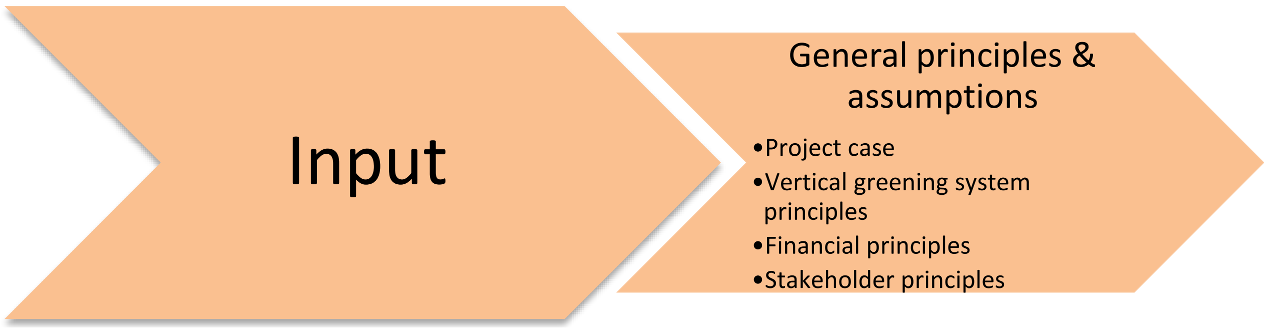


Figure 4.6: VGS Valuation Tool - 'General principles & assumptions'

The 'Case specific input' (Figure 4.7) holds different data for each project and allows for the tool to produce viable results for different locations, demographics, local climatic and environmental conditions and VGS host buildings in the Netherlands.

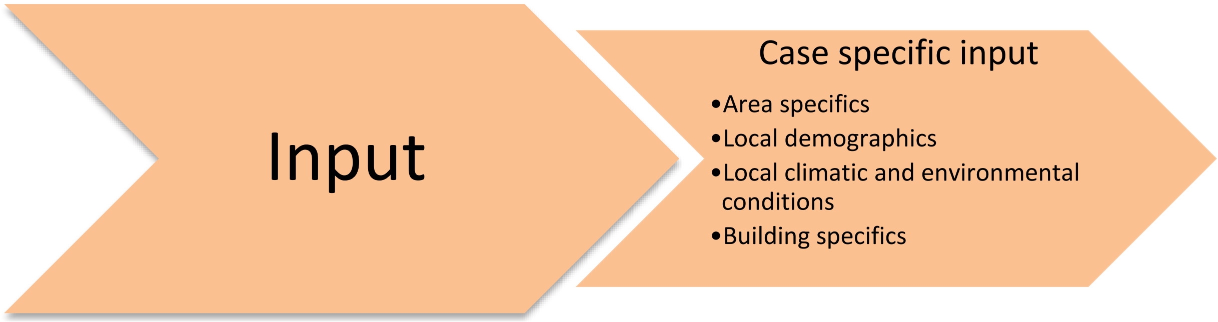


Figure 4.7: VGS Valuation Tool - 'Case specific input'

Finally, the 'Indicator specific input' (Figure 4.8) includes numerical and monetary data from literature, that is necessary to link the general and case specifics to the actual cost or benefit indicators. Some examples are additional unforeseen parameters that follow from indicator's valuation formulas, or monetary terms for translation of quantitative effects to values.

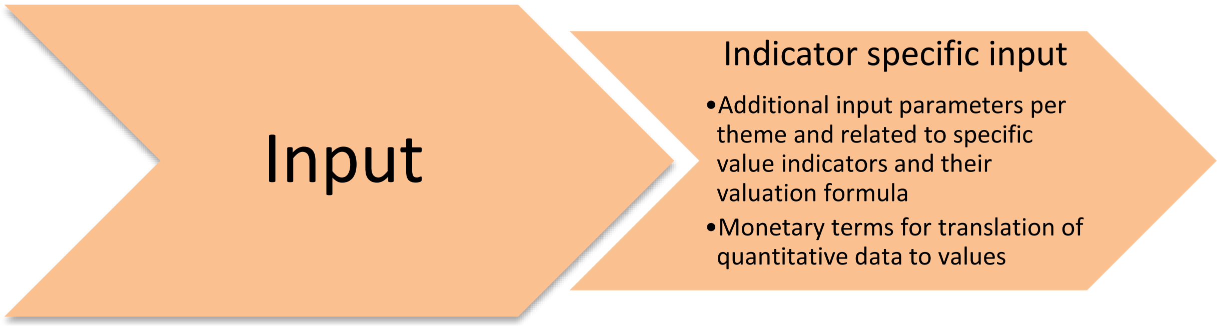


Figure 4.8: VGS Valuation Tool - 'Indicator specific input'

4.3.5 'Results' section

Section 3 (Results, 2 tabs), collects the values from all cost and benefit themes, categories and corresponding value indicators, generating an overview of the total analyses outcomes. This means that the outputs of all value indicators are redirected and visualised to these tabs. The first result tab (Figure 4.9) displays the total Net Present Value (NPV) and Benefit-Cost Ratio (BCR) per analysis and corresponding stakeholder. Also, a more compact tabular overview is generated containing thematic totals.

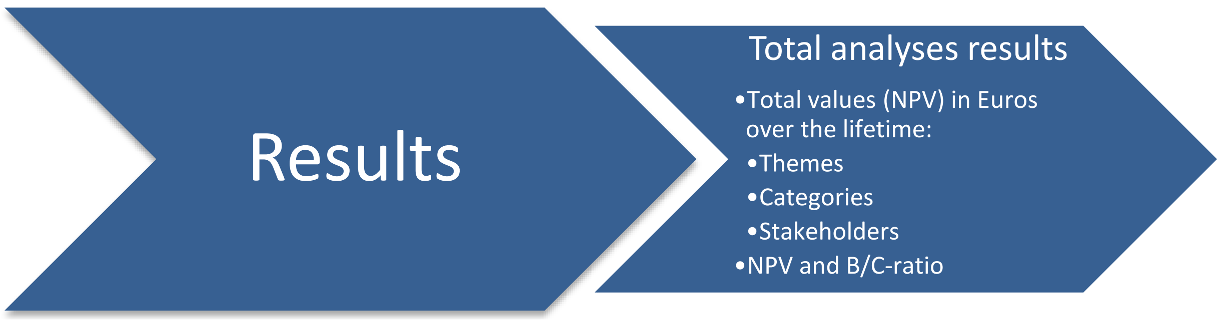


Figure 4.9: VGS Valuation Tool - 'Total analyses results'

In the result dashboard, diagrams and pie charts present the total analyses outcomes. This provides further insight into the relative contribution of different cost and benefit themes and categories towards the final results (Figure 4.10).

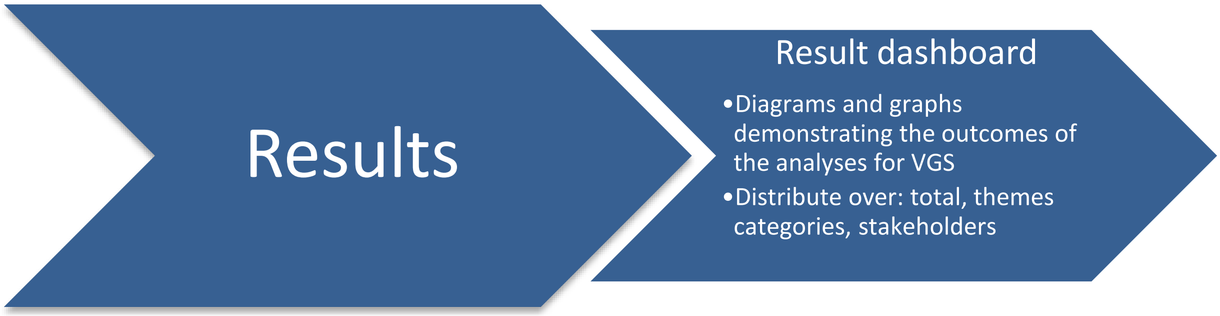


Figure 4.10: VGS Valuation Tool - 'Result dashboard'

4.3.6 'Costs' section

Section 4 (Costs, 3 tabs) of the VGS Valuation Tool, contains the sheets in which the calculations and accounting of the costs related to these systems are worked out. A distribution was made according to the thematic classification as proposed in the section 3.5. This means different sheets are designed for the *financial costs* (Figure 4.11), *environmental costs* (Figure 4.12) and merely qualitative *potential Ecosystem Disservices* (Figure 4.13). Each sheet contains the relevant cost indicators, a total cost balance table for that specific theme, value calculations and internal cell links to the PV calculations in supporting tabs. When deemed appropriate, a brief elaboration of value calculations is included at the bottom of the sheets.

The methodologic substantiation of the valuation methods for these cost indicators is based on and extracted from literature and relevant data to monetize these was gathered consequently. The elaboration of these methods is provided in section 5.3.

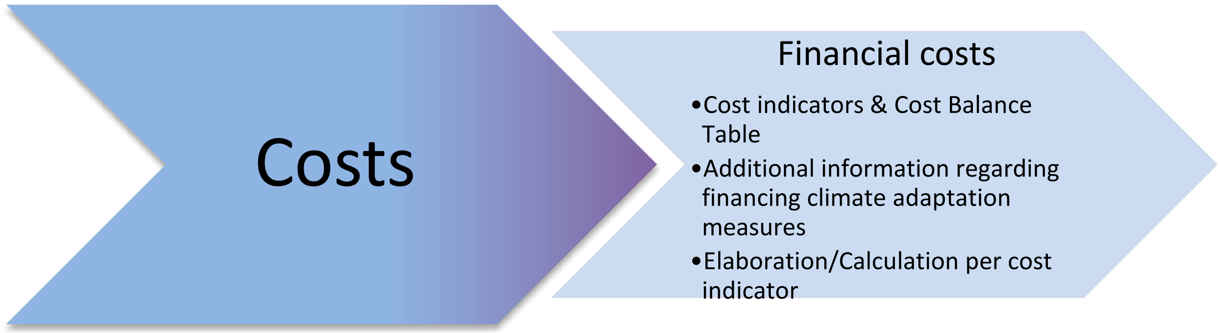


Figure 4.11: VGS Valuation Tool - 'Financial costs' theme

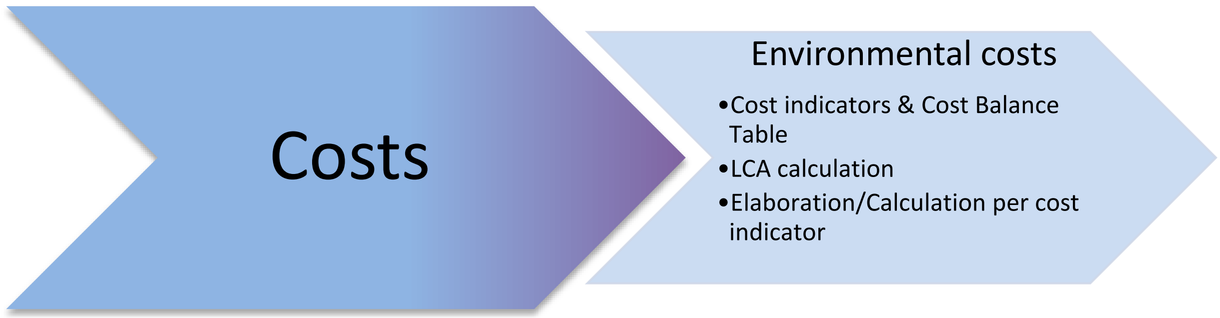


Figure 4.12: VGS Valuation Tool - 'Environmental costs' theme

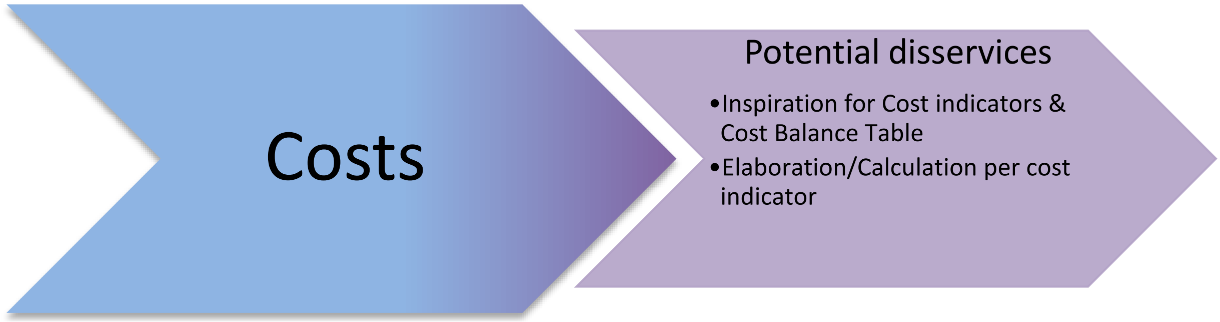


Figure 4.13: VGS Valuation Tool - 'Potential disservices' theme

4.3.7 'Benefits' section

Section 5 (Benefits, 5 tabs) contains the benefit calculations for quantifiable benefit indicators that relate to vertical greening systems. Again, the thematic classification as per section 3.5 initiated the sheet distribution. Hence, sheets are composed for the following five benefit themes: *health & well-being* (Figure 4.14), *climate adaptation & mitigation* (Figure 4.15), *real estate* (Figure 4.16), *social & recreational & commercial* (Figure 4.17) and merely qualitative *biodiversity* (Figure 4.18).
Each sheet contains the relevant benefit indicators, a total benefit balance table for that specific theme, value calculations and internal cell links to PV calculations in supporting tabs. When deemed appropriate, a brief elaboration of value calculations is included at the bottom of the sheets.

The methodologic substantiation of the valuation methods for these benefit indicators will be based on and extracted from literature and relevant data to monetize these will be gathered consequently. The elaboration of these methods is provided in section 5.4.

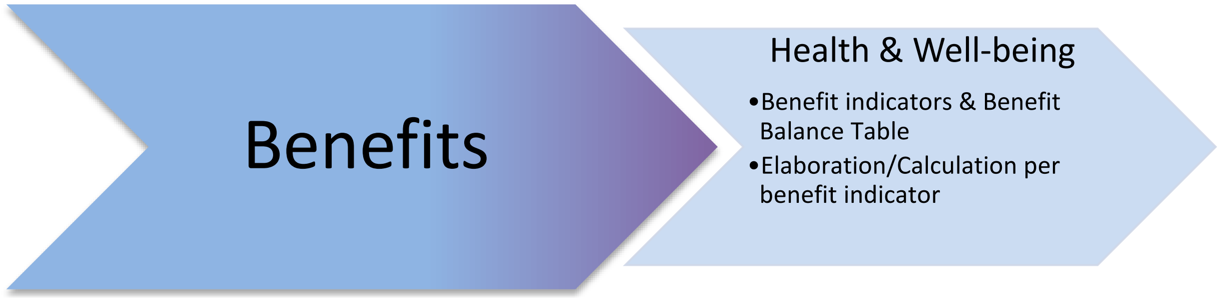


Figure 4.14: VGS Valuation Tool - 'Health & Well-being' theme

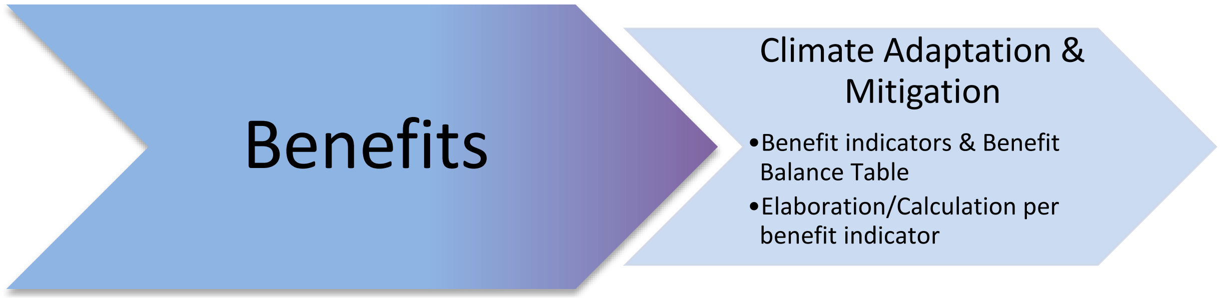


Figure 4.15: VGS Valuation Tool - 'Climate Adaptation & Mitigation' theme

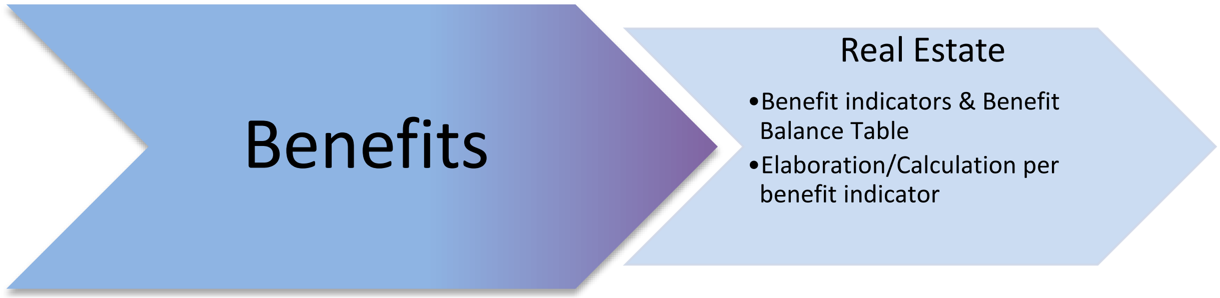


Figure 4.16: VGS Valuation Tool - 'Real Estate' theme

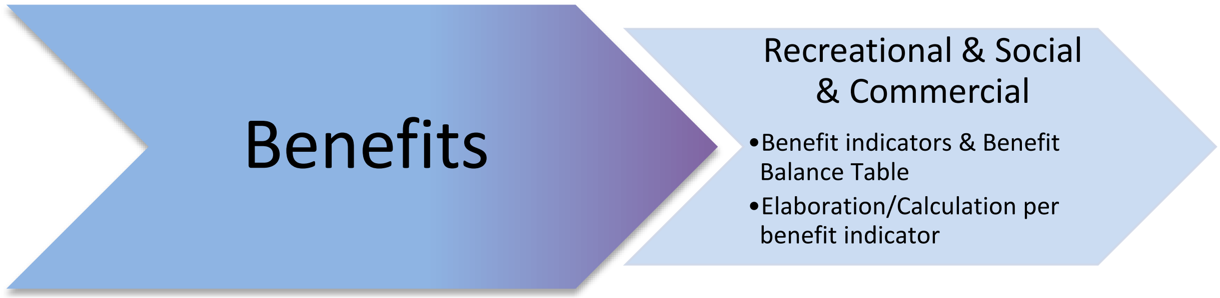


Figure 4.17: VGS Valuation Tool - 'Social & Recreational & Commercial' theme

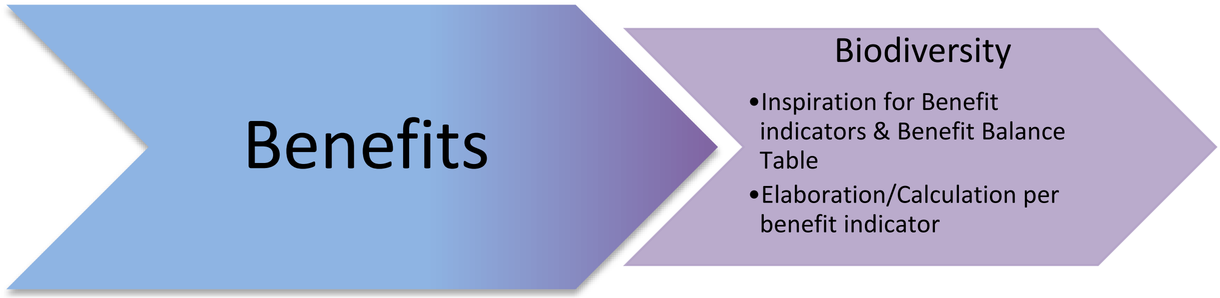


Figure 4.18: VGS Valuation Tool - 'Biodiversity' theme

5

Valuation methods and data

5.1 Introduction

Chapter 5 is dedicated to the more specific valuation methods that substantiate how monetised values are obtained. Therefore, identified and envisioned value indicators are proposed for both the cost and benefit theme, based on extensive literature review and expert knowledge. The cost and benefit indicators provide the values for which the model was set out from the start.

First, an elaboration of the cost themes is provided, diving into the financial costs, environmental costs and potential Ecosystem Disservices (qualitative). Second, the benefit themes are covered, providing backgrounds, valuation methods and pricing techniques appropriate for several benefit indicators that can be monetised. Third, the results section of the model is further explained, in which the gap between the cost and benefit themes and the result dashboard is bridged. Lastly, section 5.5 offers the conclusion for Part II, answering the second research question.

It should be noted that, due to the given timeframe for the master thesis, it was not feasible to work out values for all cost and benefit indicators as identified or proposed in the tables later on in this chapter. Yet, whenever literature sources were found on the topic of economic valuation of these indicators, these are briefly included in the explanatory texts. Thereby, these papers and reports can provide a starting point for future research. Also, future research might indicate that additional value indicators are appropriate for economic valuation of impact themes with regards to VGS. The framework and tool are designed as such, that room is left for future implementations. The current structure should be regarded as first impetus to establishing a general and comprehensive framework and tool for the economic valuation of VGS. For more detail into elaborated links, input, methods and outputs, again reference is made to the accompanied VGS Valuation Tool in the MS-Excel file. In chapter 6 a case study is worked out showing relevant input and obtainable results from the tool.

5.2 Present values of costs and benefits

As was indicated previously in chapter 4.2, all (expected) future costs and benefits should be discounted towards their present values in order to make these values directly comparable. Therefore, this procedure applies to all values that are to be analysed in the remainder of this chapter, meaning it is interwoven throughout the entire tool. Discounting of monetised future values occurs by means of applying a discount rate. This discount rate can be manually adjusted in the model, in order for the user to have the freedom to apply an adequate rate. Vrijling and Verlaan (2015) denote the formula for the present value (PV) in the following way:

$$PV = \sum_{t=t_0}^{t} I_t * (1+r)^{(t_0-t)} \qquad (1)$$

Where:	PV	=	Present value
	I_t	=	Cash flow/Value on t
	t_0	=	Reference moment of the analysis (moment of funding VGS)
	r	=	Discount rate

This formula also holds when for each indicator and each period (year), the amounts of flow vary or differ, as is the case for valuing costs and benefits of VGS. Hence, the present value is calculated by discounting all values separately to the value moment t_0 and summing them at the end. In the tool, this is facilitated by automatically accounting all yearly values for each value indicator in supporting tabs. No need for adjustments by the end-user are needed. In the costs section and benefits section, all the separated values are then again automatically discounted and summed by using the NPV function. This function allows for variable periodic (yearly) cost or benefit flows. Initial costs and benefits are added to the outcome of this function separately, since these do not need discounting.

To allow for the automated process of the abovementioned procedure, time frames for occurrence of each cost or benefit indicator are linked to the type of VGS that is analysed. Selecting the desired VGS, updates these time frames and handles the accounting of yearly values in the supporting tabs. It should be noted that this first version of the tool was developed by using (modular) LWS, hence only this VGS type can be selected yet.

5.3 Elaboration of 'Cost theme' sections

In the following sub-sections, lists are composed containing all relevant categories and coherent cost indicators per theme, which were identified, envisioned and proposed during this thesis. Naturally, there is distinguished between financial costs (Table 5.1), environmental costs (Table 5.2) and potential Ecosystem Disservices (Table 5.4). These lists are based on and derived from extensive literature research (Bustami et al., 2018; Huang et al., 2021; Perini & Rosasco, 2013; Riley, 2017). Afterwards, the lists were also validated for comprehensiveness and correctness during constructive conversations with a VGS supplier and specialist (Rotteveel, 2022), TU Delft staff (Marc Ottelé, 2022) and several Sweco employees (Sweco expert knowledge, 2022). Although these lists are extensive and comprehensive, from future research it might appear that they are not yet exhaustive. In the tool, room is left for future alterations or implementations.

Valuation methods substantiating how values are derived from cost indicators are subsequently given for the financial costs and environmental costs. Namely, these are already integrated in the tool in a quantitative manner. Whether indicators are quantitatively (QN) or qualitatively (QL) captured in the tool, is also specified in the tables. Moreover it is indicated for which stakeholders, hence which analysis (SCBA, LCCA or both), the indicators apply.

5.3.1 Cost indicators for theme 'Financial costs'

Financial costs are a major and contentious factor hindering VGS propagation, particularly LWS. Expected benefits from investments are often considered intangible, aesthetic and environmental of nature. This framework aims to become a first mechanism comparing all costs and benefits.

Therefore, financial costs is the first theme to be included in the framework. It is found to be challenging to locate uniformly documented and published cost components in research papers, partly because a one-size-fits-all solution does not exist. This causes costs to be adapted for each project and thus they vary widely. Yet also to avoid so-called "sticker shock", i.e. the shock or dismay experienced by potential buyers of a certain product on discovering its high or increased price, as well as from competitiveness and confidentiality reasons, LWS suppliers are hesitant to print and provide exact cost estimates. This is true for the initial investment costs as well as the ongoing maintenance costs during the lifetime of the LWS, which are both high in comparison to other exterior cladding systems. LWS maintenance costs over the lifetime can even be a multitude of the realisation or installation costs (Bustami et al., 2018; Riley, 2017).

The abovementioned notions were also encountered in meetings with VGS suppliers, hence detailed breakdown of prices or costs of individual components and services could not be provided. Yet, it was possible to generate a detailed list of financial cost components for VGS based on these semi-structured interviews, combined with literature review of the research papers of Perini and

Rosasco (2013) and Huang et al. (2019). It is noted that multiple categorisations can be applied and that the total financial costs of VGS implementation can be gathered through different sorts of indicator assemblies. However, the proposed list that is given in Table 5.1 forms the basis for the financial cost theme, providing the breakdown that is adopted for the current framework and tool.

Table 5.1: Comprehensive list of financial costs associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Engineering & consultancy	**1.**	**Total of engineering & consultancy category**	**LCCA**	**QN**
	1.1	Study, design, engineering of construction and planting scheme	LCCA	QL
	1.2	Permit application	LCCA	QL
2. Initialisation (off-site) & installation (on-site)	**2.**	**Total of initialisation & installation category**	**LCCA**	**QN**
	2.1	Manpower cost: salary of workers for taking care of plants in nursery stage and preparing system components	LCCA	QL
	2.2	Material cost: VGS components (structure, plants, pot/panel/module, growing media, irrigation system, drainage system and buffer tank, technical room, fertilizers)	LCCA	QL
	2.3	Utilities cost: electricity and water for initialisation	LCCA	QL
	2.4	Equipment cost: for nursing plants, preparing system, etc.	LCCA	QL
	2.5	Repair works on existing façade	LCCA	QL
	2.6	Manpower cost: salary of workers for transporting and installing the system on-site	LCCA	QL
	2.7	Material cost: transport for materials	LCCA	QL
	2.8	Equipment cost: for installation of the system (aerial lift, telescopic handler, etc.)	LCCA	QL
3. First year aftercare	**3.**	**Total of first year aftercare category**	**LCCA**	**QN**
	3.1	Follow-up/Aftercare	LCCA	QL
4. Operations & maintenance & replacement	**4.**	**Total of operations & maintenance & replacement category**	**LCCA**	**QN**
	4.1	Manpower cost: salary of workers for maintaining the system on regular schedule (pruning and panels adjustment, irrigation system and fertilization, monitoring)	LCCA	QL
	4.2	Material cost: annual replacement cost of materials (mainly plants (10%), irrigation system (10%) and panels (5%)) and transportation	LCCA	QL
	4.3	Utilities cost: electricity and water	LCCA	QL
	4.4	Equipment cost: for maintenance work	LCCA	QL
5. Disposal	**5.**	**Total of disposal category**	**LCCA**	**QN**
	5.1	Manpower cost: salary of workers for dismantling and disposal	LCCA	QL
	5.2	Material cost: transport for materials minus potential residual value of the system (reuse)	LCCA	QL
	5.3	Equipment cost: for disposal of the system	LCCA	QL
6. Rent	**6.**	**Increased rental costs (residents)**	**SCBA**	**QN**

Valuation method financial costs

Since financial costs are already expressed in monetary terms, their integration into the valuation framework should be relatively straightforward. The financial costs are retrieved through thorough analysis of published costs in similar studies that were already completed in other locations and semi-structured interviews, meaning they can be transferred into the current research in order to develop the framework and tool (Cost Transfer Method, appendix D). The costs are based on economic values of actual market prices of commodities and goods that are bought and sold, as well as services that are commonly provided (work).

In the current tool version, input data for financial costs is to be inserted at the level of the categories (bold text in Table 5.1). Although the model is already fit for, and can easily be adjusted to support, insertion of input data on the cost indicator level, no representative input values could be retrieved for this level of detail. Therefore, this more detailed elaboration of financial costs remains open for future efforts. In order to fulfil this outlook, more extensive contact should be made with, and relevant data obtained from, VGS suppliers in the Netherlands.

As main reference for input values for the financial costs, the LCCA of Huang et al. (2019), the CBA of Perini and Rosasco (2013) and information retrieved from expert talks is used. The exact cost values from reference projects of the supplier are to remain confidential, hence this is the reason they are not integrated explicitly in this report. Although abovementioned studies were performed a number of years ago in Singapore and Genoa respectively, meaning cost input data and environmental factors might differ from the current situation in the Netherlands, these provided a decent insight into the methodology that is to be applied. Also, it allowed the author to get a grip and give a fair reflection of magnitudes, proportions and relative contributions of cost items, meaning appropriate inputs could be assumed.

A total initial cost sum (€/m^2) serves as contemporary input for the categories of *'Engineering & Consultancy'*, *'Initialisation (off-site) & installation (on-site)'* and *'First year aftercare'*. Within the tool, this total sum can be relatively attributed to the distinct categories.

For *'Operations, maintenance & replacement'* and *'Disposal'*, reference costs (€/m^2/year) from literature and expert knowledge serve as input. For conversion from Singapore Dollar (study by Huang et al. (2019)) to Euro, a factor of 0,65 was be used, which is based on the average exchange rate in the year 2019. Since the input values used to demonstrate the valuation framework and tool can be considered guesstimates, no specific inflation rate was applied to the reference values.

$$C_{Fin,Inv} = C_{E\&C} + C_{I\&I} + C_A + C_{O\&M\&R} + C_D \tag{2}$$

Where:

$C_{Fin,Inv}$	=	PV of total financial costs for investor (€)
$C_{E\&C}$	=	PV of financial costs for engineering & consultancy (€)
$C_{I\&I}$	=	PV of financial costs for initialisation (off-site) & installation (on-site)(€)
C_A	=	PV of financial costs for first year aftercare (€)
$C_{O\&M\&R}$	=	PV of financial costs for operations & maintenance & replacement (€)
C_D	=	PV of financial costs for disposal (€)

'Increased rental costs (residents)' can be calculated from an assumed increase in rental price for the property (%), following from Perini and Rosasco (2013), and the total yearly initial rent for the entire building complex (€). It should be noted that this cost component for the residents equals the benefit for the investor regarding property value increase in the real estate theme.

$$C_{Fin,Res} = C_{\Delta Rent} \tag{3}$$

$$C_{\Delta Rent} = \sum_{t=t_0}^{t} \Delta P_{Rent} * P_{Rent,t_0} * (1 + r_s)^{(t_0 - t)} \tag{4}$$

Where:	$C_{Fin,Res}$ =	PV of total financial costs for residents (society) (€)
	$C_{\Delta Rent}$ =	PV of increased rental costs (residents) (€)
	ΔP_{Rent} =	Increased rental price of property (%)
	P_{Rent,t_0} =	Initial yearly rental costs, aggregated for building complex (€/year)
	t_0 =	Reference moment of the analysis (year zero: moment funding VGS)
	r_s =	Societal discount rate

5.3.2 Cost indicators for theme 'Environmental costs'

Secondly, the environmental costs are included in the framework. In order to assess these costs, the LCA methodology is incorporated in the tool, which has been developed over several decades (Jonkers, 2020). Herewith, the Environmental Cost Indicator (ECI) can be calculated, monetizing environmental impacts of VGS implementation and providing shadow costs of the evaluated system: costs that would be required to undo the environmental harm or limit this to a 'sustainable' level. Shadow costs give an idea of the costs for society, whenever environmental damage is not included in the price of a system (externalised). Also, this shadow price encompasses a comparable number, with which environmental scores from different impact categories are weighted and merged. In the shadow price method, the shadow prices per impact category reflect the highest cost level that is acceptable for governments per unit of emission control. Hence, these are prevention costs (Control Cost Method, appendix D).

Negative impacts stem from the distinct products and activities over the different life cycle stages of the system. With LCA, the total life cycle of the system can be considered, ranging from extraction of raw materials and resources to installation (cradle-to-gate), to the end of life stage (cradle-to-grave) and even potential reuse, recovery and recycling of components (cradle-to-cradle). These different life cycle stages with their respective products and processes form the cost indicators for the environmental costs theme (see Table 5.2).

Table 5.2: Comprehensive list of environmental costs associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Product Stage	**1.**	**Total of product stage**	**SCBA**	**QN**
	1.1	A1 – Raw material supply	SCBA	QL
	1.2	A2 – Transport	SCBA	QL
	1.3	A3 – Manufacturing	SCBA	QL
2. Construction Process Stage	**2.**	**Total of construction process stage**	**SCBA**	**QL**
	2.1	A4 – Transport	SCBA	QN
	2.2	A5 – Construction-installation process	SCBA	QL
3. Use Stage	**3.**	**Total of use stage**	**SCBA**	**QL**
	3.1	B1 – Use	SCBA	QL
	3.2	B2 – Maintenance	SCBA	QL
	3.3	B3 – Repair	SCBA	QL
	3.4	B4 – Refurbishment	SCBA	QL
	3.5	B5 – Replacement	SCBA	QL
	3.6	B6 – Operational energy use	SCBA	QL
	3.7	B7 – Operational water use	SCBA	QN
4. End of Life Stage	**4.**	**Total of end of life stage**	**SCBA**	**QL**
	4.1	C1 – De-construction/Demolition	SCBA	QL
	4.2	C2 – Transport	SCBA	QL
	4.3	C3 – Waste processing	SCBA	QL
	4.4	C4 – Disposal	SCBA	QL
5. Benefits and Loads	**5.**	**Total of benefits and loads**	**SCBA**	**QL**
	5.1	D – Reuse, recovery & recycling potential	SCBA	QL

Valuation method environmental costs

The procedure of conducting LCA comprises four specific steps (Jonkers, 2020), which are briefly demonstrated in the following:

1. Goal and scope definition
2. Life Cycle Inventory (LCI) analysis
3. Life Cycle Impact Assessment (LCIA)
4. Life Cycle Interpretation

LCA step 1: Goal and scope definition

Goal definition:

The main goals when performing LCA usually comprise of identification of the life cycle stages contributing most to the total environmental impact of the product and identification of the environmental hot spots over the entire life cycle of a product. This provides insight into where optimizations could be employed for environmental performance, in order to mitigate the negative environmental contributions. These insights can be obtained through visualisation of environmental impacts in environmental impact profiles (future outlook). Since the current goal is to incorporate LCA effectively into the VGS Valuation Tool, for now step 4 is excluded from this research. For the rest, the entire procedure for calculating the ECI is within scope of the research, in order to establish the methodology for acquiring the shadow costs of VGS. Hence, this LCA methodology is full-fledge integrated in the tool, allowing users (e.g. consultants) to obtain the true costs and benefits of VGS.

Scope definition:

Since the tool is an interactive medium that allows users to evaluate distinct projects, the VGS façade area for which the resulting shadow costs are calculated differs per case. In the LCI, material quantities and goods are collected per m^2 VGS, hence the functional unit of the LCA procedure is 1 m^2 of VGS. When the translation is made towards ECI (shadow costs), the obtained emissions results per m^2 are multiplied with the total VGS area. For this thesis, only future additions to the current situation are taken into account. This means only the new VGS system is incorporated in the LCA, since we assume a redevelopment instead of new built. Elements from the existing bare brick façade will not be analysed in the LCA. It is assumed the lifespan of the VGS is at minimum of 30 years, and that the supporting façade will easily survive this period as well.

The current tool version is prepared to facilitate LCA from cradle-to-cradle, however due to scope demarcation and limited data availability not all stages are yet quantitatively elaborated. From Table 5.2, it can be observed which stages and modules are covered, since for these stages data was found. This entails module A1-A3, A4, and B7, meaning at the moment a reduced analysis is performed. The LCI input data (material) retrieval was predominantly based on the research paper by M. Ottelé et al. (2014), regarding Life Cycle Analysis of VGS (modular LWS with planter boxes). This study was performed in the Netherlands. Current review of LCA research for VGS further found broad variety between results of LCA analysis, which can be largely attributed to lack of available and validated scientific data. It is especially hard to gather information regarding the installation process, water/energy use, lifespan, replacement needs etc. Upon identification of relevant data, in future research also the remaining life cycle stages should be filled.

Under normal circumstances, environmental emission data of materials, products and processes can be retrieved from the viewer of Nationale Milieudatabase (NMD) without licenses. However, since this viewer is temporary offline for major updates (at least until second quarter of 2023), retrieving this data was more complicated. Eventually, using a licensed version of LCA software, the environmental data could be retrieved by Sweco colleague Dr. Ray Jacobsen (Sustainability/LCA expert) from the Nationale Milieudatabase (NMD), or EcoInvent database when the record was missing in the NMD (Sweco expert knowledge, 2022). Per environmental impact category, indicator compound values (expressed in unit equivalent) were provided, meaning a single resulting value was obtained per category. It is noted that, per each different VGS system that is newly incorporated in the tool, obtaining these emission equivalent values is part of the developer's workflow.

For the LCA environmental profile, according to the Dutch Building Decree the complete set of eleven categories (midpoint indicators) is accounted for that needed to be analysed before 2021. Since then, 8 additional impact categories have become effective. These too can be implemented in future efforts. For now, the categories from Table 5.3 apply.

Table 5.3: Environmental impact categories for LCA

Item	Environmental impact category	Equivalent unit	Shadow price (Euro) per kg equivalent unit
1.	Abiotic depletion potential (non-fuel)	kg Sb eq	€ 0,16
2.	Abiotic depletion potential (fuel)	kg Sb eq	€ 0,16
3.	Global warming potential (GWP)	kg CO_2 eq	€ 0,05
4.	Ozone layer depletion (ODP)	kg CFC-11 eq	€ 30,00
5.	Human toxicity potential (HTP)	kg 1,4-DB eq	€ 0,09
6.	Freshwater aquatic eco-toxicity potential (FAETP)	kg 1,4-DB eq	€ 0,03
7.	Marine aquatic eco-toxicity potential (MAETP)	kg 1,4-DB eq	€ 0,001
8.	Terrestrial eco toxicity potential (TETP)	kg 1,4-DB eq	€ 0,06
9.	Photochemical oxidation potential (POCP)	kg C_2H_4 eq	€ 2,00
10.	Acidification potential (AP)	kg SO_2 eq	€ 4,00
11.	Eutrophication potential (EP)	kg PO_4^{3-} eq	€ 9,00

LCA step 2: Life Cycle Inventory (LCI) analysis

As mentioned, the LCI input data (materials and processes) retrieval was predominantly based on the research paper by M. Ottelé et al. (2014), regarding Life Cycle Analysis of VGS. This study was performed in the Netherlands. For the specific modular LWS system with planter boxes, the quantity data was used as depicted in Figure 5.1. For transport, it is assumed that all products originate from the location of the VGS supplier. This is a variable in for each project, hence also in the tool. For now Utrecht, being in the centre of the Netherlands, is assumed. Hence, the transport distance is from Utrecht to project location. When specific projects are analysed in the tool, naturally the correct data can be used. For the materials and transport modes used, LCI emission data was collected accordingly and stored in the VGS Valuation Tool.

Components	Material	Weight (kg/m^2)
Inner masonry	Limestone	147
Insulation	Mineral wool	4.3
Air cavity	Cavity	–
Outer masonry	Brick (clay)	145
Mortar	Sand + cement + water	84
Bolts	Steel S235	0.27
Spacer brackets	Steel S235	0.315
Air cavity	Cavity	–
Supporting U section	Steel S235	4.62
Planter boxes	HDPE	13.2
Growing material	Potting soil	75.6
Vegetation	*Pteropsida*	8
Watering system	PE	0.26
Water demand	Tap water	365

Figure 5.1: LCI data for the study (M. Ottelé et al., 2014)

LCA step 3: Life Cycle Impact Assessment (LCIA)

The procedure for LCIA is automated in the tool in order to assess the LCI outputs. The LCI output data (indicator compound values expressed in unit equivalents) from step 2 is collected per environmental impact categories. For each material or process, their respective quantities per m^2 VGS can be multiplied with the total equivalent emissions per impact category. This provides the emissions per material/process per m^2. In the same formula, the shadow costs per unit equivalent of each category are linked to these emissions per m^2, enabling the monetarisation of emissions. Subsequently, resulting shadow costs per material/process per m^2 are multiplied with the total VGS area that is implemented in the project in order to get the ECI values. Afterwards, these are forwarded to the cost indicators and balance table. From this, the PV calculations are performed automatically as well, eventually providing the PV per environmental cost indicator.

This results in the following expression for the total environmental costs:

$$C_{Env} = C_P + C_C + C_U + C_E + C_B \quad (6)$$

Where:

C_{Env}	=	PV of total environmental costs (€)
C_P	=	PV of environmental costs for product stage (€)
C_C	=	PV of environmental costs for construction process stage (€)
C_U	=	PV of environmental costs for use stage (€)
C_E	=	PV of environmental costs for end of life stage (€)
C_B	=	PV of environmental costs for benefits and loads (€)

The general procedure for calculation of the PV of costs in a certain stage is demonstrated by the formulas below. Here, the product stage is exemplified:

$$C_P = \sum_{t=t_0}^{t} ECI_{P,t} * (1 + r_s)^{(t_0 - t)} \quad (7)$$

Where:

C_P	=	PV of environmental costs for product stage (€)
$ECI_{P,t}$	=	Yearly Environmental Cost Indicator, aggregated for product stage (€)
t_0	=	Reference moment of the analysis (year zero: moment of funding VGS)
r_s	=	Societal discount rate

And the yearly Environmental Cost Indicator can be determined according to:

$$ECI_{P,t} = A_{VGS} * \sum_{p=p_1}^{p} \sum_{ic=ic_1}^{ic} Q_p * EqE_{ic} * SP_{ic} \quad (8)$$

Where:

$ECI_{P,t}$	=	Yearly Environmental Cost Indicator, aggregated for product stage (€)
A_{VGS}	=	Total area of VGS (m^2)
Q_p	=	Quantity of a product (kg/m^2)
EqE_{ic}	=	Equivalent emission for an impact category (kg equivalent)
SP_{ic}	=	Shadow price corresponding to an impact category (€/kg equivalent)

5.3.3 Cost indicators for theme 'Potential Ecosystem Disservices'

These potential Ecosystem Disservices will only be qualitatively stated in the tool at this level of development. Furthermore, qualitative trade-offs and implementation barriers are appended to this theme, which were identified as limit factors often hampering VGS implementation. The indicators and ecosystem disservices were gathered from papers by Gómez-Baggethun and Barton (2013), von Döhren and Haase (2015), Riley (2017) and Blanco, Dendoncker, Barnaud, and Sirami (2019).

Table 5.4: Comprehensive list of potential Ecosystem Disservices associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Potential Ecosystem Disservices	1.1	Plant allergies or poisoning (value through increase of medication costs)	SCBA	QL
	1.2	Emission of biogenic volatile organic compounds (BVOCs)	SCBA	QL
	1.3	Unpleasant smells/odours from dead plants	SCBA	QL
	1.4	Development of diseases	SCBA	QL
	1.5	People might dislike birds and insects	SCBA	QL
	1.6	Potential undesirable increase of humidity	SCBA	QL
2. Trade-offs	2.1	Potential of green gentrification (disservice for people with lower incomes)	SCBA	QL
	2.2	Increased water consumption	SCBA	QL
	2.3	Increased risk of fire spread due to excessive urban vegetation development / Risk of pyromania	SCBA	QL
	2.4	Associated management costs	SCBA	QL
	2.5	Use of agrochemicals in urban green space management may increase soil pollution, produce offsite effects and induce health problems --> Should hamper use of (harmful) chemicals	SCBA	QL
	2.6	People don't like maintenance	SCBA	QL
	2.7	Vision obstruction	SCBA	QL
	2.8	Potential of green-washing with unsustainable, non-biodiverse VGS, that are not tailored to the building's need or functioning	SCBA	QL
3. Implementation barriers	3.1	Lack of political motivation	SCBA	QL
	3.2	Lack of knowledge	SCBA	QL
	3.3	Lack of time and amount of work	SCBA	QL
	3.4	Municipal organization	SCBA	QL
	3.5	Hampering legislation	SCBA	QL
	3.6	Hampering financial factors	SCBA	QL
	3.7	Uncertainty about roles and responsibilities	SCBA	QL

5.4 Elaboration of 'Benefit theme' sections

Similar as for the costs sections, in the following sub-sections lists are composed containing all relevant categories and coherent benefit indicators per theme, which were identified, envisioned and proposed during this thesis. Also refer to Table 2.1 for initial identified benefits. Here, there is distinguished between health & well-being (Table 5.5), climate adaptation & mitigation (Table 5.6), real estate (Table 5.7), social & recreational & commercial (Table 5.8) and biodiversity (Table 5.9). These lists are based on and derived from extensive literature research (Besir & Cuce, 2018; Brković Dodig et al., 2019; Bustami et al., 2018; Does et al., 2019; El Menshawy et al., 2022; Huang et al., 2019; Manso et al., 2021; Marc Ottelé, 2011; Riley, 2017; Rosasco, 2018; Teotónio et al., 2021; Victoria University and University of Melbourne, 2018).

Afterwards, also these lists were validated for comprehensiveness and correctness during constructive conversations with a VGS supplier and specialist (Rotteveel, 2022), TU Delft staff (Marc Ottelé, 2022) and several Sweco employees (Sweco expert knowledge, 2022). Although the lists are extensive, comprehensive and composed with the greatest care, from future research it might appear that they are not yet exhaustive. In the tool, room is left for future alterations or implementations.

Valuation methods substantiating how values are derived from benefit indicators are subsequently given for those that can already be accounted quantitatively. For each quantitative benefit indicator the method is given comprising relevant assumptions, modelling considerations, formulas and potential input values or data sources. Whether indicators are quantitatively (QN) or qualitatively (QL) captured in the tool, is also specified in the tables. Moreover it is indicated for which stakeholders, hence which analysis (SCBA, LCCA or both), indicators apply.

The extensive scope of the research and detailed work for the Excel file, unfortunately hampered the author to substantiate the full contents of these benefits in this report. Yet, the methods for the quantitative monetisation of benefits are captured within the VGS Valuation Tool in Excel. Also, in purple cells the tool provides input variables that are described to be of influence to beneficial effects. Future research is recommended to perform the extensive analysis with data corresponding to a specific VGS type. From there, quantitative insights could be attained for specific systems. Methods that are not worked out in this report, are recommended for future outlook.

Links between the different benefit themes

An important aspect regarding the distribution of indicators over the benefit themes, is the prevention of double counting of values, by accounting for them in multiple themes. By the strict demarcation and listing of the different indicators, this should be guaranteed. In case when future efforts for the expansion of the tool append a number of new value indicators, it should be carefully considered and documented in which themes these monetary values are introduced.

Difficulty arises especially when certain effects, for instance reduction of urban heat island (UHI) effect, can contribute to benefits in different themes. Yet, it should be noted that the reduction of urban heat island effect is not a final benefit, instead it is linked to the regulating ES 'Climate regulation – regional and local' as covered in appendix C. Therefore, in accordance to sections 3.3 and 3.5, only final benefits should be monetised resulting from this reduction of UHI-effect.

In this case, these could be benefits for health & well-being by reduction of mortality rates and hospitalisations due to heat stress. Benefits for real estate through increased building integrity and lifespan due to reduced temperature fluctuations (which can be combined with reduction of impairment of rainwater to the façade). Also in the theme social & recreational & commercial, reduction of UHI has effect on e.g. increase of visitors in cities or increase in labour productivity. This again showcases that delivery of ES can provide final benefits in several distinct impact themes.

5.4.1 Benefit indicators for theme 'Health and Well-being'

There are ever more studies reporting on the beneficial influence of green living environments in relation to people's health and well-being. Urban nature can contribute both in the physical and mental/psychological health domain, for instance improved cardiac and respiratory health, enhanced physical condition and fitness, reduced obesity related diseases, reduced stress and anxiety levels and less heat stress related diseases (Kirk et al., 2021). However, according to Riley (2017) and Teotónio et al. (2021), up until now LWS's benefits for health and well-being are still relative intangible qualities. This is mainly due to lacking evidence-based design research for these systems (Bustami et al., 2018). Yet, linking vegetated surfaces like LWS to e.g. reduced hospitalizations, duration of stays, reduced health expenses or absence costs could be a way to monetize economic benefits related to health & well-being in the future.

This was previously done for horizontal greening in the living environment. For example, Maas et al. (2009) performed a study into the relation between (horizontal) green space and indicators of physical and mental health. Here, data regarding 24 disease clusters was used and examined in relation to the percentage of green space within a 1-3 km radius around given postal codes. Results showed that annual prevalence was lower in residential areas containing more green space within a 1-km radius for 15 of the 24 disease clusters, with the strongest relationships observed for anxiety disorders and depression. Using this study as starting point, a SCBA was performed at Sweco and a whitepaper was published regarding financial health benefits of greening (Groot Jebbink et al., 2022). Conducting such study for VGS could therefore prove to be valuable with regards to quantifying benefits for health.

Unfortunately, as mentioned before, the impact and influence of VGS (LWS specifically) with regards to these benefits has not yet been investigated at this major and comprehensive scale. Therefore, it is not appropriate to link the aforementioned research to VGS. Research into more isolated, individual and tangible indicators of VGS in relation to health and well-being should therefore be used for these systems. Fortunately, in recent years these studies are becoming more extensive. At this stage of VGS valuation research, therefore the individual benefit indicators are ought to be used to generate insight into monetised values for benefits in the theme health and well-being.

In Table 5.1 a proposed list is given that forms the basis for the health & well-being theme, thus providing the breakdown that is adopted for the current framework and tool.

Table 5.5: Comprehensive list of health & well-being benefits associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Physical health & well-being	**1.**	**Total of physical health & well-being**	**SCBA**	**QL**
	1.1	***Integral whenever possible (due to presence of natural surroundings, improved air quality, reduction of heat stress, reduction of noise pollution, increase in exercise)***	***SCBA***	***QL***
	1.1.1	Reduction of healthcare costs due to physical diseases (less hospitalizations, less medication, quicker recovery time)	SCBA	QL
	1.1.2	Reduction of premature morbidity due to physical diseases	SCBA	QL
	1.1.3	Reduction of absence costs due to physical diseases	SCBA	QL
	1.2	***Improved air quality (deposition, dispersion, modification)***	***SCBA***	***QL***
	1.2.1	Reduction of healthcare costs due to deposition of Particulate Matter (PM_{10})	SCBA	QN
	1.2.2	Reduction of healthcare costs due to deposition of Particulate Matter ($PM_{2.5}$)	SCBA	QL

	1.2.3	Reduction of healthcare costs due to sequestration of CO_2	SCBA	QL
	1.2.4	Reduction of healthcare costs due to sequestration of NO_x	SCBA	QL
	1.2.5	Reduction of healthcare costs due to sequestration of SO_x	SCBA	QL
	1.2.6	Reduction of healthcare costs due to sequestration of O_3	SCBA	QL
	1.2.7	Reduction of healthcare costs due to sequestration of VOCs	SCBA	QL
	1.3	***Reduction of heat stress***	***SCBA***	***QL***
	1.3.1	Reduction of healthcare costs due to heat stress related physical diseases	SCBA	QL
	1.4	***Reduction of noise pollution***	***SCBA***	***QL***
	1.4.1	Reduction of healthcare costs due to noise pollution related physical diseases	SCBA	QL
	1.5	***Increase of exercise***	***SCBA***	***QL***
	1.5.1	Reduction of healthcare costs due physical diseases related to lack of exercise	SCBA	QL
2. Mental health & well-being	**2.**	**Total of mental health & well-being**	**SCBA**	**QL**
	2.1	***Integral whenever possible (due to presence of natural surroundings, reduction of heat stress, reduction of noise pollution, increase in exercise)***	***SCBA***	***QL***
	2.1.1	Reduction of healthcare costs due to mental diseases (less hospitalizations, less medication, quicker recovery time)	SCBA	QL
	2.1.2	Reduction of premature morbidity due to mental diseases	SCBA	QL
	2.1.3	Reduction of absence costs due to mental diseases	SCBA	QL
	2.2	***Reduction of heat stress***	***SCBA***	***QL***
	2.2.1	Reduction of healthcare costs due to heat stress related mental diseases	SCBA	QL
	2.3	***Reduction of noise pollution***	***SCBA***	***QL***
	2.3.1	Reduction of healthcare costs due to noise pollution related mental diseases	SCBA	QL
	2.4	***Increase of exercise***	***SCBA***	***QL***
	2.4.1	Reduction of healthcare costs due to mental diseases related to lack of exercise	SCBA	QL

5.4.1.1 Reduction of healthcare costs due to deposition of Particulate Matter (PM_{10})

Particulate matter concentration has a strong correlation with adverse health effects like respiratory and cardiovascular diseases. In the long term, extensive exposure to particulate matter can cause lung cancer and premature death. The smaller the particles (e.g. fine particulate matter $PM_{2.5}$ or even ultrafine $PM_{0.1}$), the greater the risks to harmful effects, since these can penetrate deeper into lungs and end up in the human blood stream (Ysebaert, Koch, Samson, & Denys, 2021).

In 2021, Ysebaert et al. (2021) released a review paper regarding green walls as measure for mitigating urban particulate matter pollution. It was claimed that research has shown the potential of green walls to reduce PM_{10} levels in deep street canyons (H/W = 2) with around 5-30%, however the authors of the review believe in a much greater, untapped potential. Also, it is stated that green walls have advantages over other urban NBS and green infrastructure with regards to air quality improvements, due to their huge wall area covering potential and their application in vertical orientation. The latter also implies that VGS do not interfere with the prevailing natural ventilation currents in streets. Since this is the case for trees though, there it can even result in elevated PM concentration levels since PM is obstructed to leave street canyons.

Higher Wall Leaf Area Index (WLAI) results in enhanced PM accumulation of VGS. This seems logical, since the potential leaf surface area for deposition of particles is larger. Common values for WLAI range between 2-7 m^2/m^2, which is defined as the total leaf area per surface area VGS. Also, for particles larger than 5 µm, a strong relation was found between ambient PM concentrations and PM deposition on leaves. Higher concentrations result in more deposition (Ysebaert et al., 2021).

For valuing the healthcare costs due to deposition of PM_{10}, a methodology was found in the TEEB-Stadtool by Does et al. (2019). This method which was previously used for green roofs, urban trees and horizontal greening. Combining this with the literature review by Koch, Ysebaert, Denys, and Samson (2020) on VGS, allowed for a provisional estimation of the value delivered by VGS. The method, along with its corresponding formulas and input, is elaborated below and represented visually in Figure 5.2 and Figure 5.3. Naturally these are also incorporated in the VGS Valuation Tool.

The PV over the duration of the analysis period for the benefit for deposition of PM_{10} is:

$$B_{PM_{10}} = \sum_{t=t_0}^{t} B_{PM_{10},t} * (1 + r_s)^{(t_0 - t)} \quad (9)$$

Where:
$B_{PM_{10}}$ = PV of benefit reduced healthcare costs related to PM_{10} (€)
$B_{PM_{10},t}$ = Yearly value of benefit reduced healthcare costs related to PM_{10} (€)
t_0 = Reference moment of the analysis (year zero: moment of funding VGS)
r_s = Societal discount rate

The yearly value for the benefit of deposition of PM_{10} is:

$$B_{PM_{10},t} = R_{PM_{10}} * V_{PM_{10}} * A_{VGS} \quad (10)$$

Where:
$B_{PM_{10},t}$ = Yearly value of benefit reduced healthcare costs related to PM_{10} (€)
$R_{PM_{10}}$ = Retention capacity of vegetation for PM_{10} (kg/ha/year)
$V_{PM_{10}}$ = Societal value of PM_{10} in relation to healthcare costs (€/kg PM_{10})
A_{VGS} = Area of VGS surface (ha)

The value of PM_{10} in relation to healthcare costs is dependent on the population density, namely:

$$V_{PM_{10}} = 1{,}3637 * N_{inh} + 49{,}68 \quad (11)$$

Where:
$V_{PM_{10}}$ = Societal value of PM_{10} in relation to healthcare costs (€/kg PM_{10})
N_{inh} = Number of inhabitants per ha in the neighbourhood (-)

Whereas the retention capacity of vegetation in VGS for PM_{10} is denoted as follows:

$$R_{PM_{10}} = V_d * C_{PM_{10}} * fr * UC \quad (12)$$

Where:
$R_{PM_{10}}$ = Retention capacity of vegetation for PM_{10} (kg/ha/year)
V_d = Deposition velocity, which is already dependent on WLAI (cm/s)
$C_{PM_{10}}$ = Concentration of PM_{10} in surroundings (µg/m^3)
fr = Resuspension fraction for PM_{10} in VGS (-)
UC = Conversion factor cm/s to kg/ha/year (-)

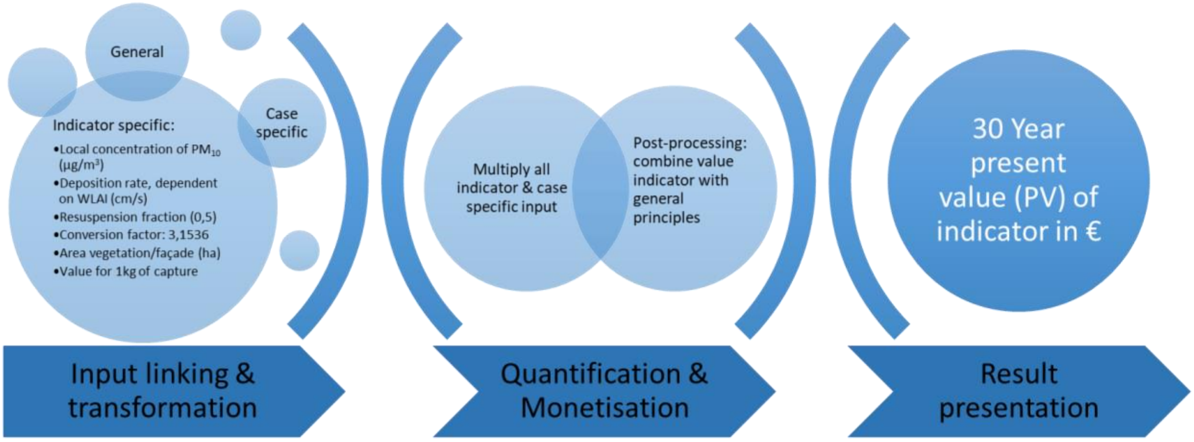


Figure 5.2: Valuation method for reduction of healthcare costs due to deposition of particulate matter (PM_{10})

Figure 5.3: Linking indicator & case specific input calculation - Reduction of healthcare costs due to deposition of particulate matter (PM_{10})

5.4.1.2 Reduction of healthcare costs due to deposition of $PM_{2.5}$ and $PM_{0.1}$

For smaller particles of PM, the same valuation method could be apply. Based on the statement by Ysebaert et al. (2021) that the smaller the particles, the greater the risks to harmful effects (penetrating deeper into lungs and end up in the human blood stream), higher values for those benefits are expected per kg of capture. It is even claimed that ultrafine $PM_{0.1}$ could be sequestered by vegetation, rather than solely deposited. This would enhance its effect. Also, for those smaller particles, resuspension into the air approaches to zero. Therefore, the resuspension factor can be kept at a lower rate (Does et al., 2019).

5.4.1.3 Reduction of healthcare costs due to sequestration of CO_2, NO_x, SO_x and O_3

For other pollutants than PM, the same valuation methods could apply. However, gaseous substances are sequestered by the leaves, rather than deposited on the leaves, there is no resuspension possible back into the air. Therefore, the resuspension factor can be kept at zero (Does et al., 2019).

5.4.1.4 Reduction of heat stress

In cities and urban regions, the urban heat island (UHI) effect can occur, implying that average temperatures are higher than in adjacent rural areas (see Figure 5.4). A difference in temperature of up to 10 °C can prevail (Koch et al., 2020). Lack of greening and blue infrastructure, anthropogenic heat sources and increased adsorption and re-radiation of heat by urban structures existing from concrete, brick, asphalt and metals are the main contributors to this effect. The negative effects of UHI are increased due to the greater temperature difference at night, when human bodies should be allowed to rest and recharge their batteries. Urban green infrastructures, including vertical greening, pose to be beneficial mitigation and adaptation strategies with regards climate change through their cooling capacity by providing shade and evapotranspiration. This enhances human comfort and reduces risks of excess mortality rates, hospitalizations and increase in healthcare costs due to heat stress. This especially among elderly and children, as well as groups with pre-existing health problems (Koch et al., 2020; Moens, Hand, & Hegger, 2020).

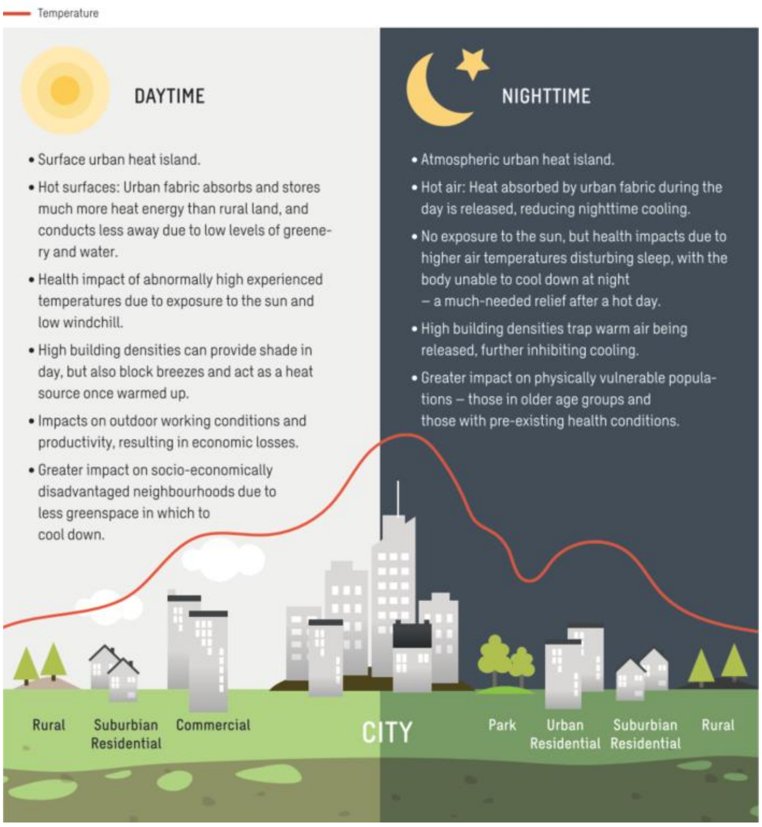


Figure 5.4: The Urban Heat Island (UHI) effect (Moens et al., 2020)

5.4.1.5 Reduction of noise pollution

Studies into outdoor VGS revealed that these systems were capable of increasing acoustic insulation properties of building, as well as providing noise-attenuation in the outdoors through scattering and dispersing sound waves (Bustami et al., 2018; Veisten et al., 2012). This positively effects both physical health (reduced blood pressure and prevention of hearing loss), as well as mental health (reduced stress levels and sleep disturbance, enhanced living comfort).

5.4.2 Benefit indicators for theme 'Climate Adaptation & Mitigation'

Through their properties which contribute to climate adaptation, VGS can enhance urban resilience. According to Bush and Doyon (2019), urban resilience is dependent upon the ability to adapt and adjust to changes within the cities' environment. For cities to be climate resilient, they require a response that is fit both to gradual changes and chronic stresses (e.g. heat stress), as well as to abrupt change or shocks (natural disasters).

The way we have gotten used to designing our cities, i.e. with paved streets and grand buildings, has proven to be less resilient to the effects of climate change. The removal of trees and other vegetation and use of impervious materials in urban areas have impaired normal ecosystem functions like the circulation of carbon, water and nutrients. Cities' resilience capacity increases however, when natural systems, services and resources are integrated within the urban infrastructure. (Ojala & Campbell, 2020)

Hence, VGS can play a role in supporting climate change mitigation and adaptation. Mitigating qualities are for instance reflected in the carbon storing capacity of vegetation. For climate adaptation, e.g. reduction of effects of heat stress and local water storing capacity (in buffers, which is to be used as irrigation water) can be evaluated. In Table 5.6 the benefit indicators for the theme climate adaptation & mitigation are provided. Note that some of the effects that relate to climate adaptation are already encapsulated by other themes as well, hence to prevent double counting they are not integrated again in this category. All indicators are only qualitatively integrated in the VGS Valuation Tool. Working these out quantitatively is recommended as further research.

Table 5.6: Comprehensive list of climate adaptation & mitigation benefits associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Climate mitigating effects (Sequestration and stabilization of greenhouse gases)	**1.**	**Total of climate mitigating effects**	**SCBA**	**QL**
	1.1	Sequestration of carbon dioxide - photosynthesis (CO_2)	SCBA	QL
	1.2	Sequestration of methane (CH_4)	SCBA	QL
	1.3	Deposition of nitrous oxide (N_2O)	SCBA	QL
	1.4	Deposition of ozone (O_3)	SCBA	QL
	1.5	Potential sequestration or deposition of other GHG (e.g. chlorofluorocarbons - CFCs)	SCBA	QL
	1.6	Reduction of GHG emissions due to reduced energy consumption	SCBA	QL
	1.7	Reduction of GHG emissions due to reduced urban motorised traffic: Natural surroundings increase pedestrian/bicycle traffic	SCBA	QL
2. Reduction of effects 'Heat stress'	**2.**	**Total of reduction of effects 'Heat stress'**	**SCBA**	**QL**
	2.1	Indicators are for now stored in other themes	SCBA	QL
3. Reduction of effects 'Precipitation & Flooding' (account for local storage of irrigation water needed)	**3.**	**Total of reduction of effects 'Precipitation & Flooding'**	**LCCA/SCBA**	**QL**
	3.1	Reduction of pressure on sewage system and corresponding management costs	SCBA	QL
	3.2	Reduction / Avoided water treatment costs	SCBA	QL

	3.3	Reduction of sewage renewal/development costs due to smaller discharge	SCBA	QL
	3.4	Reduction of the 'Value at risk' due to reduced risk of street flooding (investor)	LCCA	QL
	3.5	Reduction of the 'Value at risk' due to reduced risk of street flooding (surrounding society)	SCBA	QL
4. Reduction of effects 'Drought'	**4.**	**Total of reduction of effects 'Drought'**	**LCCA**	**QL**
	4.1	Reduced risk of soil settlements (infringement of foundation and structure)	LCCA	QL

5.4.2.1 Climate mitigating effects

VGS possess the capacity to sequester GHG like CO_2 and CH_4, their leaves have deposition capacity for N_2O and O_3. Not only is this sufficient for health and well-being of urban residents and dwellers, as was elaborated in the previous section. This can also contribute to the deceleration of climate change. Furthermore, due to the insulating properties of VGS to buildings, a reduced energy demand can be achieved, also leading to reduced GHG emissions related to heating and cooling. Hence, the values contributing to climate mitigation can be classified both in the domain of damage cost avoidance (prevention of GHG emissions through enhanced insulating capacity) as well as restoration costs (sequestration and deposition). The quantification of these effects are proposed via LCA methodology in the near future (Rowe et al., 2022). In order to do so, first the amount of deposition of particles or substances on leaves should be assessed, as well as the carbon sequestration capacity of VGS through photosynthesis.

5.4.2.2 Reduction of effects of Precipitation & flooding

According to Bustami et al. (2018), reducing negative effects of extreme rainfall can be achieved when buffer tanks are installed at the project, which then use the collected rainwater for irrigation of the LWS. This field of study is new to VGS, yet it shows promising results for significantly reducing the demand for potable water. Hence, although the contributing effect of reduced rainwater discharge during peaks is not fully attributable to the VGS themselves (but to the storage capacity of water tanks), the subsequent use of the collected water for irrigation does offer a benefit (avoided water treatment costs). Also, providing a user function for the collected rainwater, might generally stimulate the implementation of water buffer systems.

5.4.3 Benefit indicators for theme 'Real Estate'

The theme real estate constitutes an important benefit base for VGS, as urban greening measures can significantly contribute to higher real estate values, reduced energy bills for heating and cooling and increased structural and building lifetime combined with reduced maintenance needs for the existing façade. Furthermore, value for real estate can be reflected in potential subsidies for installation of these systems, as well as tax incentives or even in the requirement for integration of greening measures in order to obtain building permits. Benefits for real estate show overlap with climate adaptation values, like e.g. the reduced risk of damage due to street flooding. Enhanced building envelope's lifetime is furthermore related to heat stress (mitigates diurnal temperature fluctuation and hence degradation and fatigue of materials). In Table 5.7 the benefit indicators for the theme real estate are provided. For now, some indicators worked out quantitatively in the VGS Valuation Tool. Elaboration of the other indicators is recommended as further research.

Table 5.7: Comprehensive list of real estate benefits associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Real estate value	**1.**	**Total of social values**	**LCCA/SCBA**	**QL**
	1.1	Increase of real estate value for the real estate investor/owner (increased rental incomes) (financial cost component for residents)	LCCA	QL
	1.2	Increase of real estate value for the property resident (increased living comfort and satisfaction level - increased liveability index)	SCBA	QL
	1.3	Increase of real estate value for society at large (increased aesthetics and visual interest)	SCBA	QL
	1.4	Increase of real estate value for government body (increased housing value tax payments by owner)	SCBA	QL
2. Building specific benefits	**2.**	**Total of building specific benefits**	**LCCA/SCBA**	**QL**
	2.1	Increased building envelope's integrity and lifetime (mitigates diurnal temperature fluctuation and degradation due to rainwater and substances)	LCCA	QL
	2.2	Reduced building envelope's standard maintenance over lifetime	LCCA	QL
	2.3	Reduced risk of undesired graffiti and vandalism (maintenance)	LCCA	QL
	2.4	Reduced energy usage for building heating (in winter)	SCBA	QN
	2.5	Reduced energy usage for building cooling (in summer)	SCBA	QL
	2.6	Reduced energy usage for (mechanical) ventilation	SCBA	QL
	2.7	Increased energy efficiency for vertical solar panels in façade	LCCA	QL
3. Subsidies, tax incentives and legislative benefits	**3.**	**Total of subsidies, tax incentives and legislative benefits**	**LCCA**	**QL**

(due to sustainability measures to property)	3.1	Subsidies	LCCA	QL
	3.2	Tax incentives MIA	LCCA	QN
	3.3	Tax incentives Vamil	LCCA	QN
	3.4	Comply for building permits: integration of green measures might be a necessity obtain building permits	LCCA	QL
	3.5	BREEAM or LEED certification / Cradle-to-cradle certification	LCCA	QL

5.4.3.1 Increase of real estate value for the real estate investor/owner

Since the assumption was made that residential complexes are owned by investors, the increase of real estate value for the real estate investor/owner is reflected through the increased rental incomes. This is done, because increase of the rents can be made tangible, depend on actual market prices and are more consistent, while the potential increase of value with regards to selling the complex is dependent upon market fluctuations and trends. Also, the potential future value increase when selling the properties is not assured in the contemporary perspective. Hence, when investors tend to keep the properties in their portfolio for the foreseeable future, valuation of increased rental incomes tends to be most appropriate.

The valuation method is similar to the calculation of the financial cost component for residents as described in section 5.3.1, since rent flows from the residents to the investor. Hence, the increase in property value due to VGS implementation for the real estate investor is calculated from an assumed increase in rental price for the property (%), following from Perini and Rosasco (2013), and the total yearly initial rent for the entire building complex (€).

$$B_{R,inv} = B_{\Delta Rent} \tag{13}$$

$$B_{\Delta Rent} = \sum_{t=t_0}^{t} \Delta P_{Rent} * P_{Rent,t_0} * (1 + r_I)^{(t_0 - t)} \tag{14}$$

Where:

$B_{R,inv}$	=	PV of benefit of increased rent for real estate investor (€)
$B_{\Delta Rent}$	=	PV of increased rental income (investors) (€)
ΔP_{Rent}	=	Increased rental price of property (%)
P_{Rent,t_0}	=	Initial yearly rental costs, aggregated for building complex (€/year)
t_0	=	Reference moment of the analysis (year zero: moment funding VGS)
r_I	=	Investor discount rate

Other stakeholders

Looking at increased real estate values for residents or society at large, other factors are at stake. For residents, increase of the perceived real estate value of the property can be expressed in terms of increased living comfort and (tenant) satisfaction level, or an increased liveability index.

Society at large will value the implementation of VGS with regards to real estate in terms of increased aesthetics and visual interest or appeal. This value can be reflected through the willingness to pay (WTP) for enhanced aesthetics of greenery by the general public (Collins et al., 2017).

Government bodies might benefit from housing tax increase revenues due to VGS implementation. Yet, these benefits can again be nullified by the provision of subsidies or other tax incentives that stimulate the further implementation of these kind of systems. This will then provide additional benefits for society.

5.4.4 Benefit indicators for theme 'Social & Recreation & Commercial'

VGS can play a role in supporting and providing social, recreational and commercial values. These qualities are for in for instance reflected in the enhanced social cohesion in green areas, (joint) food production (Bustami et al., 2018), the increase of visitors for cities (Hatan, Fleischer, & Tchetchik, 2021), increase in productivity and marketing values (Magliocco, 2018; Manso et al., 2021; Teotónio et al., 2021). In Table 5.8 the benefit indicators for the theme recreation & social & commercial are provided. For now, all indicators are only qualitatively integrated in the VGS Valuation Tool. Working these out quantitatively is recommended as further research.

Table 5.8: Comprehensive list of social & recreational & commercial benefits associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Social values	**1.**	**Total of social values**	**SCBA**	**QL**
	1.1	Enhanced potential for social cohesion (e.g. through joint 'gardening' or meeting)	SCBA	QL
	1.2	Reduced rate of criminal offenses and violence	SCBA	QL
	1.3	Enhanced sense of safety & security	SCBA	QL
	1.4	Enhanced potential for educational value	SCBA	QL
	1.5	Enhanced potential for childhood cognitive development	SCBA	QL
	1.6	Food production - Urban agriculture (value of cultivated food)	SCBA	QL
2. Recreational values	**2.**	**Total of recreational values**	**SCBA**	**QL**
	2.1	Increase of transactions by local residents (attracted by enhanced aesthetics, public art and visual interest)	SCBA	QL
	2.2	Increase of transactions by visitors/commuters/tourists (attracted by enhanced aesthetics, public art and visual interest)	SCBA	QL
	2.3	Increase of region visits (attracted by enhanced aesthetics, public art and visual interest)	SCBA	QL
3. Commercial values	**3.**	**Total of commercial values**	**LCCA/SCBA**	**QL**
	3.1	Increase in work productivity in for remote working locations/offices/shops (due to natural surroundings, reduced heat stress, reduced noise pollution)	SCBA	QL
	3.2	Marketing value for investor (e.g. through media coverage)	LCCA	QL
	3.3	Marketing value for local government (e.g. through media coverage)	SCBA	QL

5.4.5 Benefit indicators for theme 'Biodiversity'

Given the notion that Ecosystem functioning and delivery of ES is dependent on the richness of biodiversity on multiple trophic levels and based on some requirements that should be met to obtain high biodiversity levels inside VGS, for this thesis the assumption was made that biodiversity in the valued VGS is sufficient. Also, with biodiversity being at the base of ES delivery, the value of internal VGS's biodiversity is largely captured and reflected within the indicators for other benefit themes. In that sense, biodiversity serves as given input or minimum requirement, in order to obtain benefits in the other themes.

Yet, some values perceived by stakeholders that are related to biodiversity as output might remain untouched. At the current level of development of the framework and tool, these remaining values are captured qualitatively within this final benefit theme. It is noted that always the consideration should be made whether these values are still to be addressed or that they are surplus and initiate double-counting of values.

Table 5.9: Comprehensive list of biodiversity benefits associated with VGS

Category	Item	Description of cost indicator	LCCA/SCBA	QL/QN
1. Contribution to further biodiversity increase in surroundings	**1.**	**Total of further biodiversity increase in surroundings**	**SCBA**	**QL**
	1.1	Preservation or improvement of ecosystem functioning (e.g. nutrient cycling and soil formation)	SCBA	QL
	1.2	Enhanced growing conditions for plant species and urban nature (due to improved air quality and local temperatures)	SCBA	QL
	1.3	Habitat provision for animals like birds & insects (due to nesting places and food security)	SCBA	QL
2. Non-use values for natural environment	**2.**	**Total non-use values for natural environment**	**SCBA**	**QL**
	2.1	Bequest value: value from satisfaction of preserving a natural environment and ensuring the availability of biodiversity for future generations	SCBA	QL
	2.2	Existence value: value resulting from the satisfaction that something exists (existence of biodiversity/species in the living environment)	SCBA	QL

5.5 Conclusion Part II – Synthesis phase

In the synthesis phase, the economic valuation framework and VGS Valuation Tool are developed based on the literature review from Part I. This has resulted in an initial version of a comprehensive and interactive tool for valuation of costs and benefits of VGS across several distinct themes. First, the applied analyses methods are introduced and elaborated. Then a tool design and setup were presented, which serve as a semi-automated infrastructure. Subsequently, in chapter 5 all specific cost and benefit indicators were distributed and assigned to their applicable themes. Some valuation methods were elaborated as well. This together has formed the basis for answering the second sub-question of the research:

Which analysis method and valuation methods are proposed to enable the comprehensive economic valuation of the costs and benefits of vertical greening systems?

Resulting from the goal to account for multiple stakeholders, offer different perspectives to values of costs and benefits of VGS and use the framework as a conversational mechanism between parties, the proposed valuation framework will distinguish between a financial analysis (LCCA) for the real estate investor and an economic analysis (SCBA) for society as a whole. Both of these analysis are performed following the nine basic steps of the procedure for SCBA. For each analysis, distinct discount factors apply for calculation of the present values of costs and benefits. Aside from 'zero discount rate' for both analyses, an 'investor discount rate' is applied for LCCA and a 'social discount rate' for ecosystem services valuation in SCBA. This is due to the difference in time horizons and perceived risks or values of these stakeholders.

The framework functioning is thoroughly elaborated and divided into a user workflow and an automated tool workflow (Figure 4.1 and Figure 4.2). The framework for user workflow standardises the data gathering and implementation with regards to VGS properties, case specifics and indicator specifics that relate to VGS. When calculations and result presentation are automatically performed by the tool, only interpretation of these results is necessary in order to allow for informed decision-making. The automated tool workflow first links and, where needed, transforms data into correct units. Then, the quantification and monetarisation processes are performed. Finally, the results of these calculations are visually presented in the result dashboard in tables, diagrams and graphs.

The design and infrastructure of the VGS Valuation Tool is presented, in which the framework is integrated. The tool is divided into 5 sections containing 15 accessible tabs. With this, a utilization focussed, interactive tool was designed and established in MS-Excel, which is applicable to different projects in the Netherlands but extendable to other countries. In the current version, the tool's infrastructure is full-fledged and operational.

First, two extensive tabs with background information and a user guide are provided. Then in the input section, the users have to choose several starting principles for valuation and manually insert a number of parameters for case specific and indicator specific input variables. Next, the result section directly presents and visualizes the final outcomes of the analyses in a result dashboard. The cost and benefit sections automatically perform value calculations for the indicators listed throughout the tables in chapter 5. This is achieved through established valuation methods and corresponding present value calculations.

For the costs, a valuation method and sequence for financial costs is fully integrated within the tool. This allows for quantification of costs at category level, however when relevant data is collected for more detailed indicators as listed, these can be quantified instead. For the environmental costs, the LCA procedure is encapsulated in the framework and tool. Identification and insertion of materials quantities and processes needed for distinct VGS, allows for monetisation of environmental costs with the ECI. Potential disservices are qualitatively captured.

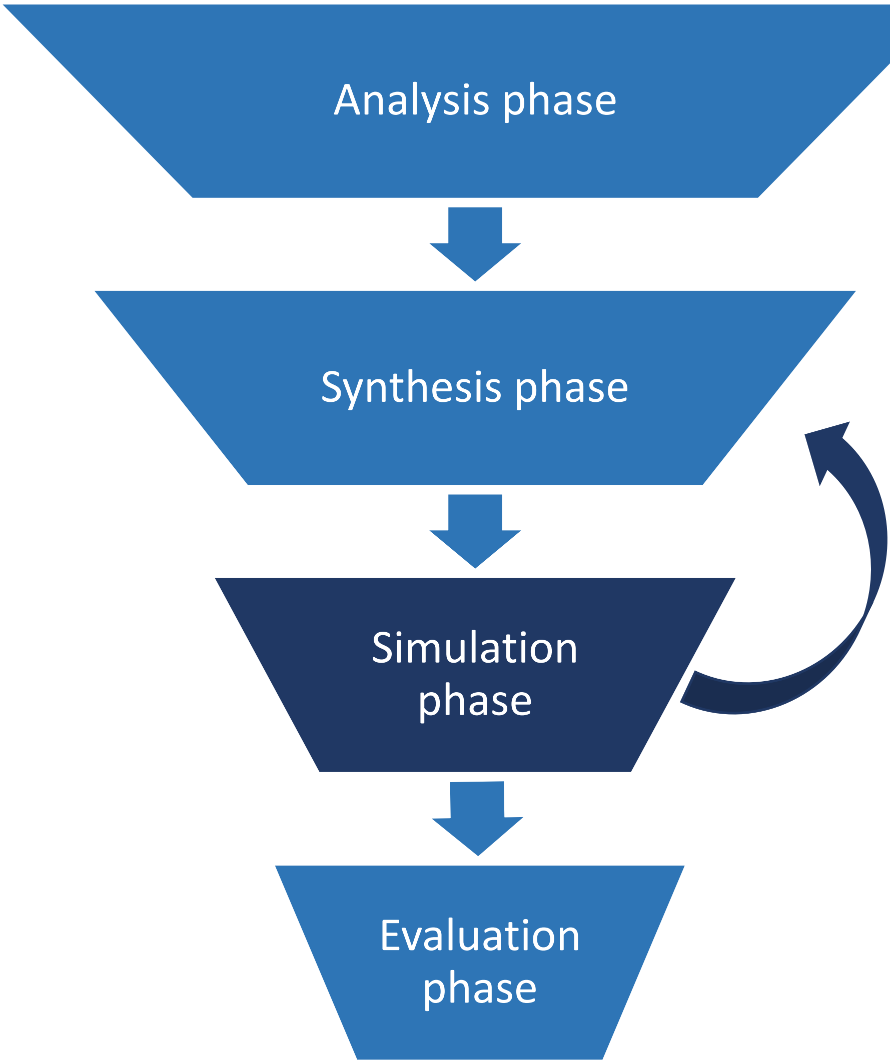
For the benefits, in the health & well-being theme currently the value of reduced healthcare costs due to deposition of PM_{10} is monetised. The same method could be applied for $PM_{2.5}$ and $PM_{0.1}$, while also application for gaseous substances could be investigated. Other indicators are yet hard to quantify. The climate adaptation & mitigation, social & recreational & commercial and biodiversity themes are qualitatively captured. For real estate, for several indicators a valuation method was appended to the tool for them to be monetised. I.e. the increase of real estate value for the real estate investor (through increased rental incomes), the reduced energy usage for building heating in winter and tax incentives for VGS (MIA & Vamil).

In conclusion, the developed framework and VGS Valuation Tool comprise a first version, allowing to evaluate an all-encompassing number of costs and benefits regarding the implementation of VGS on buildings. In order to do so, it automates the proposed valuation methods for different themes and value indicators, meaning users only have to insert input parameters for given variables. In future research, further integration of other valuation methods should occur for indicators that are only qualitatively incorporated in the tool. Literature review provided some additional methods for several indicators in all themes. For others, evidence based research was not yet available at a sufficient level.

Part III

-

Case study & Results



6

VGS Valuation Tool – Case study and result dashboard

6.1 Introduction

This third part of the report (Part III – Case study & Results), contains the simulation phase of the research. Here, the end product of the valuation framework is presented: i.e. the VGS Valuation Tool, containing the results and dashboard for cost and benefit calculations of VGS. The VGS Valuation Tool forms the mechanism with which end-users are enabled and facilitated to gain insights into the different costs and benefits associated with VGS implementation in the urban environment. The results and dashboard tabs in the tool are the place where all the outcomes are brought together. These will be used by the end-user to make substantiated considerations regarding potential VGS options at specific locations. To involve anticipated end-users, the validation of the tool is partially based on a user experiment. This simulation phase of the research is dedicated to the third sub-research question, which will be answered in the conclusion of Part III (section 7.4):

"Based on a case study, what results can be obtained from the developed economic valuation tool and how can these results be interpreted?"

Chapter 6 is dedicated to the demonstration of the VGS Valuation Tool based on a case study, which is first introduced. Also the relevant parameters and corresponding variables for this case are inserted in the input sheets of the VGS Valuation Tool. Hereafter, the obtained results are presented, including the functionality of the result dashboard. Finally, the obtained results are presented and the functionality of the result dashboard is elaborated. As this thesis work is the initial impetus to obtain full and comprehensive insight into all monetised costs and benefits through an interactive tool, it should be noted that the presented overview is still a provisional version of the VGS Valuation Tool.

6.2 Background of case study

In order to tackle the biggest obstacles in the tool and test whether the developed VGS Valuation Tool could produce valid and sound results, a case study was conducted. The elaboration of this case study provides an outlook into the basic functionality, intended use and generated results by the tool. The analysed project has provided the necessary location- or case specific input for the tool in order to run the underlying model.

Because of land scarcity in high-density urban areas and the ability of VGS to provide multiple ecosystem services, city centres are ideal locations to exercise these system's potential to positively impact the living environment. VGS enable the opportunity for new natural and biodiverse vertical surfaces at locations that were previously inaccessible for vegetation, without harming the underlying construction. Shafique et al. (2018) already acknowledged that the lack of horizontal spaces at ground level makes that integration of VGS (or green roofs) onto building's envelopes are often favoured over other NBS. Furthermore, the research was initially aimed towards residential real estate.

To comply with the previously mentioned conditions, in correspondence with Sweco and one of their real estate client organisations a suitable case study was selected from their property portfolio. This was opted for, since the client organisation is actually exploring opportunities to effectively invest in making their portfolio more sustainable, healthy and climate resilient.

6.2.1 'Paradium 3' - Dordrecht

The object that was eventually selected to serve as case study is the residential rental complex called 'Paradium 3' (the three closest buildings in Figure 6.1), located at the edges of the historical city centre of Dordrecht. These rental apartments were originally constructed in 1967 and are situated along Spuiboulevard (7-95, uneven addresses). Due to the inner-city location and paved streetscape, the assumption is met that there is little room for incorporation of horizontal greenery at this location. According to the so called 'Basiskaarten' in the 'Klimaateffectatlas' (Kennisportaal Klimaatadaptatie, 2022), this neighbourhood has less than 10% green area (Figure 6.2). For the case study, VGS are applied on all of the building's façades (total of 1858 m^2).

Hence, by choosing this real estate object, the case study would not only contribute towards validation of the framework and tool (by demonstrating its practical application). Also, initial results and insights could be manifested towards a specific project. This might lead to real societal impact.

Figure 6.1: Residential housing complex 'Paradium 3', Spuiboulevard in Dordrecht (Vesteda, 2022)

Figure 6.2: Percentage of green area in the neighbourhood (Contours of the apartment building in red) (Kennisportaal Klimaatadaptatie, 2022)

6.2.2 Data gathering

Among others the building itself, its surroundings and location type, local demographics and various climatic and environmental factors, contain distinct properties which apply to one case specifically. Relevant data, specific to the aforementioned components, should therefore act as input in the tool. Hence, using this as input data enables the diversification between cases and provides adequacy in the economic valuation of individual projects. These are the variables that should ultimately elevate the value and relevance of the cost and benefit results that can be obtained, and the insights that can be gained, by utilizing the VGS Valuation Tool: to make the valuation framework project specific.

Depending on the project and available information beforehand, due to the comprehensiveness of the tool it can be time-consuming to acquire all input data correctly when first time exercising the framework. For sake of user-friendliness, -experience and intuitiveness, and for users to effectively and correctly collect these input values themselves, relevant information and data extraction sources were included in the tool using hyperlinks. Also, due to technical project backgrounds or data needed, not all input values can be determined via desk research or internet. Some data should be directly gathered at the client or property owner in order to allow for adequate and precise input.

In order to perform a valuation for the costs and benefits that are already in the framework and tool, specifically for the proposed case study, the researcher made an effort to collect adequate and precise data. Most data was retrieved from digital sources, yet for example façade areas were precisely quantified according to construction drawings provided by the client organisation. An overview of the data that was integrated in the tool, is provided in appendix F.2.

Note that some indicator specific data for value calculations was linked to the choice for Modular LWS, meaning it was collected during the literature review stage of the researcher. Unfortunately, due to the innovative nature of LWS research and its relatively limited content (Rowe et al., 2022), not all information is available with data specifically governing for the Netherlands. Hence, some research papers are used that apply to VGS and cases in Southern Europe or other parts of the world. Although the indicators that are currently quantitatively included in the tool do not depend on climatic conditions specifically, it should be noted that in future efforts it would be appropriate to select and use papers that apply to the region of interest. This also applies with regards to e.g. real estate values.

Therefore, future tool developers are recommended to implement the data that is related to e.g. a specific VGS type in the VGS database tab that was initiated in the tool, this also with regards to distinct climatic conditions. Linking this input to different input variables, then allows for automatic update of the parameters whenever another VGS type or climatic region is selected for valuation.

General principles & assumptions

In the VGS Valuation Tool, for the input tabs only the orange cells have to be adjusted by the user. The blue cells are fixed by the developer of the tool or are dependent and linked to selection of certain general principles or certain case specific inputs. The purple cells in the input tabs are future outlook, and comprise foreseen input variables needed to quantify and monetarise values of costs and benefits of VGS. These are given in this report for comprehensiveness, but not yet integrated in the workflow or valuation methods comprised in the model. In appendix F.2, the general principles and assumptions related to the case study is provided, which was implemented in the VGS Valuation Tool.

Case specific input & assumptions

In appendix F.2, also the case specific input data related to the case study is provided, which was implemented in the VGS Valuation Tool.

Indicator specific input & assumptions

In appendix F.2, finally the indicator specific input data related to the case study is provided, which was implemented in the VGS Valuation Tool.

6.3 Results and result dashboard

While the main goal of this thesis was the initiation, establishment and general outline of the valuation framework and tool to provide quantification of costs and benefits, the results and insights that eventually follow have the ability to provide great insight for clients, consultants and other decision-makers. An overview of the model and tool development results can be viewed in appendix F.

6.3.1 Results from the case study in result dashboard

An overview of the valuation results is provided in the result totals and result dashboard tabs of the tool, which form a comprehensive insight into the contributions of different cost and benefit themes involved with valuation. Furthermore, the difference in perceived costs and benefits between the investor and the residents (and society at large) is illustrated. Providing a Net Present Value (NPV) and Benefit-Cost Ratio BCR) for both analysis types allows for a quick first glimpse at economic or financial feasibility. Furthermore, the tabular value overviews accompanied by the dynamic and visual diagrams and graphs, dive deeper into distribution and contribution of effects and values.

First, their interpretation in combination with examination of the different themes and categories from which the costs and benefits origin, can provide client and consultant with valuable insight for effective, substantive and scientifically based decision-making on VGS implementation in a project.

Second, the results could consult suppliers and manufacturers on which themes or categories they should focus to reduce (societal) lifetime costs, or which benefits could be amplified by making certain adaptions to a VGS. Ultimately, when multiple VGS are integrated in the valuation tool, project specific optimized systems can be proposed, to offer functionalities that meet project characteristics or needs.

Moreover, the VGS Valuation Tool can constitute an appealing service to clients who are eager to implement green infrastructure measures into their real estate projects. The tool can raise awareness regarding VGS and their costs and benefits within the AEC industry and urban development and ecology industry. This way, it can potentially generate a more widespread acceptance of these systems, when ultimately benefits become more apparent in valuation efforts.

In the following, a brief overview presents results retrieved from the case study in the current tool version. The results can be retrieved from the MS-Excel file *‘VGS_Valuation_Tool_V.1.01’*. Since the results and result dashboard are quite extensive, please also refer to appendices F.3, F.4 and F.5, where a complete overview of the results that can be obtained are illustrated.

Indicators for financial/economic feasibility & sustainability

The two tables below provide compact and conclusively the final results of the LCCA and SCBA.

Table 6.1: Net Present Values (NPV) of total analyses

NPV of analyses over period of 30 years (€)			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
-€ 2.793.963,25	-€ 1.956.529,66	€ 335.491,64	€ 249.889,71

Table 6.2: Benefit-Cost Ratios (BCR) of total analyses

BCR of analyses over period of 30 years (€)			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
0,3734	0,3051	1,2754	1,2746

Total costs & benefits balance table

Table 6.3 present a tabular overview of the monetisation results per theme, a total for costs and benefits and a resulting NPV (which corresponds to the values in Table 6.1).

Table 6.3: Total costs & benefits balance table

	(Net) Present values over analysis period			
	Total PV of all cost & benefit themes over 30 years (€)			
	Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
Cost themes				
Financial costs	€ 4.459.200,00	€ 2.815.632,07	€ 1.180.413,00	€ 878.998,16
Environmental costs	N/A	N/A	€ 16.338,57	€ 15.777,21
Potential Ecosystem Disservices	N/A	N/A	€ 0,00	€ 0,00
Total of all costs	€ 4.459.200,00	€ 2.815.632,07	€ 1.196.751,57	€ 894.775,37
Benefit themes				
Health & Well-being	N/A	N/A	€ 16.869,72	€ 12.562,09
Climate Adaptation & Mitigation	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Real Estate	€ 1.378.986,75	€ 769.856,19	€ 101.613,49	€ 75.666,79
Social & Recreational & Commercial	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Biodiversity	N/A	N/A	€ 0,00	€ 0,00
Total of all benefits	€ 1.378.986,75	€ 769.856,19	€ 118.483,20	€ 88.228,88
Grand total	-€ 3.080.213,25	-€ 2.045.775,88	-€ 1.078.268,36	-€ 806.546,49

Costs vs. benefits totals – contributions of the impact themes

The figures below illustrate how the different contributions per impact theme are visualised in the tool and how these themes relate to the total costs and benefits.

Figure 6.3: Bar charts of costs vs. benefits per impact theme - LCCA

Figure 6.4: Bar charts of costs vs. benefits per impact theme - SCBA

Contributions of cost & benefit categories towards thematic totals

Two examples are provided that illustrate how the contributions of each cost and benefit category are reflected against their thematic totals in the tool.

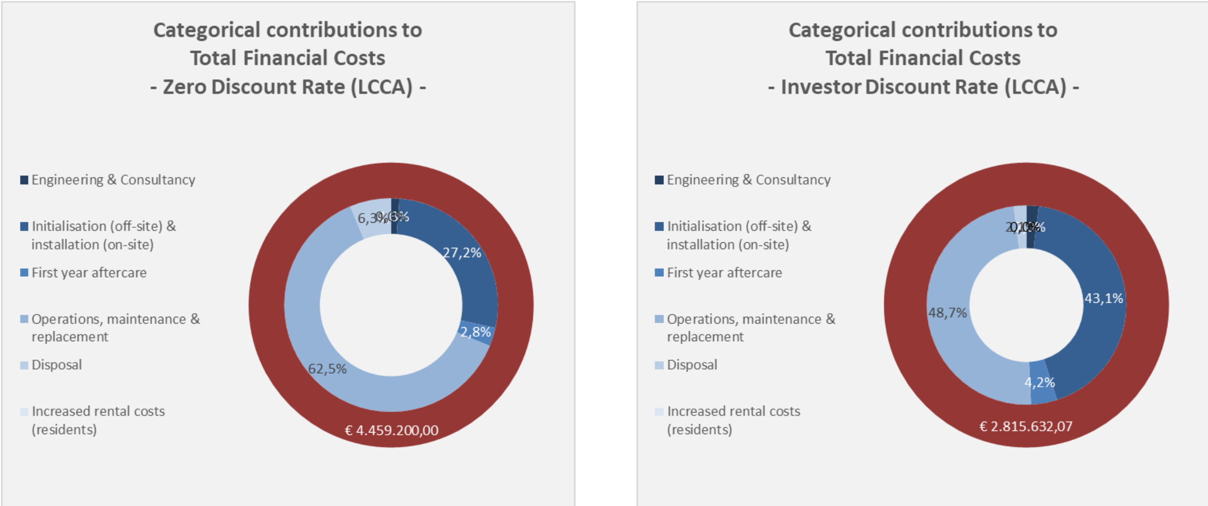


Figure 6.5: Pie chart of categorical contributions to total financial costs – LCCA

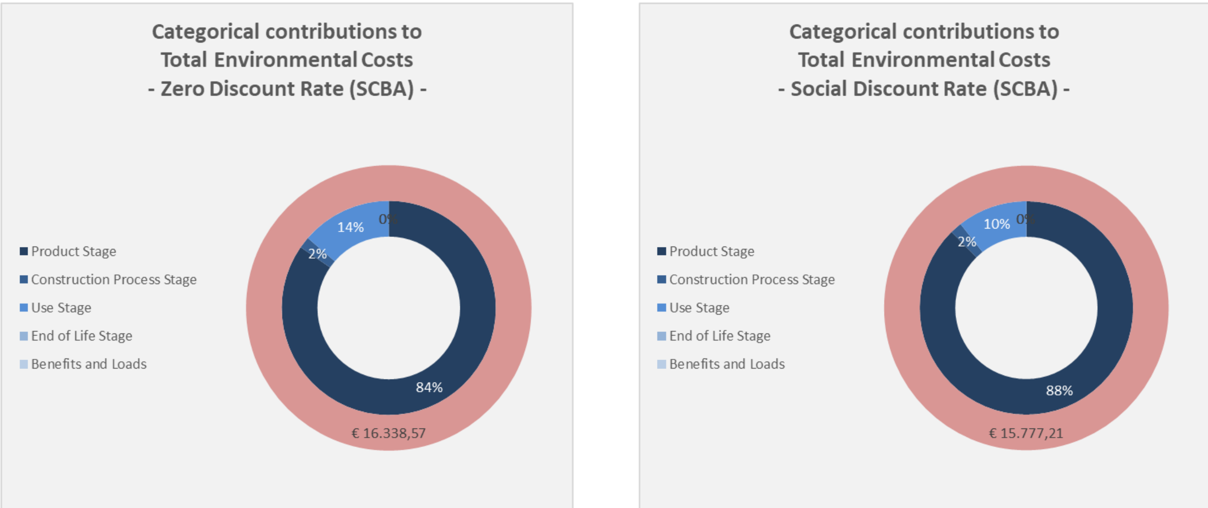


Figure 6.6: Pie chart of categorical contributions to total environmental costs – SCBA

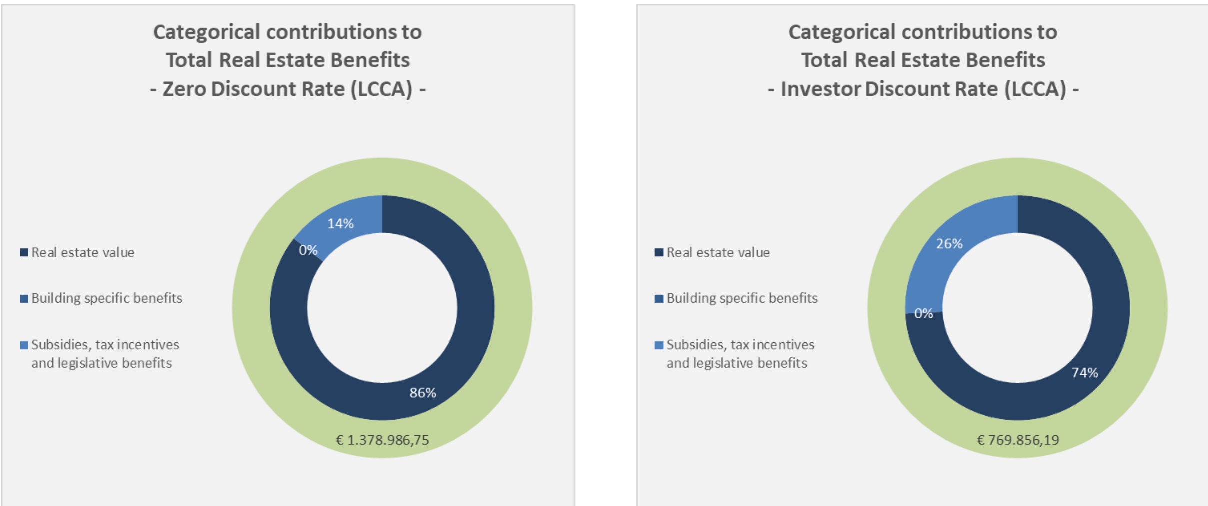


Figure 6.7: Pie chart of categorical contributions to total real estate benefits – LCCA

Contributions of cost & benefit categories towards thematic totals

In Table 6.4, the monetised values are provided for the cost and benefit indicators that were already quantitatively integrated in the tool. These values follow from application of the valuation methods as established in chapter 5. Note that the difference in value of rental costs for residents and income for investors follows from distinct discount rates for both analysis types.

Table 6.4: Case study results of monetised indicators

Themes	Item in tool	Quantified cost indicator	LCCA (PV investor)	SCBA (PV society)
Financial costs	1.	Total of engineering & consultancy category	€ 55.740,00	N/A
	2.	Total of initialisation & installation category	€ 1.212.345,00	N/A
	3.	Total of first year aftercare category	€ 119.028,13	N/A
	4.	Total of operations & maintenance & replacement category	€ 1.370.423,75	N/A
	5.	Total of disposal category	€ 58.095,20	N/A
	6.	Increased rental costs (residents)	N/A	€ 878.998,16
Environmental costs	1.	Total of product stage (A1-A3)	N/A	€ 13.823,68
	2.1	A4 – Transport	N/A	€ 282,10
	3.7	B7 – Operational water use	N/A	€ 1.671,43
Health & well-being	1.2.1	Reduction of healthcare costs due to deposition of Particulate Matter (PM10)	N/A	€ 12.562,09
Real estate	1.1	Increase of real estate value for the real estate investor/owner (increased rental incomes)	€ 571.282,44	N/A
	2.4	Reduced energy usage for building heating (in winter)	N/A	€ 75.666,79
	3.2	Tax incentives MIA	€ 156.768,75	N/A
	3.3	Tax incentives Vamil	€ 41.805,00	N/A

6.3.2 Interpretation and analysis of results

From the total analyses results as presented in Table 6.1, Table 6.2 and Table 6.3, it can be observed that at this moment in time, no positive NPVs are delivered for the case study. Hence, also the B/C-ratio stays below one, since there are more total costs than benefits.

It can be concluded that with the current input data and the so far monetised costs and benefits, it seems that no financial nor economical feasible VGS project can be initiated. In this case, the VGS implementation would not be beneficial for the real estate investor, nor is it beneficial for the residents (society as a whole). In both cases, especially the financial costs cannot be outweighed by benefits in any other theme.

Life cycle cost analysis (LCCA) - Investors

For the investors discount rate, the NPV equals -€2.045.775,88, with a corresponding B/C-ratio of 0,2734. Performing the same LCCA with a zero discount rate results in -€3.080.213,25 and a corresponding B/C-ratio of 0,3092 (see Table 6.1 and Table 6.2).

This difference in values is solely generated by the application of distinct discount rates. In the scenario where time value of money is disregarded (zero discount rate) and when only actual nominal cash flows are considered, a higher net loss would be incurred, yet the B/C-ratio results in a slightly higher value.

Due to the influence of time value of money, especially discounting the future values of financial maintenance costs and disposal costs causes a reduction of the total perceived costs. On the other hand, future rental income values are discounted to present value as well, meaning less benefit is perceived. Yet, because the absolute value of total maintenance and disposal costs is higher than the total absolute value of rental income, NPV increases (less negative). However, since the relative initial costs (around 30%) are higher than the relative initial benefits (14%), and these do not need discounting, this also results in the fact that the B/C-ratio slightly decreases. Namely, higher proportion of costs sustain their original value when there is discounted to PV as compared to the benefits. Figure 6.5 and Figure 6.7 visually illustrate this (expected) phenomenon.

Social costs-benefit analysis (SCBA) – Residents and society

For the social discount rate for ES valuation, the NPV equals to -€806.546,49, with a corresponding B/C-ratio of 0,0986. Performing the same SCBA with a zero discount rate results in -€1.078.268,36 and a corresponding B/C-ratio of 0,9090 (see Table 6.1 and Table 6.2).

The same logic applies here as for the LCCA. Due to application of a non-zero discount rate, future expenses (rental increase) will be revalued to a lower PV, while this is also the case for future benefits (deposition of PM_{10}, reduced energy usage for heating). Yet, since the future value of the costs comprise a higher value, in absolute terms their reduction to PV entails a greater number, hence the increase in NPV (less negative).

Since for the SCBA all costs and benefits that are monetised produce cash flows annually (from year 1-30), the B/C-ratio stays virtually the same between both discount rates. The marginal decrease for the social discount rate is due to the fact that for first year's benefits, only half of the calculated yearly indicator values is taken. This due to the assumption that modular LWS need 1 year for vegetation to mature, hence only half of the benefits is delivered in year 1. As a consequence of this, a slightly higher proportion of benefit cash flows occurs further into the future as compared to cost cash flows. This implies a marginal higher reduction for PV of benefits as compared to PV of costs, causing the limited effect of B/C-ratio reduction.

Incorrect representation of true benefit-cost ratio at this stage of development

It should be explicitly noted that these monetary analysis results give a distorted picture and do not represent the complete reality, in which there are many more benefits present that have not been made quantitative and are not expressed in monetary terms yet. Namely, the financial costs are fully integrated in monetary terms in the tool at this moment. Same goes for the environmental costs, although here the use stage and end of life stage are not yet considered with data. Yet, these depict a true guestimate of the total costs in both themes.

However, for the benefits merely the limited number of five indicators was monetised so far, hence the benefits are significantly undervalued in the tool. Qualitatively, they are incorporated and also most infrastructure for their quantification is modelled, yet they are not represented in the result tables or distribution graphs. Caution should therefore be raised, since no appropriate conclusions can be drawn from comparing or weighing the monetary terms of costs and benefits in the tool at this moment in time.

Furthermore, for the modular LWS that was proposed, input data was used and guestimates were established based on scientific review. Hence, the coherency and accuracy of the input values is not guaranteed. In order to verify the developed procedure in the tool for the several indicators that were modelled so far, data from different research papers and VGS were used. Future efforts should be made to use all correct input data from one specific VGS type, by gathering data from suppliers and manufacturers. Also, environmental data and inputs regarding indoor comfort levels or energy usage should be obtained. The difficulty or delicacy here lies in the fact that often times input data from suppliers is confidential, hence they are not eager to share this for public use and published research.

Ratio of financial costs and environmental costs

What can be concluded, it the significant contribution of financial costs to the total cost spectrum (98%). Environmental costs (from stage A1-A3, A4 and B7) only contribute for about 2% to the cost palette. This was expected beforehand, especially due to the high financial costs of the proposed VGS type for this thesis: the modular LWS. It should be noted though that replacement of the system components over the lifetime is not yet included in the environmental costs. It is expected the environmental costs will more or less double when these are added (due to 5% annual replacement rate of e.g. planter boxes and 10% annual rate for irrigation system and vegetation).

From Figure 6.5, it follows that the operation and maintenance costs (including replacement of components) over the lifetime have the highest contribution to the total financial costs. They outweigh the initialisation and installation costs and represent nearly half of the total financial costs. Of course, this was to be expected since this notion was already made in literature. The input results to verify the operations of the tool were retrieved from these research papers. The ratio between the costs corresponds to what was further discussed in the review papers, indicating the methodology incorporated in the tool is correct. The same applies for the environmental costs.

6.3.3 Discussion of results

Analysis methods and valuation methods

Methodologically and theoretically speaking, it might not have been necessary to distinguish between performing both a LCCA and SCBA. In hindsight, the execution of the SCBA would have been sufficient, whereas it is common practice to attribute effects (costs and benefits) to stakeholders. Therefore, the different costs and benefits could have been distributed after quantification and monetarisation in SCBA. Namely, a good SCBA does not solely quantify and present the total effects of a project, it also attributes their values to relevant actors (distributional aspect). Hence, the LCCA can also be considered a distributional aspect of SCBA towards the real estate investor. Yet, the methodological differentiation into both analyses types did allow for discounted cash flow analysis with distinct discount rates, which relate better to their perception of the future costs and benefits.

The valuation method for monetisation of reduced healthcare costs due to deposition of PM_{10} is based on an established method governing for horizontal greening and green roofs (Does et al., 2019). In this, a linear relation between population density and the value for PM_{10} was used that was indexed for inflation until 2018. Namely, Remme, de Nijs, and Paulin (2018) argued that external costs of PM_{10} should rise whenever population density increases, since PM_{10} concentrations affect every inhabitant in a living environment. Therefore, they accounted for population distribution in the PM_{10} value formula by extrapolating the external costs of PM_{10} as provided in 'Milieuprijzen 2017' (CE-Delft) by de Bruyn et al. (2018). In order to ensure case specific results for the tool, this is something to take away for other valuation methods that are to be integrated in the future.

Assumptions

No values for indexation of monetary terms have been considered, since for monetary values predominantly guestimates were established based on literature review.

A main assumption for this work was that biodiversity as priority for functioning ecosystems and provision of ES was met. Yet, so far there is not distinguished in values for different levels of biodiversity in the surroundings, although higher biodiversity levels imply higher potential for delivering ES and corresponding benefits. This relation should be further investigated in future efforts.

The applied discount rates have a major impact on the results, since long term costs and benefits are discounted heavily to assess the PV. Therefore, correct implementation of an adequate discount rate should have priority, as its effects are larger than some total values of other indicators. For SCBA involving nature or climate change (with long time horizons), lower discount rates are proposed than for financial decision-making by investors or companies. Otherwise, future costs and benefits could seem negligible due to severe discounting. This could create the impression that those long term future benefits do not matter as compared to the (high) initial costs. For these subjects (nature and climate change), high costs today might prevent for even larger costs or loss of benefits in the future. But if one would discount with a high rate, it could seem that those future costs aren't a big deal while today's costs are. To fix this, the lower discount rate for SCBA was proposed (2% real discount rate) according to Dutch standards for monetisation of nature (Koetse et al., 2017). In the LCCA, a higher investor discount rate was still applied (5,4% real discount rate). It should be evaluated whether this diversification is appropriate, however the author of this work believes this distinction in discount rate (for different methodologies) adequately represents the stakeholder's perceived values of costs and benefits.

Data availability and robustness for VGS

Note that some indicator specific data for value calculations was linked to the choice for Modular LWS, meaning it was collected during the literature review stage of the researcher. Unfortunately, due to the innovative nature of LWS research and its relatively limited content (Rowe et al., 2022), not all information is available with data specifically governing for the Netherlands. Hence, some research papers are used that apply to VGS and cases in Southern Europe or other parts of the world. Although the indicators that are currently quantitatively included in the tool do not depend on climatic conditions specifically, it should be noted that in future efforts it would be appropriate to select and use papers that apply to the region of interest (Figure 6.8). This also applies with regards to e.g. real estate values.

Monitoring and documenting data related to identified impacts of different types of VGS should occur, in order to improve the input values for targeted VGS. Namely, this would allow distinct inputs for different VGS types in the tool, widening its scope beyond a modular LWS and making it applicable to specific product types of manufacturers, rather than the aggregated VGS category of modular LWS.

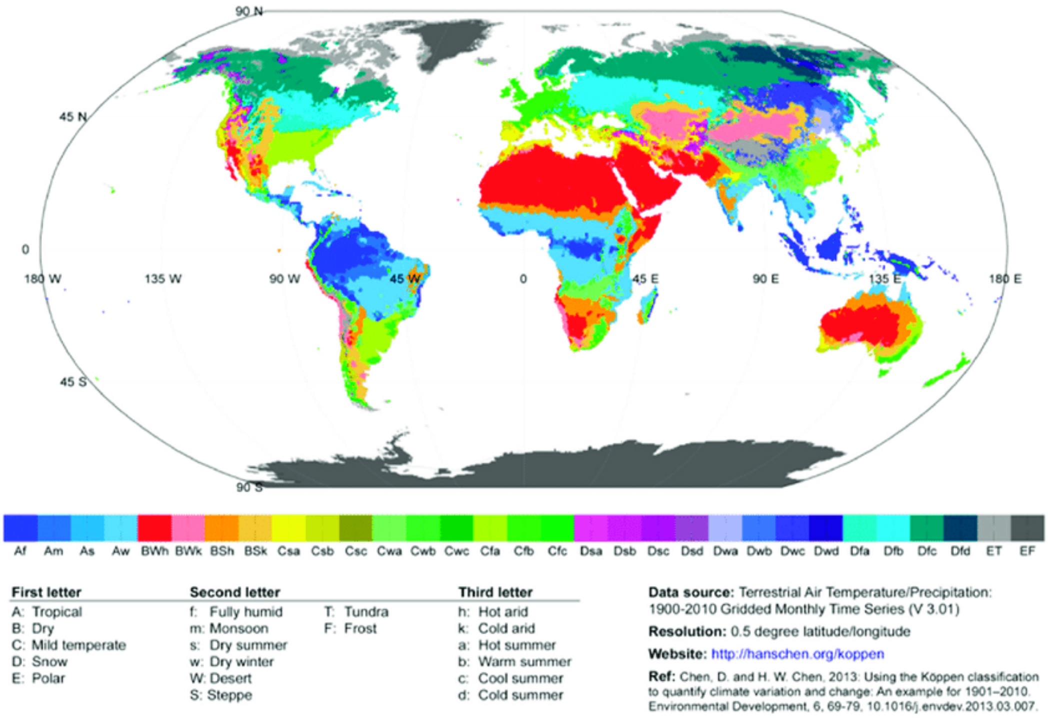


Figure 6.8: Worldwide climate zones based on climate classification of Köppen-Geiger (Rahman, Salam, Shaari, & Ramli, 2019)

Climatic conditions of VGS research

A growing amount of scientific literature on VGS includes studies from all over the world. Nevertheless, for example VGS impact on heating, ventilation and air cooling (HVAC) is still not well understood (Bustami et al., 2018). For certain value indicators like these, the climatic conditions in which the VGS is situated have influence on the indicator effectiveness. Pérez, Coma, Martorell, and Cabeza (2014) therefore recommended that VGS research would be classified according to the Köppen-Geiger climate classification (Figure 6.8), based on average annual and monthly temperature and rainfall in order to make better comparisons between systems.

Therefore, studies carried out in the green regions (Cfb) of Figure 6.8 are assumed to be representative for the Dutch climate, hence for the input data of the valuation model. When other studies are used, this should be addressed and well documented. Nowadays, according to Bustami et al. (2018), especially a lot of research publications are found in hot Mediterranean countries in southern Europe (e.g. Italy and Spain), although the Netherlands follow in fourth place.

Relations between value indicators

The valuation methods for value indicators mostly follow from scientific theories and previously conducted valuation studies. Hence, identification of established methods underpins the model. Due to the diversity of indicators that are to be monetised in the framework, undoubtedly some perceived values (perhaps from different themes or stakeholders) will go against each other or clash, at least counter one another. Hence it will not be possible to maximise all values for each stakeholder or in each theme, since certain boundary conditions apply or contextual factors are governing.

This is for instance the case for increased rental costs for residents and increased rental income for the real estate investor. Therefore, the tool is regarded more of a balancing mechanism that relates and deliberately compares indicators and stakeholders to each other, rather than a maximisation medium for all value indicators.

For the future recommendation of including the level of biodiversity as an input variable, a strong relation with benefit indicators is foreseen. The higher the level of biodiversity, the higher the potential for ES delivery and the higher the value of benefits that can be obtained. Yet, as is illustrated in the framework, biodiversity in itself can also be an output value of VGS integration.

7
Validation

7.1 Introduction

An important step in the development of the VGS Valuation Framework and Tool is to assess the validity of the work. Validation would ensure that the framework and tool provide users with sound and valid results, meaning the outcomes generated with this thesis can be applied in real-life projects in the future.

The elaboration of the case study and its results in chapter 6 have provided an initial outlook into the basic functionality and results generated by the VGS Valuation Tool. These results and values are strongly dependent on numbers obtained/assumed from available literature and studies. However monetization of the costs and benefits is still no exact science, but rather economic and social science. Hence, a definitive answer regarding good or wrong for these values is hard to give.

What can be verified and validated though, is the soundness and correct use of the methodologies applied in the framework and tool. Also, validation of the practical value, user experience and intuitiveness by anticipated users is needed. In order to validate the proposed framework and tool and confirm their reliability, a twofold approach was employed.

First, the framework and tool were presented to experts in the field of VGS. This step aims at generating overall recommendations and corrections to the executed work, based on the profound knowledge of these experts. Also, the experts could give their judgement regarding the relevance of the research, as well as the functionality of the tool. Comments for improvements are considered and processed, either directly in the framework and tool or in the future outlook of this work (section 9.3).

Secondly, a user experiment was initiated among a targeted group of participants (8), working in environmental and climate adaptation consultancy, urban planning, ecology or otherwise related to the field of VGS. By working through a case study, the test panel should provide substantive input and feedback regarding the developed tool. This too should test and validate the tool's soundness and whether the utilization perspective, as mentioned in the first research gap (section 1.2), is accounted for and satisfied. Furthermore, the test panel could analyse whether the tool is applicable in future projects and what the practical value of the VGS Valuation Tool is.

Lastly, section 7.4 offers the conclusion for Part III, answering the third research question.

7.2 Expert judgement

In order to validate the framework design and the tool developed during this research, the judgement of experts was requested. Therefore, Dr.ir. Marc Ottelé (Delft University of Technology), whose research expertise is in the upcoming scientific field of sustainable building envelopes, and Mark Rotteveel (Ambassador for a liveable city and project advisor at Koninklijke Ginkel Groep) were approached and consulted to share critical thoughts based on their experience and expert knowledge.

7.2.1 Tool and thematization

During constructive conversations with experts in this field of study (Marc Ottelé, 2022; Rotteveel, 2022; Sweco expert knowledge, 2022), the proposed VGS Valuation Tool and corresponding thematization was presented (and validated). Besides the TEEB-Stadtool (Does et al., 2019), which was the main source for the current thematization, studies by Costanza (2008) and Fisher et al. (2009) elaborated the backgrounds for this classification, while CAS (2022) and the Victoria University and University of Melbourne (2018) illustrated similar themes in their works.

Ottelé complimented the comprehensive and integral approach for the tool and acknowledged that a functioning mechanism like this is still a missing link, which can provide great new insights with regards to VGS valuation. Furthermore, separately from each other, both Marc Ottelé (2022) and Rotteveel (2022) supported the categorisation into the cost themes and the 5 main benefit themes: health & well-being, climate adaptation & mitigation, real estate, recreational & social & commercial and biodiversity. They stated that these were recurring themes in scientific studies and projects in the field of VGS, NBS and urban planning, and that these touch upon urgent issues at play in contemporary society.

Also, aside from expansion of current scientific knowledge, the objective for the tool is to inform decision-makers in real estate companies or politics (usually laymen in this scientific field) and to engage with other stakeholders, where the tool acts as a conversational mechanism. Especially with the proposed objective and the target group in mind, compilation of the distinct benefits of VGS into these themes (to which they can relate and which capture their imagination) can help to meet this goal, rather than a classification into the abstract and more complex ES (Marc Ottelé, 2022; Rotteveel, 2022). Hereby, it should be noted that the proposed thematization is one way of classifying and aggregating the benefits delivered, and not necessarily the only correct way (Fisher et al., 2009).

7.3 User experiment

As discussed in the introduction of this chapter, a user experiment was initiated in order to validate the practical value, user experience and intuitiveness by anticipated users (consultants). Therefore, a targeted group of eight participants was compiled, consisting of Sweco employees working in environmental and climate consultancy, ecology and urban planning, as well as other experts in the field of VGS. This should provide substantive input and feedback regarding the developed tool, testing and validating its soundness and whether the utilization perspective is accounted for and satisfied. The lack of focus on utilization perspective in Ecosystem Services Valuation for decision-making was a key element in the first research gap (section 1.2).

The practical value of the VGS Valuation Tool should be in the equipment of consultants (or clients) with a straightforward method, which values the costs and benefits relating to implementation of VGS on building projects. Hence, exploration and interpretation of these costs and benefits per different VGS, location, or stakeholder perspective should be made possible in the future. This would enable a rational guidance by consultants for decision makers, to generate insights and make substantiated choices regarding implementation of VGS in the urban fabric.

7.3.1 Experiment setup

The test panel was invited to attend a digital meeting via MS Teams at a given date and time that was scheduled several weeks in advance. Before the meeting, they also received all necessary documents via email. These include a 'blank' VGS Valuation Tool, a user manual and a link to a digital questionnaire (Google Forms). In total the test panel consisted of 8 participants.

For this meeting, an agenda was applicable like displayed in the steps below, leading the participants through the experiment:

1. Plenary introduction of research, experiment and case study
2. Individually testing of valuation model according to manual
3. Individually filling in the questionnaire
4. Submission of results
5. Plenary reflection

Since the majority of the participants were not familiar with the thesis work, first the research, the experiment and a case study which should be performed were briefly introduced in the digital meeting. The case study was the same as the one that was used by the researcher in order to develop the valuation model (see chapter 6). Providing the test panel with the same case as performed by the researcher, the generated results could indicate whether the panel inserted the input in a correct way. Hence, if the results match with those of the researcher, this would indicate a certain (sufficient) level of intuitiveness and understanding of the model proceedings.

In order to test the tool, a user manual was created which should lead the test panel through the valuation process in the digital model prototype file. After the introduction, the participants were asked to work through this user manual individually. This guide was also equipped with the basic assumptions and some general input which should be inserted in the tool. The manual is attached to this thesis work in Appendix G.

Alongside the manual for the case study, a digital questionnaire was distributed among the participants, allowing them to denote and formulate feedback regarding user experience, intuitiveness, display of obtained results and perceived practical future value of the tool. Here, several feedback questions were asked and also the opportunity was given to provide additional feedback. In the multiple choice questions a ten-point grading system was used ranging from 1 to 10, allowing for precise judgement. Since this grading system has an even number of options, no neutral middle option can be chosen. This forces the respondents to lean towards either one of the extremes, avoiding safe neutral choices. For this questionnaire, reference is made to Appendix G as well.

When the participants had finished the experiment and they had generated outcomes in the valuation model, they were asked to transmit their results to the researcher. The results of the valuation sequence were transferred by email and the ‘Google Forms’ questionnaire could be submitted digitally as well. Based on the generated outcomes by the participants and their feedback in the questionnaire, the researcher should be able to draw some conclusions. These are elaborated in the adjacent sections.

A short plenary reflection with the panel concluded the experiment and digital meeting. Here, participants could give some general remarks and a podium for a joint discussion was created.

The fact that this experiment was the first introduction of the tool to the consultants, made that the experiment was designed to be relatively compact and conceptual. The main intention of this user validation session was not to determine whether the calculated values for the indicators are quantitatively and substantively correct, but to gather information on the user experience. This implies that no abundance of input values was given, hence preventing an information overload. Consultants will become more familiar with the proceedings of all input parameters when they are to actually use the tool for real life projects.
Therefore, an important note for the user guide was that the presented model was only a prototype of what in the future could become a complete and comprehensive valuation tool. Clearly, this tool would contain calculations of costs and benefits in all themes that are given. With this in mind, feedback was mainly requested about the general valuation framework, setup and lay-out of the tool, future practical value and user experience. Further development of the model with multiple value indicators will remain work in progress, but also recommendations for future research and tool extensions were established. This could be conducted and continued after completion of the current study. In order to obtain scientifically sustained and monetized values for these indicators, a deep-dive into the specific value indicators and all their belonging input parameters is necessary. For more information regarding these recommendations, reference is made to section 9.3.

7.3.2 Experiment results

The experiment resulted in the submission of 8 completed Excel files of the VGS Valuation Tool. In these files, each of the participants filled the requested blanks in the model by insertion of the provided variables. The results obtained by the test panel matched those of the researcher. Also a second check into the inserted variables led to matches, meaning the participants had correctly filled in all requested parameters. This gives a first indication that the tool is clear and convenient to use and fill in.

Furthermore, important feedback and results were obtained through the questionnaire. For a complete overview of the questionnaire outcomes, reference is made to Appendix G. There, all responses to the questions (both grades and explanations) are gathered and the average grades are calculated per question. The average grades per question are also presented in Table 7.1.

Table 7.1: Average grade for each question in the questionnaire

Question Nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Average grade	7.9	7.5	7.9	8.5	8.5	9.1	8.1	7.0	-	9.0	7.0	-	8.1	8.4	-	-	-

From the table above, it can be observed that all average grades range between 7.0 and 9.1 out of 10. These high grades imply that the respondents gave positive responses to the questions asked, since a score of 10 entailed ‘very good’, ‘very high value’, ‘comprehensive’, etc. Also in the open questions, responses were predominantly positive with some points of constructive criticism or suggestions for improvement. For most respondents, the feedback points had the same angle or aim. These are elaborated and taken into consideration in the following paragraphs.

Overall composition and structure of the framework and tool

Firstly, the panel was requested to give their opinions on the overall composition and structure of the VGS Valuation Tool. Generally, participants expressed their interest and enthusiasm regarding the tool. Also, consultants could relate to the thematic and categorical classification that was adopted throughout the tool. Further, their feedback indicated that the naming, numbering and colour coding provided insight and clarity on how to use the tool.

For further development, some specific feedback based on the user experience was provided. In case the tool is to be used by other people as well, e.g. a client or policy-maker (hence, not solely by a consultant who knows how to operate it), they suggested to shorten the user guide and introduction text. Also, they recommended to revaluate on where to place these tabs in the tool. Finally, it was recommended to eliminate the extra columns in between the description of the data and the data itself.

User experience, intuitiveness and accessibility

In addition, participants were asked to assess user experience (ease of use), intuitiveness and accessibility of the tool. All three were rated predominantly positive by the participants. The participants stated that for the target group, i.e. trained consultants, the tool would be intuitive to use. For first time users it could be overwhelming though, since the tool contains a lot of information. In addition, one suggestion would be to add a glossary to the tool. In this manner, potential doubt about the meaning of abbreviations can be avoided. Furthermore, ease of use was positively assessed because of, among other things, the lock on several cells, which helps the user to find the relevant input cells.

Furthermore, the participants were asked about the accessibility of the tool (being developed in Excel). Answers were rather divided; according to some, basic knowledge of Excel would be sufficient, others thought it would be difficult for certain individuals who have only basic knowledge of Excel. In the plenary discussion it was concluded that for the most predominant anticipated users (i.e. consultants), the tool would be accessible in its current form. A suggestion for future development would be to divide the tool into a front- and backend version. The consultant would have access to the backend, which contains all background information (the current tool). A client would only see a simplistic ‘frontend’ version, containing data input and final results. This ‘frontend’ version could be described as a light version of the tool. In addition, this ‘light’ version could be transformed into a web application to further enhance accessibility and share (project) information. Furthermore, a quick and easy to read print-out or summary report as output of the valuation sequence would make it valuable for multiple organisations.

Scientific and practical value

Looking more into the substantive part of the questionnaire results, in general the consultants stated that the tool was highly promising. They were impressed by the substantiation of scientific information in the tool. Since at the time of the experiment the result dashboard was not completely finished yet, it was a bit tricky and cumbersome to interpret the results correctly. Therefore, some participants experienced difficulties in assessing the final outcomes of the tool. An important improvement would be to visualize the results in the tool. This recommendation was acknowledged by the researcher and the proposed result visualisation were implemented in order to provide a clearer overview and generate more valuable insights.

With regards to the practical value of the tool, the test panel unanimously agreed on the high applicability of the tool for consultants. Additionally, they expressed a high anticipated future value of the tool. It was stated that the tool has the ability to produce extensive output with only little input. Points of improvement referred primarily to the final advice for the client. A future recommendation was to expand the results of the tool with more elaborate outcomes. This could help consultants to offer the best advice to clients. As mentioned earlier, this recommendation has been implemented.

Completeness, comprehensiveness and generation of new insights

When asked to assess the completeness and comprehensiveness of the tool, all participants agreed that the tool looked very comprehensive and elaborate. One of the participants highlighted the importance of direct and indirect damage reduction of climate risks, but acknowledged that these were already partially included (as placeholders) and could be elaborated in future research. Besides that, all the others stressed that the topics in the tool were complete, very comprehensive and would provide elaborate insights of the costs and benefits of VGS. The fact that results were to be location specific rather than generic increased the value of the outcomes of the tool. Moreover, insights into environmental or social costs and benefits are often not considered (sufficiently) by real estate parties. The integration of these are considered to be a powerful and innovative aspect of the tool. To conclude, the consultants indicated that the tool is comprehensive with regards to the included topics and it has great potential to provide themselves and others with new insights. This enables them and their clients to draw scientifically substantiated conclusions.

The anticipated comprehensiveness was also mentioned as main motivation for the participants to recommend the tool to others. It was acknowledged that trade-offs based on cost-effectiveness in this field are scarce but highly important. The tool could help to gain quantitative insights on aspects that would otherwise probably not have been accounted for.

Discovered bugs and time limit

No bugs, notable mistakes or glitches in the tool were discovered by the test panel. Overall, the time limit of 30 minutes was regarded sufficient to read through the tool's introduction and insert the provided variables, however more time was requested to gain a more thorough understanding of all processes behind the tool.

7.3.3 Experiment conclusions

Overall, the high grades and their accompanying feedback imply that the respondents look favourably upon the VGS Valuation Tool. The overall composition and structure was perceived positively due to the tool's classification, naming, numbering and colour coding. This provided insight and clarity on how to use the tool.

In addition, the user experience (ease of use), intuitiveness and accessibility of the tool were rated predominantly positive by the participants. One suggestion for future research would be to develop a 'light' version of the tool which could be transformed into a web application, to further enhance accessibility and share (project) information.

Moreover, participants thought the tool was promising and they were impressed with the substantiation of scientific information in the tool. Also the high practical and future value of the tool was agreed upon. It was stated that the tool has the ability to produce extensive output with only little input. However, in order to provide a clear overview of the results an improvement would be to visualize the results in the tool. This could help consultants to offer the best advice to clients. This recommendation was acknowledged by the researcher and thus implemented in the tool.

Further, all the experts agreed upon the completeness and high comprehensiveness of the topics in the tool. Only the expansion of direct and indirect damage reduction with regards to climate risks was mentioned to be considered for future research. Positively received and noted as powerful, was the fact that the results would be location-specific rather than generic. Same goes for the insights into environmental or social costs and benefits as these are often omitted.

Given the points above, it could be concluded that the experiment resulted in predominantly positive outcomes. The participants expressed their support and indicated that the tool is all-encompassing, has great future potential and could provide consultants with new insights to help their clients draw scientifically based conclusions.

7.3.4 Discussion and evaluation of test methodology

The test experiment has generated some valuable results (section 7.3.2) and insights into the functioning of the VGS valuation tool as perceived by potential users. This section reflects on some of the proceedings and choices made in order to conduct the user experiment, as well as on what their potential effects might have been on the outcomes.

With 8 participants the experiment was performed on a relatively small scale. The preferred number of participants in the test was already discussed with the thesis committee prior to its execution, resulting in a minimum demand of 5 people. This number was mainly based on the scope of validation, time limitations of the research and desired feedback subjects. In correspondence to the paper "Usability Engineering at a Discount", Nielsen (2012), who holds a Ph.D. in human–computer interaction, argues that 5 participants are sufficient for testing usability problems in a digital tool. Five people usually allow the researcher to find 85% of the usability problems and get close to a maximum benefit-cost ratio for user testing, while a test pool of 15 will result in finding 99% of relevant issues (Figure 7.1). Hence, 8 participants for the user experiment in this phase of the digital tool should results in a rather complete overview of problems and feedback. Therefore this is regarded as representative and sufficient.

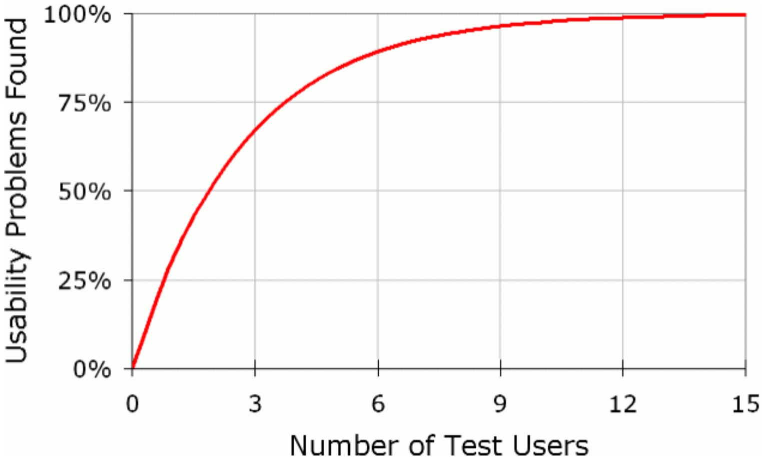


Figure 7.1: Usability problems found vs. number of test users (Nielsen, 2000)

Like elaborated in section 7.3.1, the method of testing consisted of a digital MS Teams meeting in which an introductory part was plenary explained, whereas the actual testing of the tool and filling of the questionnaire was carried out on an individual basis. The participants were not physically in the same room so they could not cooperate or help each other offline, however they were allowed to pose potential questions to the researcher. The researcher was present in the digital meeting during the entire duration of the experiment.

The reasoning behind this methodology was predominantly of pragmatic and practical nature. This had several benefits as compared to e.g. a live meeting at a given location, or a fully remote experiment where the invitees would conduct the proceedings at any random moment suiting their agendas. The most important considerations (pros and cons), as well as potential influence or limitations of the methodology on the experiment results, are listed below:

- Since a collective meeting was scheduled, the non-committal nature of the experiment was mitigated, ensuring that those who were attending finished the test in one go. The official nature of the meeting constituted that they were less distracted and would not find refuge in other matters during the validation session. There is certainty in delivery of results. However, participants might want more time for the experiment than provided during the session.

- The researcher was in control of schedule and timing. The timeframe in which the participants would test the tool was scheduled several weeks in advance in order to ensure sufficient attendees. Moreover all feedback and results are delivered within one meeting, providing certainty to the researcher.
- A digital MS Teams meeting was preferred over a physical meeting, since this offered flexibility as to the location from where the participants would take part in the user experiment. This also meant that the participants were not in the same room while working on the test experiment, ensuring the results and responses were their individual effort and opinion.
- The researcher could witness the participants while working on the user experiment, observing their expressions and facilitating that questions could be asked via chat or audio in case of any ambiguities. Furthermore he could guide the attendees through the test session, ensuring no steps were missed and all tasks were completed. When the experiment would be executed remotely on an individual basis, there would be more distance to share all the information about experiences. The plenary reflection facilitated in direct feedback, aside from the questionnaire. Hence, the digital meeting allowed presence of the researcher, yet ensured his distance to prevent influencing participants.
- A fixed time for the execution of the experiment might reduce the number of participants in the user experiment due to overlap or clashes in agendas, as it limits flexibility. This would not be the case when respondents could test the tool and fill the questionnaire during their own preferred time. However, given the number of attendees and the reasoning provided in accordance with Figure 7.1, this was not an issue in the current research. For this research, it's therefore concluded that the fixed date and time did not impose a significant negative effect on the obtained experiment results.
- The 'Google Forms' format for the questionnaire allowed the participants to deliver their feedback and answers anonymously. This can result in more open feedback and prevents respondents to mince their words or choose responses they believe are more socially desirable. This is also known as social desirability bias (Grimm, 2010). Thus, stage is given to speak out plainly and in all honesty.
- The test panel predominantly consisted of experts in the field of VGS, ecology, climate adaptation services and environmental consultancy. Most invitees for the user experiment were acquainted to the researcher since they were peers at Sweco. Therefore, their willingness to cooperate might be higher as compared to when this was not the case. However, care must be taken to ensure that feedback towards the tool remains objective.
- The composition of the test panel also entailed that the personal validation effect, also known as subjective validation, might occur. In psychology, this is a cognitive bias that affects an individual's opinion. It allows them to consider a statement or another piece of information correct if it has any significance or personal meaning to them. The test panel is not completely independent and might benefit from the use of the research and tool in their work. This could result in the outcome of the experiment to be brighter it actually should be, due to a positive bias. However, in order to validate the VGS Valuation Tool, feedback from anticipated end users enriches the research.
- For the plenary discussion at the end of the session, although every one of the participants had their say and made valuable contributions, this discussion might have been even more open if this was held during a live session. However, with people thinking out loud it still ensured that participants could directly comment on the tool and the validation session. Furthermore, it gave insights into each other's opinions, paving the way for further discussions after the session.
- Feedback from the test panel stated that it was an advantage for providing feedback that the situation was created in which the participants had to perform in a case study. This made it feel like they had to use the tool for consultancy work, hence they engaged fully into the experiment. Provision of all relevant input parameters by the researcher made it a bit easier, but the impression was that this did not influence the outcomes of the experiment.

Weighing the aforementioned considerations, it was concluded that the followed methodology (section 7.3.1) was a valid and adequate strategy for the validation in the user experiment. Although the way of conducting the experiment might have had some minor implications on the results, this will be the case for any methodological choice made. Also the participants themselves acknowledged that the method of testing did not influence their responses. Furthermore they did not experience any events that might have had significant impact on the results obtained from the session.

7.4 Conclusion Part III – Simulation phase

In the simulation phase, the framework and VGS Valuation Tool were demonstrated using a case study which suited the main conditions to consider implementation of VGS. The simulation provides insight into how the tool should be operated, and what results can be generated by using it. This also verified the current version of the tool on a technical level: it can operate as intended and no crashes or errors were encountered. Recommended future efforts were identified and will be further elaborated in section 9.3. Furthermore, the framework and tool were validated during discussions with experts and through a user experiment. This simulation phase formed the basis for answering the third sub-question of the research:

"Based on a case study, what results can be obtained from the developed economic valuation tool and how can these results be interpreted?"

In order to tackle the biggest obstacles in the tool and test whether the developed VGS Valuation Tool could produce sound results, a case study was conducted. The elaboration of this case study provides an outlook into the basic functionality, intended operation and generated results by the framework and tool. The case study that was selected in collaboration with Sweco and the client company provided the necessary project specific grip for input data for the tool. For a basic understanding and insight into the input values, reference is made to appendix F.

The results section of the tool provides the user with a total analyses results table. Furthermore, the result dashboard generates graphical visualisations of the contributions of different themes and categories towards the total costs and benefits of VGS, by means of charts and graphs. Indicators for economic and financial feasibility are the Net Present Value (NPV) and Benefit-Cost ratio (B/C-ratio). With this, consultants can provide more substantiated advice to clients who are interested in adopting green measures for real estate objects. The results displayed in the dashboard are retrieved from the cost and benefit sections, which are inserted at the back-end of the tool to perform the actual calculations and provide methodological transparency. Here, values per indicator can be found as well.

The current version of the tool is able to perform quantification and monetisation for financial costs, large parts of the environmental costs, reduction of airborne PM_{10}, increased rental incomes (investors) and costs (residents), reduced energy usage for heating and MIA & Vamil tax incentives. Based on implemented valuation methods, the case study delivers project specific results. It is explicitly noted that these results do not yet provide a complete representation of all costs and benefits, due to the limited (benefit) indicators that are monetised. Hence, this version of the tool should be regarded as initial impetus for further development, in order to ultimately obtain an all-encompassing VGS Valuation Tool, fit for project specific economic valuation of costs and benefits of VGS.

Nevertheless, the tool generated a NPV of -€2.045.775,88 with a corresponding B/C-ratio of 0,2734 for the LCCA and investor's discount rate. For the SCBA with social discount rate, the NPV equalled to -€806.546,49, with a corresponding B/C-ratio of 0,0986. The lower B/C-ratio for residents or society at large as compared to the one for investors seems contradictory, but is explained since most benefits for society still are to be incorporated in the tool. Recommendations and outlines are proposed in order to facilitate future research in section 9.3.

Through validation of the framework by experts and the functionality of the tool via a user experiment, recognition was acquired that the valuation framework was grounded on solid foundations and the tool has high anticipated future value. VGS experts acknowledged that a functioning mechanism like the developed tool is still a missing link in their field, which can provide great new insights with regards to VGS valuation. Supporting the literature review performed by the author, the general structure and thematization were deemed fit-for-purpose: to inform decision-makers in real estate companies or politics and to engage with other stakeholders, where the tool acts as a conversational mechanism.

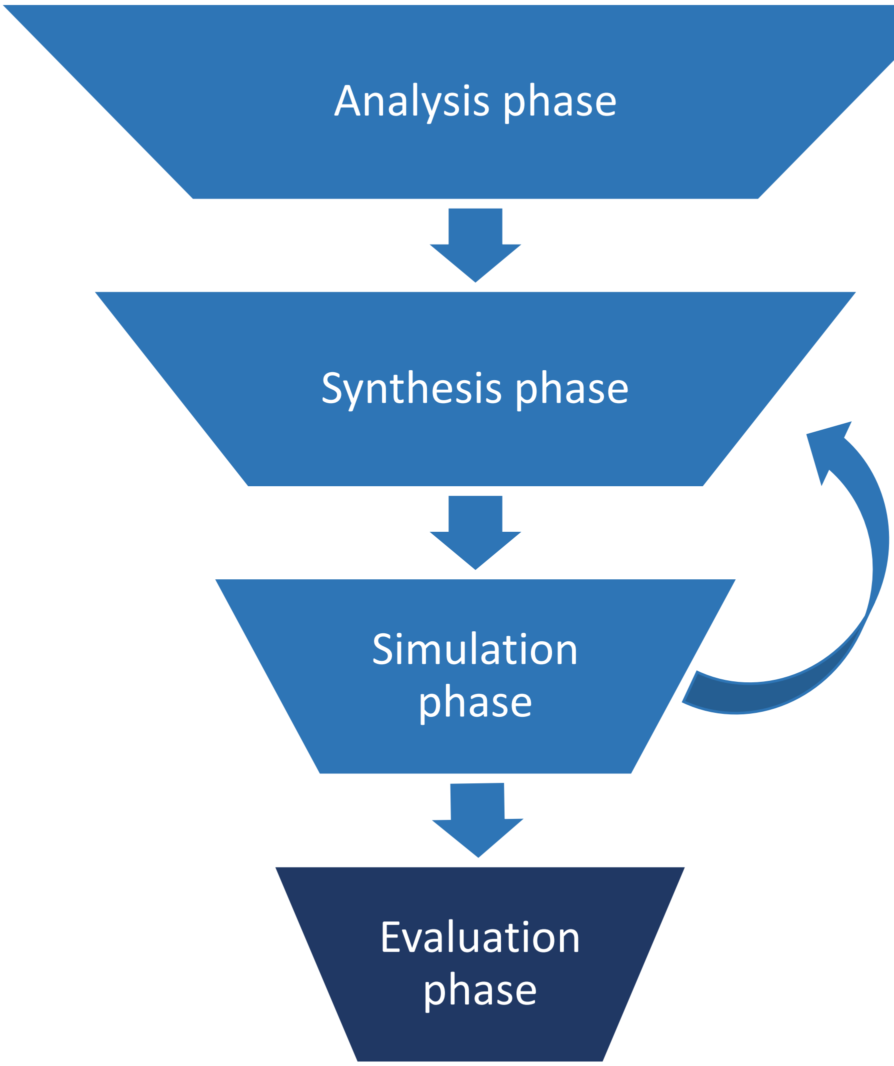
Consultants that engaged in the user-experiment for the tool reacted positively on its contents. High feedback grades were obtained for tool composition and structure, user experience, intuitiveness, accessibility and comprehensiveness. Furthermore, participants were impressed with substantiation of scientific information, while not compromising the foreseen practical value in projects. Furthermore, high future potential is foreseen for the time when the tool is even more extensively developed, robust and tested on several distinct cases. This would most certainly facilitate adequate and rational consultancy and decision-making based on facts and substantive figures.

In conclusion, the contemporary project specific results that can be obtained with the tool are not to be regarded as final values of costs and benefits of VGS. Further implementation of predominantly benefit indicators would probably enhance the NPV and B/C-ratio for the specific project. Integration of input parameters for other VGS would naturally provide different NPV and B/C-ratio as well. The tool as developed during this thesis should be regarded as initial impetus for further development, in order to ultimately obtain an all-encompassing VGS Valuation Tool.

Part IV

-

Reflective



8

Discussion

8.1 Introduction

This chapter provides the discussion of this research. First, some remarks regarding data collection and results in this phase of development is given. Hereafter, the relevance and implications of the framework and tool to science and society are elaborated. The chapter concludes by showcasing some limitations and shortcomings of the research and the tool in its current form. These will serve as further inspiration for the recommendations for future research in chapter 9.3.
Combined, the findings as described in this discussion form an answer to sub-question 4.

"How can the final product be put into its context, given its relation and contribution to the current level of scientific knowledge and society as a whole?"

8.2 Relevance and implications of framework and tool to science and society

8.2.1 Framework and tool for academia

Considering the problem statement in the beginning of this process, the present research provides a framework to help fill this gap. Firstly, the lack of comprehensive aggregation of scientific content and knowledge regarding VGS's benefits, economic valuation and implementation was one of the hampering factors of more widespread acceptance. Secondly, existing studies do not attribute values of perceived costs and benefits related to VGS to different stakeholder groups. Therefore, valuation proved to be one-sided, focussing merely on the costs for funding parties and potential direct financial revenues that follow. In addition, an all-encompassing and integral mechanism that could interactively inform on the multiple, project specific value perspectives of a given VGS was lacking in the scientific field (Marc Ottelé, 2022), hampering the inclusive analysis in a single method.

Through the establishment of the presented framework and tool, guidance is offered for a more standardised way of comprehensive VGS valuation in the future. The framework is based on theoretical concepts like the ESC framework and the method for Integrated Valuation, accompanied by previous conducted valuation studies for VGS. The full perspective of financial, environmental and social costs and benefits is covered, with indicators to quantify and eventually monetise these values being clearly distributed among the proposed impact themes. Furthermore, distinct analysis methods (LCCA and SCBA) allowed for attribution of costs and benefits over relevant stakeholders, also accounting for potential differences in perceived value for certain indicators.

In its current level of development, the framework offers a standardised approach to economic valuation of distinct indicators. By defining, documenting and integrating required input variables in the tool, practitioners are enabled to perform fit-for-purpose economic valuation based on inserting (where possible) publicly available data. This in order to inform and consult different interested parties that relate to VGS implementation, justify decision-making based on substantive research and potentially promote a more widespread awareness or acceptance of these systems.

Researchers in the field of VGS are invited to assess and evaluate this established framework and tool and encouraged to append additional valuation methods for indicators that are yet only qualitatively incorporated. For this, it is recommended to initiate multi- and interdisciplinary research with scientists from theme specific fields, for instance engineers, ecologists, environmental consultants, manufacturers and suppliers, health scientists, social scientists. This in order to ultimately arrive at a full-fledged quantitative VGS Valuation Tool which can evaluate distinct VGS in specific location, helping to optimise choices for functional application or to set an agenda for optimisation of the systems themselves.

8.2.2 Framework and tool for industry and society

This research should be regarded as an impetus to rethink the values attached to (vertical) greening in the built environment. Through their implementation in dense urban environments, VGS can represent nature and provide enhanced natural surroundings for the everyday life of a great deal of people. Obviously, it can be of great aesthetical value. Yet, they can also help to rearrange the urban setting. Using them to exploit every high valued square meter in inner city centres, helps to accomplish what human society tends to do with all technological breakthroughs, however now through the contribution of nature: to design a highly efficient urban (eco-) system, in order to create an optimised society and use it for the enhancement of the common living environment of many.

It should be noted that the previous paragraphs are not an appeal to think of natural systems as mere functional and convenient assets, only to be exploited for the benefits they provide to society through the delivery of ES (nature for society). In the eyes of the author and widely supported in the field of ESV, this could be a negative implication of the research. Nature should still be adored, maintained and preserved for its intrinsic value (nature for nature). However showcasing the fact that besides their intrinsic value, ecosystems and biodiversity also possess economic value and contribute to benefits to which our human society addresses great importance, could enhance green urban planning and decision-making.

Hence, this work should not be used to ultimately put an actual price value on nature in order to make it a tradable or transferable market good. This could for instance infer the negative implication of someone paying the price that was set for a piece of natural land through economic valuation in order to use it as building plot for real estate or exploit it for other services, which might encompass a higher economic value. Yet, in the opinion of the author it is important to obtain information regarding the economic values in order to provide natural systems with a voice in (urban) decision-making as well and establishing a more widespread awareness and support for conservation of nature and ecosystems. An important notion is that decisions should not solely be based on these economic values, since most certainly not all value aspects can be encapsulated in these valuation models (yet). When performed correctly without overestimations or misconceptions of literature or valuation methodologies, research outcomes therefore only illustrate a part of the value equation, most preferable a minimum.

Economic valuation of VGS should not be an end, it should be a means to further develop these systems, making them more cost-efficient, sustainable and oriented towards value optimisation to do good for society. Since these are not purely natural systems but man-made, in a sense they should be valued for their efficiency and societal value driven properties.

When after future research eventually it turns out that this cannot be accomplished using modular LWS, more appropriate systems be sought. Also, LWS can be optimized based on the outcomes of the VGS Valuation Tool. This particularly through the insights that can be generated in the result dashboard in terms of financial and environmental costs (materialization, quantities of material, circularity, reuse and life span, water and energy consumption, maintenance perils and plans). For instance, great potential for LWS to become more sustainable are foreseen in material usage. Potentially, there is the possibility of using more natural, biobased materials in the secondary support structure or planter boxes, which either retain or sequester CO_2 and other greenhouse gases as they grow, rather than emitting them during production process. Also optimisations can take place with regards to delivered benefits and advantages. Here, optimisation of systems could be proposed in relation to location specific requirements for ES and functions. These requirements can be identified with thorough environmental research prior to the preparation of the planting plan, indicating what type of nature or biodiversity would be needed for certain locations in order to contribute most to local challenges.

8.3 Limitations and future results

The present research comes with some limitations. Since VGS are a relatively innovative solution, not much comprehensive (valuation) research has been conducted yet. Also, due to their vertical application, more standard valuation methods and studies cannot simply be copied, since the perceived values are not proven to be congruent. These statements among others, led to several limitations and shortcomings in this work. Yet, by naming these flaws, they also pave the way to implement changes for the better in order to obtain more robust and insightful future results. Future recommendations (chapter 9.3 and appendix I) are partially based on these limitations.

Limitation of number of integrated valuation methods and stakeholders in the tool

Mainly due to a lack of scientifically established relations and valuation methods and the limited coherent research data for value indicators and specific VGS types, the comprehensive value integration of all indicators is still hard and prohibited. Therefore, the results that can be generated by the tool are to be regarded as provisional results, which do not yet offer a complete representation of reality. The limited number of quantitative indicators affects the valuation results, emitting potential important values that are not included in these methods. NPV and B/C-ratio thus probably are presented too pessimistic, although qualitative benefits are mentioned in the tool. The framework offers guidance for integration of additional value indicators. Hence, the amount of scientific research in this field of study, both for effects of VGS in general as well as for valuation methods of these benefits, should have priority.

Since scope was initially demarcated to real estate investors and society as a whole (with a clear focus on residents), interests of certain other stakeholders might not be represented in the study. This entails that power imbalances may arise, or some concerns and perspectives might be forgotten completely (Jacobs et al., 2016). Integration of more, or the division into more detailed, stakeholders is facilitated by the guidance provided in the framework.

Limitation of generated quantitative valuation results

As a direct result from the previous limitation, only limited project specific results could be obtained for the case study. This hampered an effective analysis and discussion of quantitative results for the modular LWS. When a more comprehensive number of indicators can be monetised in the tool, this analysis can be performed for this system. Also, by exercising the framework for multiple types of VGS or different project locations, relations between input data could be found.

This constitutes the recommendation to perform multiple distinct case studies, which would also further validate and verify the model. For instance, it could be investigated whether systems with higher financial costs or in more dense locations, provide more or higher quality of benefits. A comparison of feasibility indicators could be performed, both for different VGS at the same location, or for the same VGS at different locations. Furthermore, a sensitivity analysis could then be performed in order to elaborate on the relations between certain input variables and indicators.

This further implementation of specific VGS types and indicator valuations could enhance the decision-making process and initiate the deliberation for a VGS that is beneficial to the specific requirements of the client or suits the needs of the location.

Limitation of unrealised features or functionalities in the VGS Valuation Tool

More of the input data that is currently in the tool, could be automatically linked to choices for general principles (VGS type), location or building type or climate region. Currently, these links are not made consistently for all input parameters that are dependent on these principles. This implies end-users have to insert and check a greater number of data inputs, while the time needed for the analysis is elongated. Also, pinning certain inputs to the initial principles or project choices that are made, prevents insertion of incorrect data, hence improving the adequacy of results.

The framework and tool is already designed in such a way that all these 'fixed' input parameters can be inserted at a separate input tab. Input cells in case or indicator specific tabs would then be linked and become dependent on e.g. the type of VGS that is chosen in the general principles tab. Moreover, when new VGS types from suppliers arrive on the market, the relevant input data for these sub-types could be implemented in the tool, (automatically) generating outputs in the different cost and benefit categories. Hence, this way a kind of VGS input database could be established in one central file.

Limitation of the framework and tool as a stand-alone software solution

The characteristic of VGS to be vertical systems, poses the limitation that no previous valuation tools could be found like is the case for horizontal greening or green roofs. Furthermore, no environmental (GIS-) data could be used that relates to horizontal greening in order to establish relations, since coherency is not proven. Most case or indicator specific input used for economic valuation should be updated manually by the user. Hence, MS-Excel provides a sufficient platform for the tool in the current level of development of the framework.

However, integration with other software packages to generate automatic input for the tool would be interesting. For instance, the complete LCA procedure is now integrated in Excel. In the future, LCA results could be automatically generated in SimaPro for example, meaning the intermediate LCA data does not have to be transferred into the tool. Also, so-called Feature Manipulation Engine (FME) scripting could automatically extract, import and edit data from sources and files. Automated data import could for example be based on the choice for VGS category or type, or the exact project location for case and indicator specific input data (BAG-ID, year of construction, façade surface area, geographical maps, etc.).

Furthermore, to enhance user-experience and generate a more widespread use of the framework and tool, in the future a more user-oriented (web-) application could be designed.

9

Conclusions and recommendations

This research aims to contribute to the development of scientific knowledge related to economic valuation of costs and benefits of vertical greening systems (VGS). The goal of applying these new insights to the real estate sector is to create a more widespread acceptance of VGS and enhance consultancy and decision-making. When after deliberate consideration the benefits of a certain VGS appear to balance its costs, this might stimulate their implementation in the urban environment.

From the problem definition in chapter 1.2, it followed that there was need for a method and mechanism enabling the comprehensive economic valuation of VGS costs and benefits. This with clear focus on the utilization perspective and decision-making, also taking into account attribution of perceived values to different stakeholders. From this, the main research question was established:

"What framework and tool can be proposed to economically value the costs and benefits of vertical greening systems within the built environment and how can these costs and benefits be attributed among different stakeholders involved?"

The research aids in answering this question by providing insight into a broad spectrum of costs and benefits of VGS and by designing a comprehensive and utilization focussed economic valuation tool: the VGS Valuation tool. To do this in a structured way, the research was divided into 4 sub-questions.

This chapter provides both the conclusions of this research, as well as the recommendations for future research. First, the sub-research questions are answered in section 9.1, providing the basis for answering the main research question in section 9.2. From previous chapters and observations throughout this thesis work, section 9.3 constitutes recommendations for future research.

9.1 Conclusions sub-research questions

Sub-research question 1:

"What is the state of the art regarding the effects of vertical greening systems and the economic valuation of these systems for different stakeholders?"

Although the concept of VGS has a long history, these systems are an innovative field of scientific research in urban planning and the area of urban NBS. In contemporary society, implementation of VGS within the urban fabric is deemed a rational solution to enhance the built environment. Namely, they can offer numerous benefits to human society in the private and public domain. A comprehensive list of 19 distinct benefits was composed (Table 2.1). However, it cannot be ruled out that in the future even more benefits become scientifically sustained.

Upon identification of VGS types, *modular LWS* were deemed most feasible for the development of a comprehensive valuation framework and tool. Reasoning comprised their huge potential for biodiversity integration, a priority for Ecosystem Services (ES) delivery, and the elaborate secondary support system of LWS. This allows for extensive integration of environmental costs in a first framework already. Minimum standards regarding biodiversity and sustainability were established.

A scientific introduction into natural value and reasons to value nature presented multiple value perspectives. For this thesis work, predominantly the perspective of 'Nature for society' is utilised in order to append values to the benefits that are delivered by ES.

The concepts of ES, Ecosystem Services Valuation (ESV) and Ecosystem Service Cascade (ESC) framework were studied. Healthy ecosystem functioning is at the basis of ES delivery. When this is ensured, ESV can inform urban planning in different decision-making contexts. The ESC framework explains the relationship and pathway from ecosystems and biodiversity towards human welfare benefits. It urges one to link complex ecosystem processes and intermediate ES to perceived benefits, which can then be valued. There is increasing recognition that from an application oriented perspective, multiple disciplines and methods should be combined in order to represent the diverse set of costs, benefits and coherent values imposed by nature. Integrated Valuation is therefore proposed, combining value dimensions in economic, environmental, ecological, social, cultural, self-interest, electoral, or ethical field.

Merely two previous studies could be identified in which Cost-Benefit Analysis (CBA) or Life Cycle Cost Analysis (LCCA) was more or less comprehensively performed. The study by Perini and Rosasco (2013) accounted for personal and social costs and some benefits over the life cycle. In the LCCA of Huang et al. (2019), only an eye was cast upon the pure financial costs and the benefit of reduced energy consumption. Yet, taking into account and including remaining findings from literature review, the mentioned studies form a solid basis for development and design of a comprehensive VGS valuation framework and tool.

Options for thematic classification of costs and benefits were reviewed based on literature. This led to thematization for this research as per the following themes: *financial costs, environmental costs, potential Ecosystem Disservices, health & well-being, climate mitigation & adaptation, real estate, social & recreational & commercial and biodiversity*. It is noted that this is just one option for classifying and pooling VGS's costs and benefits, which is fit for the intended purpose and suits the decision context of the valuation tool. As set out by Costanza (2008) and Fisher et al. (2009), it is not necessarily the only correct way. Namely, different classification systems should be "regarded as an opportunity to enrich our thinking about ecosystem services, rather than a problem to be defined away".

Finally, the stakeholder perspective was extensively elaborated. For the sake of feasibility, the most important stakeholders were identified and proposed as scope demarcation. This research distinguished between 'real estate investors' (private) and 'society as a whole' (public). Appropriate analysis methods were identified matching these stakeholders. The financial analysis (LCCA) and economic analysis (SCBA) respectively relate to these stakeholders and show different perspectives of value (Posma et al., 2018).

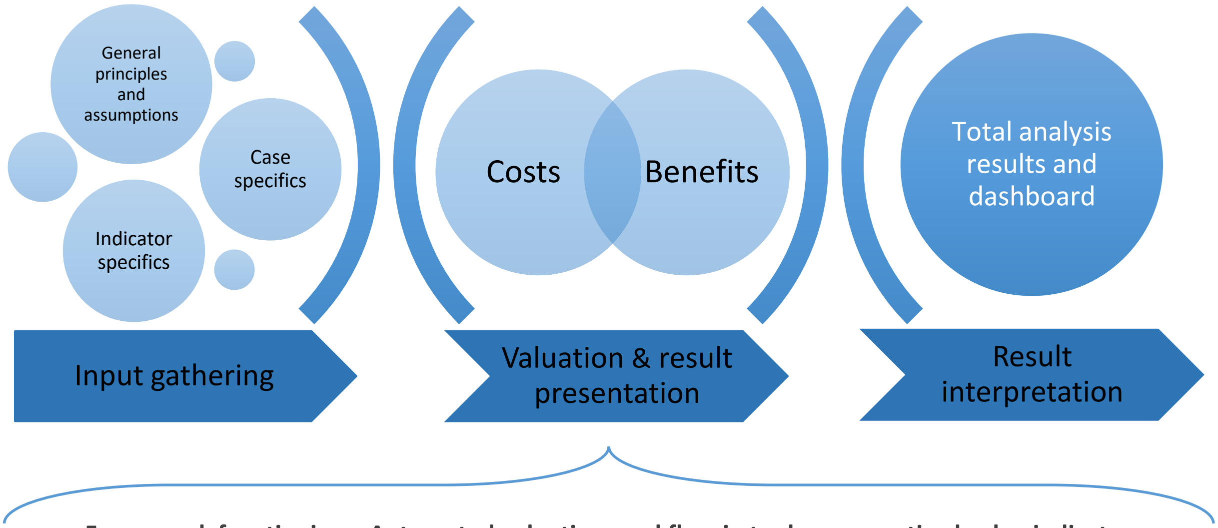
Sub-research question 2:

Which analysis method and valuation methods are proposed to enable the comprehensive economic valuation of the costs and benefits of vertical greening systems?

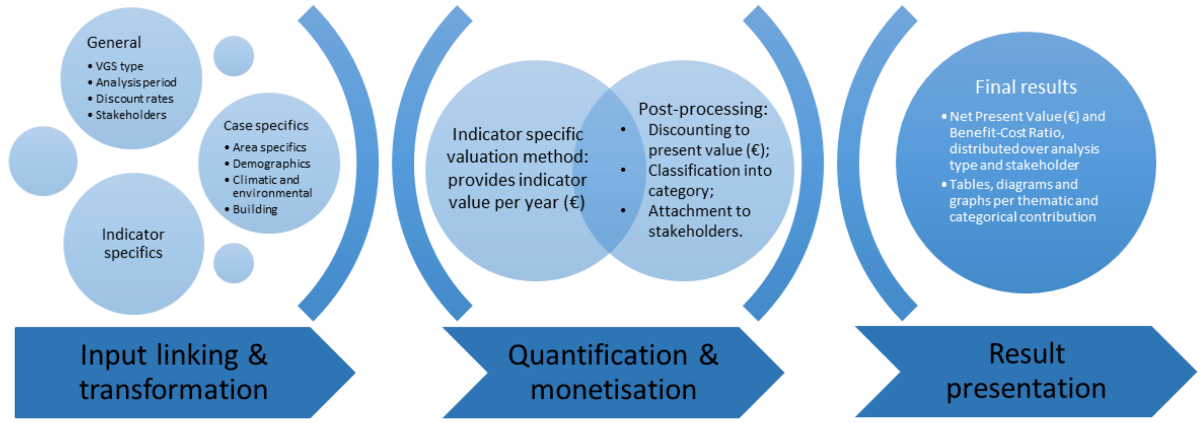
Following from the goals to account for multiple stakeholders, offer different perspectives to values of costs and benefits of VGS and use the framework as a conversational mechanism between parties, the proposed valuation framework distinguishes between *a financial analysis for the real estate investor (LCCA)* and *an economic analysis for society as a whole (SCBA)*. This latter one includes the *property residents*. Both analyses were performed following nine basic steps of the procedure for SCBA. For each analysis, distinct discount factors apply for calculation of the present values (PV) of costs and benefits. Aside from a *'zero discount rate'* for both analyses, an *'investor discount rate'* is applied for LCCA and a *'social discount rate'* for ES valuation in SCBA. This is due to the difference in time horizons between perceived risks, costs and benefits for stakeholders and the assumption that ES become relatively scarcer than regular consumption goods and are not substitutable.

The framework functioning is thoroughly elaborated and divided into a *user workflow* and an *automated tool workflow* (visualisation below). The framework for user workflow standardises the data gathering and implementation with regards to general principles (e.g. VGS properties), case specifics and indicator specifics that relate to VGS. Since calculations and result presentation are automatically performed by the tool, only interpretation of these results is necessary to allow for informed decision-making. The automated tool workflow first links, where needed transforms, data into correct units. Then, the quantification and monetarisation processes are performed. Finally, the results of these calculations are visually presented in the result dashboard in tables graphs. Indicators for economic and financial feasibility are the *Net Present Value (NPV)* and *Benefit-Cost ratio (B/C-ratio)*.

Framework functioning – User workflow and main tool contents



Framework functioning – Automated valuation workflow in tool per monetised value indicator



The design and infrastructure of the VGS Valuation Tool is presented, in which the framework is integrated. The tool is divided into *5 sections* containing *15 accessible tabs*. With this, a utilization focussed, interactive and comprehensive tool was designed and established in *MS-Excel*, which is applicable to different projects in the Netherlands but extendable to other countries. In the current version, the tool's infrastructure is full-fledged and operational.

First, two extensive *introductory tabs* with background information and a user guide are provided. Then in the *input section*, users have to choose several starting principles for valuation and manually insert a number of parameters for case specific and indicator specific input variables. Next, the *result section* directly presents and visualizes final outcomes of the analyses in a result dashboard. *The cost and benefit sections* automatically perform value calculations according to identified methods and discounting, for indicators that were established and assigned to the themes (see tables in chapter 5).

For the costs, a valuation method and sequence for *financial costs* is fully integrated within the tool. This allows for quantification of costs at category level, however when relevant data is collected for more detailed indicators as listed, these can be quantified instead. For the *environmental costs*, the *LCA procedure* is encapsulated in the framework and tool. Identification and insertion of materials quantities and processes needed for distinct VGS, allows for monetisation of environmental costs with the *Environmental Cost Indicator (ECI)*. *Potential disservices* are qualitatively captured.

For the benefits, in the *health & well-being theme* currently the value *of reduced healthcare costs due to deposition of* PM_{10} is monetised. The *same method could be applied for* $PM_{2.5}$ *and* $PM_{0.1}$, while also application for gaseous substances could be investigated. Other indicators are yet hard to quantify. The *climate adaptation & mitigation*, *social & recreational & commercial* and *biodiversity themes* are qualitatively captured. For *real estate*, for several indicators a valuation method was appended to the tool for them to be monetised. I.e. the *increase of real estate value for the real estate investor (through increased rental incomes)*, *the reduced energy usage for building heating in winter* and *tax incentives for VGS (MIA & Vamil)*.

Sub-research question 3:

"Based on a case study, what results can be obtained from the developed economic valuation tool and how can these results be interpreted?"

In order to tackle the biggest obstacles in the tool and test whether the developed *VGS Valuation Tool* could produce sound results, a case study was conducted. The elaboration of this project case *demonstrated the basic functionality, intended operation* and *generated results* by the framework and tool. Also, this *verified the current version of the tool on a technical level*: it can operate as intended and no crashes or errors were encountered. The case study was selected in collaboration with Sweco and a client company, suited the main conditions to consider implementation of VGS and provided the necessary project specific grip for input data for the tool. For a basic understanding and insight into the extensive list of input values, reference is made to appendix F.

The results section of the tool provides the user with a *total analyses results table*, indicating whether the project is financially or economically feasible (NPV and B/C-ratio). Furthermore, the *result dashboard* generates *graphical visualisations* of the *contributions of different themes and categories towards the total costs and benefits* of VGS, by means of *charts and graphs*. Herewith, consultants can provide more substantiated advice to their clients, who are interested in adopting green measures for real estate objects. The results displayed in the dashboard are retrieved from the cost and benefit sections, which are inserted at the back-end of the tool to perform the actual calculations and provide methodological transparency. Here, values per indicator can be found as well.

The current version of the tool is able to perform quantification and *monetisation for financial costs*, *large parts of the environmental costs*, *reduction of airborne* PM_{10}, *increased rental incomes (investors) and costs (residents)*, *reduced energy usage for heating* and *MIA & Vamil tax incentives*. Based on implemented valuation methods, the case study delivers project specific results. It is explicitly noted that these results do not yet provide a complete representation of all costs and benefits, due to the limited (benefit) indicators that are monetised. Hence, this *version of the tool* should be regarded as *initial impetus for further development*, in order to ultimately obtain an all-encompassing VGS Valuation Tool, fit for project specific economic valuation of costs and benefits of VGS.

Nevertheless, the tool generated a NPV of -€2.045.775,88 with a corresponding B/C-ratio of 0,2734 for the LCCA and investor's discount rate. For the SCBA with social discount rate, the NPV equalled to -€806.546,49, with a corresponding B/C-ratio of 0,0986. The lower B/C-ratio for residents or society at large as compared to the one for investors seems contradictory, but is explained since most benefits for society still are to be incorporated in the tool. Recommendations and outlines are proposed in order to facilitate future research in section 9.3.

Through *validation of the framework by experts* and *the functionality of the tool via a user experiment*, recognition was acquired that the valuation framework was grounded on solid foundations and the tool has high anticipated future value. VGS experts acknowledged that a functioning mechanism like the developed tool is still a missing link in their field, which can provide great new insights with regards to VGS valuation. Supporting the literature review performed by the author, the general structure and thematization were deemed *fit-for-purpose*: to *inform decision-makers* in real estate companies or politics and *to engage with other stakeholders*, where the *tool acts as a conversational mechanism*.

Consultants that engaged in the user-experiment for the tool reacted positively on its contents. *High feedback grades* were obtained for *tool composition and structure*, *user experience*, *intuitiveness*, *accessibility* and *comprehensiveness*. Furthermore, participants were *impressed with substantiation of scientific information*, while *not compromising the foreseen practical value in projects*. Furthermore, *high future potential* is foreseen for the time when the tool is even more extensively developed, robust and tested on several distinct cases. This would most certainly *facilitate adequate and rational consultancy and decision-making based on facts and substantive figures*.

9.2 Conclusion main research question

"What framework and tool can be proposed to economically value the costs and benefits of vertical greening systems within the built environment and how can these costs and benefits be attributed among different stakeholders involved?"

Answering the sub-questions paved the way towards a final conclusion for the main research question.

First, the Ecosystem Service Cascade (ESC) framework explains the relationship and pathway from ecosystems and biodiversity towards human welfare benefits, urging one to link complex ecosystem processes and intermediate ES to perceived benefits, which can then be valued. For an application oriented perspective, Integrated Valuation is proposed to combine multiple disciplines and methods, representing the diverse set and dimensions of costs, benefits and coherent values imposed by nature. This led to the classification of costs and benefits as per the following themes: financial costs, environmental costs, potential Ecosystem Disservices, health & well-being, climate mitigation & adaptation, real estate, social & recreational & commercial and biodiversity. Real estate investors and society as a whole (including property residents) were selected as important stakeholders.

Secondly, Life Cycle Cost Analysis (LCCA) and Social Cost-Benefit Analysis (SCBA) were identified as financial and economic analysis methods that appropriately could reflect perceived values of the selected stakeholders. In LCCA, merely pure financial costs and benefits are regarded (for investors), while SCBA accounts for all costs and benefits that can emerge in society (leaving aside implementation costs). The analyses methods leave room for future implementation of other stakeholders. Distinct discount rates are applied and the feasibility indicators are Net Present Value (NPV) and Benefit-Cost Ratio (B/C-ratio). The framework functioning is further explained by means of a user workflow and an automated tool workflow, which is linked to MS-Excel. This way, for several value indicators that were established and assigned to the cost and benefit themes, semi-automatic monetisation calculations can be performed according to identified valuation methods and value discounting.
By performing a case study, the basic functionality, intended operation and generated results by the framework and the VGS Valuation Tool were demonstrated. Also, this verified the current version of the tool on a technical level. It should be noted that the quantitatively obtained results are not yet conclusive nor decisive, since valuation methods for other benefit indicators should still be established. The structure, functionality and user experience, comprehensiveness and future potential of the framework and tool were validated by means of expert judgement as well as a user-experiment with practitioners.

To conclude, in this research a framework is presented and a first version of the VGS Valuation Tool is developed, which offers resource for decision-making-support based on economic valuation of costs and benefits that are associated with the implementation of VGS on buildings. A comprehensive collection of indicators for costs and benefits were identified and all qualitatively incorporated in the tool, while some of these are already monetised. The developed tool structure offers guidance for future efforts with regards to implementation of valuation methods, which should ultimately allow the evaluation of a comprehensive collection of costs and benefits of VGS. This should be an ongoing process based on multi-disciplinary collaboration and new scientific insights in the field of VGS valuation. Feedback from experts and practitioners was predominantly positive with high envisioned potential for implementation and use in the field. It was acknowledged that the developed tool could act as a mechanism to initiate conversations and support rational and pragmatic decision-making regarding potential implementation of VGS.

Thereby, the objective of this research to contribute to development of a knowledge base and a proposal for a standardized way of valuating costs and benefits of VGS is met. Nonetheless, still a lot of research is required within this scientific field. Guidance is offered by setting recommendations for further research in the final section of this report.

9.3 Recommendations for further research and tool development

This research is regarded as initial impetus in the development of a comprehensive, interactive, user-oriented framework and tool. It should ultimately allow for the monetisation of all costs and benefits of VGS over its lifetime. Within the given scope and time of this thesis work, a first version of the envisioned final end-product was delivered. As previously mentioned, the proposed framework offers guidance to further develop the VGS Valuation Tool, which can be expanded and improved with future efforts. Especially, further establishment of experimental and empirical research in different climatic regions and for different VGS would facilitate progress in this innovative field of research.

As such, there are a number of research topics to be further explored in the field of VGS in general and into economic valuation of these systems. In order to ultimately arrive at the desired and anticipated level of development for the tool, the remainder of this section proposes several important recommendations for a future research agenda and tool development. These are given in relation to scientific purposes (academia), tool extensions and practical & organisational purposes. Far more extensive and elaborated recommendations are described in detail in Appendix I, which may serve as reference for those interested and willing to contribute in further development of this growing scientific field. Herewith, this constitutes an important contribution and outcome of the current study.

Recommendations for academia

In order to allow all research to be reported in the same terminology, enabling more straightforward comparison and correct use of results, it would be greatly beneficial when uniform, standardised or consistent classification and documentation of VGS nomenclature, categories and types would be universally agreed upon within the scientific field.

Also a comprehensive review of research results, as well as new empirical research, regarding the numerous identified cost and benefit indicators per distinct VGS type and in different climates and locations is proposed. Extension and improvement of the valuation methods of indicators based on empirical data can be interesting topics. This can facilitate the further integration of several indicators and distinct VGS types into the tool. Interesting research topics might be extension of building lifespan, recreational possibilities, further values due to enhanced health and well-being, aesthetical and social values. In line with the school of 'Integrated Valuation', multi-disciplinary cooperation is proposed to establish such (complex) valuation methods. Also, as additional outputs it could be interesting to analyse how much of a certain benefit (in quantitative term, e.g. kg PM_{10}) would be achieved by a certain investment in VGS per m^2. This would provide a B/C-ratio with a unit (e.g. kgPM_{10}/€/m^2), rather than only a dimensionless ratio. It would allow for quantitative comparison of different VGS per indicator or theme.

When more comprehensive overviews can be provided due to integration of multiple indicators, sensitivity analysis is recommended in order to assess the robustness of these results or account for uncertainties in monetary values.

Moreover, future research can focus on how natural or biodiversity levels of the surroundings would influence perceived values from the VGS, or the other way around, what influence the VGS might have on (local) biodiversity. Some kind of benchmark for biodiversity and sustainability aspects of VGS could prove to be beneficial for their further development. Specifically impaired or low-quality systems could be marked via these benchmarks. Subsequently, measures could be taken to improve these systems' quality or exclude them from the consultancy palette, in order to prevent implementation of bland, disingenuous or cost-ineffective measures focussing on a single function, rather than offering a multifunctional solution to the challenges faced in urban environments.

With regards to stakeholders, a comprehensive analysis on differences in perceived values for certain cost or benefit indicators could pave the way for more detailed and diverse integration of stakeholder's interests within the valuation framework. Herewith, the character of the tool to act as conversational mechanism between stakeholder groups could be further enhanced, by providing insights into values for multiple interesting parties.

Recommendations for VGS Valuation Tool

Findings from the scientific research as proposed in the previous sub-section could also well be incorporated in the VGS Valuation Tool. That is, additional valuation methods for value indicators, dependencies on type of vertical greening systems or climatic conditions, etc. Furthermore it would be interesting to integrate a kind of biodiversity scaling factor into the tool based on specific VGS's contribution to Ecosystem Services provision, which would then affect the values of delivered benefits.

Moreover, input data that now is to be adapted manually based on the decision for which VGS to choose, could all be linked to the options in the drop-down menu for VGS type selection or other project's starting principles and hence, be updated automatically. This would also contribute to enhanced user experience and intuitiveness. For this to work, of course all applicable data should be retrieved and stored in a database or list, which can be done internally in Excel. Occasionally updating this data with new scientific insights or knowledge is then required. Nevertheless, since tool actualisation is recommended on a yearly basis, these activities could be integrated.

Recommendations for practice & organisations

Since first time experience with the VGS Valuation Tool might overwhelm potential users, for successful implementation of the product within Sweco, it is recommended to organise a training session for consultants and other employees that will work with it. This will allow them to become familiar with the potential of the tool for their consultancy work relating VGS in urban environments and make it an equipment of standard practise for consultancy with regards to urban planning and greening.

Integration of, or joint use with, other Sweco tools used for e.g. climate adaptation or valuation services, could further enhance the usefulness of the outcomes.

Finally, by applying the tool to multiple different real estate projects, comparison between these projects would be enabled, facilitating users with more instinctive knowledge and experience regarding specific VGS values or properties. To further enhance this effect and make sure not every new project has to be inserted from scratch, a project database could be established. For instance, this can be done on the company's network drive, containing multiple projects and their corresponding weighted variants.

On a more general basis, also a community of practice could be established between several companies regarding VGS: e.g. scientists, consultants, engineers and asset managers. This would create a 'collective intelligence' where peers can benefit from each other's efforts and knowledge. Potentially, this joint force could help promote a more widespread acceptance of VGS in the built environment.

Bibliography

Handbooks and E-books

Boardman, A., Greenberg, D., Vining, A., & Weimer, D. (2011). *Cost-Benefit Analysis: Concepts and Practice, 4th edition*.

Bonner, S. (2022). *Social Cost Benefit Analysis and Economic Evaluation*: The University of Queensland.

de Bruyn, S., Ahdour, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., & Vergeer, R. (2018). *Environmental Prices Handbook 2017 - Methods and numbers for valuation of environmental impacts*. Retrieved from https://ce.nl/wp-content/uploads/2021/03/CE_Delft_7N54_Environmental_Prices_Handbook_2017_FINAL.pdf

Grimm, P. (2010). Social Desirability Bias. In *Wiley International Encyclopedia of Marketing*.

Kotzen, B. (2018). Economic Benefits and Costs of Green Streets. In G. Pérez & K. Perini (Eds.), *Nature Based Strategies for Urban and Building Sustainability* (pp. 319-331): Butterworth-Heinemann.

Magliocco, A. (2018). Vertical Greening Systems: Social and Aesthetic Aspects. In G. Pérez & K. Perini (Eds.), *Nature Based Strategies for Urban and Building Sustainability* (pp. 263-271): Butterworth-Heinemann.

Ottelé, M., Perini, K., & Haas, E. M. (2014). Life cycle assessment (LCA) of green façades and living wall systems. In (pp. 457-483): Elsevier.

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., . . . Eppink, F. (2010). The economics of valuing ecosystem services and biodiversity. *The economics of ecosystems and biodiversity: Ecological and economic foundations*, 183-256.

Rosasco, P. (2018). Economic Benefits and Costs of Vertical Greening Systems. In G. Pérez & K. Perini (Eds.), *Nature Based Strategies for Urban and Building Sustainability* (pp. 291-306): Butterworth-Heinemann.

Journal papers

Amadei, A. M., De Laurentiis, V., & Sala, S. (2021). A review of monetary valuation in life cycle assessment: State of the art and future needs. *Journal of Cleaner Production, 329*, 129668. doi:10.1016/j.jclepro.2021.129668

Apfelbeck, B., Snep, R. P. H., Hauck, T. E., Ferguson, J., Holy, M., Jakoby, C., . . . Weisser, W. W. (2020). Designing wildlife-inclusive cities that support human-animal co-existence. *Landscape and Urban Planning, 200*, 103817. doi:10.1016/j.landurbplan.2020.103817

Besir, A. B., & Cuce, E. (2018). Green roofs and facades: A comprehensive review. *Renewable and Sustainable Energy Reviews, 82*, 915-939. doi:10.1016/j.rser.2017.09.106

Blanco, J., Dendoncker, N., Barnaud, C., & Sirami, C. (2019). Ecosystem disservices matter: Towards their systematic integration within ecosystem service research and policy. *Ecosystem Services, 36*, 100913. doi:10.1016/j.ecoser.2019.100913

Brković Dodig, M., Radic, M., & Auer, T. (2019). Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits. *Sustainability, 11*. doi:10.3390/su11174579

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute? *Cities, 95*, 102483. doi:10.1016/j.cities.2019.102483

Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. *Building and Environment, 146*, 226-237. doi:10.1016/j.buildenv.2018.09.045

Calheiros, C. S. C., & Stefanakis, A. I. (2021). Green Roofs Towards Circular and Resilient Cities. *Circular Economy and Sustainability, 1*(1), 395-411. doi:10.1007/s43615-021-00033-0

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., . . . Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature, 486*(7401), 59-67. doi:10.1038/nature11148

Catalano, C., & Baumann, N. (2017). Biosolar Roofs: A Symbiosis between Biodiverse Green Roofs and Renewable Energy. *City Green*, 42-49.

Chàfer, M., Pérez, G., Coma, J., & Cabeza, L. F. (2021). A comparative life cycle assessment between green walls and green facades in the Mediterranean continental climate. *Energy and Buildings, 249*, 111236. doi:10.1016/j.enbuild.2021.111236

Collins, R., Schaafsma, M., & Hudson, M. D. (2017). The value of green walls to urban biodiversity. *Land Use Policy, 64*, 114-123. doi:10.1016/j.landusepol.2017.02.025

Costanza, R. (2008). Ecosystem services: Multiple classification systems are needed. *Biological Conservation, 141*(2), 350-352. doi:10.1016/j.biocon.2007.12.020

de Graaf, K. J., Platjouw, F. M., & Tolsma, H. D. (2018). The future Dutch Environment and Planning Act in light of the ecosystem approach. *Ecosystem Services, 29*, 306-315. doi:10.1016/j.ecoser.2016.12.018

de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity, 7*(3), 260-272. doi:10.1016/j.ecocom.2009.10.006

El Menshawy, A. S., Mohamed, A. F., & Fathy, N. M. (2022). A comparative study on green wall construction systems, case study: South valley campus of AASTMT. *Case Studies in Construction Materials, 16*, e00808. doi:10.1016/j.cscm.2021.e00808

Farber, S. C., Costanza, R., & Wilson, M. A. (2002). Economic and ecological concepts for valuing ecosystem services. *Ecological Economics, 41*(3), 375-392. doi:10.1016/s0921-8009(02)00088-5

Feng, H., & Hewage, K. (2014). Lifecycle assessment of living walls: air purification and energy performance. *Journal of Cleaner Production, 69*, 91-99. doi:10.1016/j.jclepro.2014.01.041

Ferreira, V., Barreira, A. P., Loures, L., Antunes, D., & Panagopoulos, T. (2021). Stakeholders' perceptions of appropriate nature-based solutions in the urban context. *Journal of Environmental Management, 298*, 113502. doi:10.1016/j.jenvman.2021.113502

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics, 68*(3), 643-653. doi:10.1016/j.ecolecon.2008.09.014

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics, 86*, 235-245. doi:10.1016/j.ecolecon.2012.08.019

Gunawardena, K., & Steemers, K. (2019). Living walls in indoor environments. *Building and Environment, 148*, 478-487. doi:10.1016/j.buildenv.2018.11.014

Hatan, S., Fleischer, A., & Tchetchik, A. (2021). Economic valuation of cultural ecosystem services: The case of landscape aesthetics in the agritourism market. *Ecological Economics, 184*, 107005. doi:10.1016/j.ecolecon.2021.107005

Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B: Biological Sciences, 375*(1794), 20190124. doi:10.1098/rstb.2019.0124

Huang, Z., Lu, Y., Wong, N. H., & Poh, C. H. (2019). The true cost of "greening" a building: Life cycle cost analysis of vertical greenery systems (VGS) in tropical climate. *Journal of Cleaner Production, 228*, 437-454. doi:10.1016/j.jclepro.2019.04.275

Huang, Z., Tan, C. L., Lu, Y., & Wong, N. H. (2021). Holistic analysis and prediction of life cycle cost for vertical greenery systems in Singapore. *Building and Environment, 196*, 107735. doi:10.1016/j.buildenv.2021.107735

Jacobs, S., Dendoncker, N., Martín-López, B., Barton, D. N., Gomez-Baggethun, E., Boeraeve, F., . . . Washbourne, C.-L. (2016). A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosystem Services, 22*, 213-220. doi:10.1016/j.ecoser.2016.11.007

Kirk, H., Garrard, G. E., Croeser, T., Backstrom, A., Berthon, K., Furlong, C., . . . Bekessy, S. A. (2021). Building biodiversity into the urban fabric: A case study in applying Biodiversity Sensitive Urban Design (BSUD). *Urban Forestry & Urban Greening, 62*, 127176. doi:10.1016/j.ufug.2021.127176

Koch, K., Ysebaert, T., Denys, S., & Samson, R. (2020). Urban heat stress mitigation potential of green walls: A review. *Urban Forestry & Urban Greening, 55*, 126843. doi:10.1016/j.ufug.2020.126843

Langergraber, G., Pucher, B., Simperler, L., Kisser, J., Katsou, E., Buehler, D., . . . Atanasova, N. (2020). Implementing nature-based solutions for creating a resourceful circular city. *Blue-Green Systems, 2*(1), 173-185. doi:10.2166/bgs.2020.933

Laurans, Y., & Mermet, L. (2014). Ecosystem services economic valuation, decision-support system or advocacy? *Ecosystem Services, 7*, 98-105. doi:10.1016/j.ecoser.2013.10.002

Lavorel, S., Locatelli, B., Colloff, M. J., & Bruley, E. (2020). Co-producing ecosystem services for adapting to climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences, 375*(1794), 20190119. doi:10.1098/rstb.2019.0119

Maas, J., Verheij, R. A., de Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health, 63*(12), 967-973. doi:10.1136/jech.2008.079038

Maca-Millán, S., Arias-Arévalo, P., & Restrepo-Plaza, L. (2021). Payment for ecosystem services and motivational crowding: Experimental insights regarding the integration of plural values via non-monetary incentives. *Ecosystem Services, 52*, 101375. doi:10.1016/j.ecoser.2021.101375

Manso, M., Castro-Gomes, J., Paulo, B., Bentes, I., & Teixeira, C. A. (2018). Life cycle analysis of a new modular greening system. *Science of the Total Environment, 627*, 1146-1153. doi:10.1016/j.scitotenv.2018.01.198

Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews, 135*, 110111. doi:10.1016/j.rser.2020.110111

McCauley, D. J. (2006). Selling out on nature. *Nature, 443*(7107), 27-28. doi:10.1038/443027a

Medl, A., Stangl, R., & Florineth, F. (2017). Vertical greening systems – A review on recent technologies and research advancement. *Building and Environment, 125*, 227-239. doi:10.1016/j.buildenv.2017.08.054

Naeem, S., Duffy, J. E., & Zavaleta, E. (2012). The Functions of Biological Diversity in an Age of Extinction. *Science, 336*(6087), 1401-1406. doi:10.1126/science.1215855

Oquendo-Di Cosola, V., Olivieri, F., Ruiz-García, L., & Bacenetti, J. (2020). An environmental Life Cycle Assessment of Living Wall Systems. *Journal of Environmental Management, 254*, 109743. doi:10.1016/j.jenvman.2019.109743

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

Peltola, T., & Arpin, I. (2017). How We Come to Value Nature? - A Pragmatist Perspective. *Ecological Economics, 142*, 12-20. doi:10.1016/j.ecolecon.2017.06.009

Pereira, L. M., Davies, K. K., Belder, E., Ferrier, S., Karlsson-Vinkhuyzen, S., Kim, H., . . . Lundquist, C. J. (2020). Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. *People and Nature, 2*(4), 1172-1195. doi:10.1002/pan3.10146

Pereira, P., & Baró, F. (2022). Greening the city: Thriving for biodiversity and sustainability. *Science of the Total Environment, 817*, 153032. doi:10.1016/j.scitotenv.2022.153032

Pérez, G., Coma, J., Martorell, I., & Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and Sustainable Energy Reviews, 39*, 139-165. doi:10.1016/j.rser.2014.07.055

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

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

Perini, K., & Rosasco, P. (2016). Is greening the building envelope economically sustainable? An analysis to evaluate the advantages of economy of scope of vertical greening systems and green roofs. *Urban Forestry & Urban Greening, 20*, 328-337. doi:10.1016/j.ufug.2016.08.002

Rahman, A., Salam, Z., Shaari, S., & Ramli, M. (2019). Methodology to Determine Photovoltaic Inverter Conversion Efficiency for the Equatorial Region. *Applied Sciences, 10*, 201. doi:10.3390/app10010201

Raworth, K. (2017). Why it's time for Doughnut Economics. *IPPR Progressive Review, 24*(3), 216-222. doi:10.1111/newe.12058

Rea, A. W., & Munns Jr, W. R. (2017). The value of nature: Economic, intrinsic, or both? *Integrated Environmental Assessment and Management, 13*(5), 953-955. doi:10.1002/ieam.1924

Riley, B. (2017). The state of the art of living walls: Lessons learned. *Building and Environment, 114*, 219-232. doi:10.1016/j.buildenv.2016.12.016

Riley, B., de Larrard, F., Malécot, V., Dubois-Brugger, I., Lequay, H., & Lecomte, G. (2019). Living concrete: Democratizing living walls. *Science of the Total Environment, 673*, 281-295. doi:10.1016/j.scitotenv.2019.04.065

Rosasco, P., & Perini, K. (2018). Evaluating the economic sustainability of a vertical greening system: A Cost-Benefit Analysis of a pilot project in mediterranean area. *Building and Environment, 142*, 524-533. doi:10.1016/j.buildenv.2018.06.017

Rowe, T., Poppe, J., Buyle, M., Belmans, B., & Audenaert, A. (2022). Is the sustainability potential of vertical greening systems deeply rooted? Establishing uniform outlines for environmental impact assessment of VGS. *Renewable and Sustainable Energy Reviews, 162*, 112414. doi:10.1016/j.rser.2022.112414

Salah, G. M. J. A., & Romanova, A. (2021). Life cycle assessment of felt system living green wall: Cradle to grave case study. *Environmental Challenges, 3*, 100046. doi:10.1016/j.envc.2021.100046

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews, 90*, 757-773. doi:10.1016/j.rser.2018.04.006

Soliveres, S., Van Der Plas, F., Manning, P., Prati, D., Gossner, M. M., Renner, S. C., . . . Allan, E. (2016). Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. *Nature, 536*(7617), 456-459. doi:10.1038/nature19092

Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Economics of green roofs and green walls: A literature review. *Sustainable Cities and Society, 69*, 102781. doi:10.1016/j.scs.2021.102781

Veeger, M., Prieto, A., & Ottelé, M. (2021). Exploring the Possibility of Using Bioreceptive Concrete in Building Façades. *Journal of Facade Design and Engineering, 9*, 73-86. doi:10.7480/jfde.2021.1.5527

Veisten, K., Smyrnova, Y., Klæboe, R., Hornikx, M., Mosslemi, M., & Kang, J. (2012). Valuation of Green Walls and Green Roofs as Soundscape Measures: Including Monetised Amenity Values Together with Noise-attenuation Values in a Cost-benefit Analysis of a Green Wall Affecting

Courtyards. *International Journal of Environmental Research and Public Health, 9*(11), 3770-3788. Retrieved from https://www.mdpi.com/1660-4601/9/11/3770

von Döhren, P., & Haase, D. (2015). Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators, 52*, 490-497. doi:10.1016/j.ecolind.2014.12.027

Wang, P., Wong, Y. H., Tan, C. Y., Li, S., & Chong, W. T. (2022). Vertical Greening Systems: Technological Benefits, Progresses and Prospects. *Sustainability, 14*(20), 12997. Retrieved from https://www.mdpi.com/2071-1050/14/20/12997

Wong, N. H., Tan, A. Y. K., Tan, P. Y., Sia, A., & Wong, N. C. (2010). Perception Studies of Vertical Greenery Systems in Singapore. *Journal of Urban Planning and Development, 136*(4), 330-338. doi:doi:10.1061/(ASCE)UP.1943-5444.0000034

Ysebaert, T., Koch, K., Samson, R., & Denys, S. (2021). Green walls for mitigating urban particulate matter pollution—A review. *Urban Forestry & Urban Greening, 59*, 127014. doi:10.1016/j.ufug.2021.127014

Zhang, C., Li, J., & Zhou, Z. (2022). Ecosystem service cascade: Concept, review, application and prospect. *Ecological Indicators, 137*, 108766. doi:10.1016/j.ecolind.2022.108766

Master's and PHD Theses

Mir, M. A. (2011). *Green facades and Building structures.* (MSc. Thesis). Delft University of Technology, Retrieved from http://resolver.tudelft.nl/uuid:f262c218-8801-4425-818f-08726dde5a6c

Ottelé, M. (2011). *The green building envelope: Vertical greening.* (Doctoral Thesis). Delft University of Technology, Retrieved from http://resolver.tudelft.nl/uuid:1e38e393-ca5c-45af-a4fe-31496195b88d

van den Biesen, J. (2018). *Participating in Vertical Gardens: A stakeholder analysis on the implementation of vertical gardens in the urban environment.* (MSc. Thesis). Wageningen University & Research, Retrieved from https://www.semanticscholar.org/paper/Participating-in-Vertical-Gardens-%3A-A-stakeholder-Biesen/be5f0b4860468438ee3dd247cb5f7b9a0baf0c38#extracted

Readers

Jonkers, H. (2020). *Reader CIE4100 - Materials and Ecological Engineering*. Delft: Delft University of Technology, Faculty of Civil Engineering & Geosciences.

Vrijling, J. K., & Verlaan, J. G. (2015). *Reader CME2300 - Financial Engineering*. Delft: Delft University of Technology, Faculty of Civil Engineering & Geosciences.

Reports

Bockarjova, M., & Botzen, W. (2017). *Review of Economic Valuation of Nature-Based Solutions in Urban Areas*. Retrieved from https://naturvation.eu/sites/default/files/result/files/review_of_economic_valuation_of_nature_based_solutions_in_urban_areas.pdf

Burrows, V. K., & Watson, E. (2021). *Advancing Net Zero Whole Life Carbon - Offsetting Residual Emissions from the Building and Construction Sector*. Retrieved from https://www.worldgbc.org/sites/default/files/WorldGBC%20Advancing%20Net%20Zero%20Whole%20Life%20Carbon_PUBLICATION.pdf

Busuttil, E. (2021). Internship Product Report - Climate Risk Assessments in the Financial Sector. In: WUR & Sweco.

de Vries, S., Kamphorst, D., & Langers, F. (2022). *Beleidsdenken over stedelijk groen en gezondheid*. Retrieved from https://klimaatadaptatienederland.nl/publish/pages/203466/beleidsdenken_over_stedelijk_groen_en_gezondheid_-wageningen_university_and_research_569997.pdf

Does, B., Remme, R., & de Nijs, T. (2019). *TEEB Stadtool : Actualisatie en Doorontwikkeling*. Retrieved from Rijksinstituut voor Volksgezondheid en Milieu RIVM: https://www.rivm.nl/publicaties/teeb-stadtool-actualisatie-en-doorontwikkeling

Gemeente Amsterdam. (2021). *Puntensysteem voor natuurinclusief bouwen*. Retrieved from https://www.amsterdam.nl/publish/pages/982633/puntensysteem_voor_natuurinclusief_bouwen_2021.pdf#PagCls_16294772

Groot Jebbink, S., Meliefste, J., Visser, M., Ligterink, J., Hantelmann, S., van Munster, L., & van Oosterhout, K. (2022). *Voorkomen is beter dan genezen: ruim 8 patiënten minder voor elke hectare extra groen*. Retrieved from https://www.sweco.nl/wp-content/uploads/sites/5/2022/10/Whitepaper_Sweco_Voorkomen-is-beter-dan-genezen.pdf

IPCC. (2002). *Climate Change and Biodiversity - IPCC Technical Paper V*. Retrieved from https://www.tnrf.org/files/E-INFO_IPCC_2002_Climate_Change_and_Biodiversity_0.pdf

Koetse, M. J., Renes, G., Ruijs, A., & de Zeeuw, A. J. (2017). *Relatieve prijsstijging voor natuur en ecosysteemdiensten in de MKBA*. Retrieved from https://www.pbl.nl/sites/default/files/downloads/PBL-2017-Achtergrondrapport-relatieve-prijsstijging-natuur-en-ecosysteemdiensten-2229.pdf

Mabon, L. (2021). Nature-Based Solutions and the Green Economy. In. London: The British Academy.

Meijer, G., & Mossink, F. (2021). *Handreiking Nieuwegein City Natuurinclusief - Maatregelen en richtlijnen voor een natuurinclusieve binnenstad*. Retrieved from

Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Synthesis. In. Washington, DC.,: Island Press.

Moens, E., Hand, A., & Hegger, D. (2020). *Building resilience: being young and getting old in a hotter Europe*. Retrieved from https://www.swecourbaninsight.com/wp-content/uploads/2020/10/report-building-resilience.pdf

Mommers, V., Dekker, G., van de Leemkolk, W., & Handgraaf, S. (2021). *Analyse knelpunten natuurinclusief bouwen*. Retrieved from https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2021/05/25/analyse-knelpunten-natuurinclusief-bouwen/analyse-knelpuntenonderzoek-natuurinclusief-bouwen.pdf

Ojala, T., & Campbell, I. (2020). *Building in biodiversity: For climate, for health*. Retrieved from https://www.swecourbaninsight.com/wp-content/uploads/2020/10/urban-insight-report_building-in-biodiversity_booklet.pdf

Posma, J., de Kort, R., & Warringa, G. (2018). *LIFE @ URBAN ROOFS - SCBA multifunctional roofs - General report*. Retrieved from https://cms.4bg.nl/uploads/12/files/180525_LIFE@Urban-Roofs-Report-SCBA-General-English-Version.pdf

Remme, R., de Nijs, T., & Paulin, M. (2018). *Natural Capital Model - Technical documentation of the quantification, mapping and monetary valuation of urban ecosystem services*. Retrieved from https://www.atlasnatuurlijkkapitaal.nl/documenten/natural-capital-model-technical-documentation-of-quantification-mapping-and-monetary

Romijn, G., & Renes, G. (2013). *General Guidance for Cost-Benefit Analysis*. Retrieved from https://www.pbl.nl/en/publications/general-guidance-for-cost-benefit-analysis

van 't Hoff, V., Siebers, M., van Vliet, A., Broer, W., & de Groot, D. (2022). *Make nature count - Integrating nature's values into decision-making*. Retrieved from https://www.asnbank.nl/web/file?uuid=a50f13c5-01ec-4f73-8a23-8b61573bbdba&owner=6916ad14-918d-4ea8-80ac-f71f0ff1928e&contentid=5054

van der Heide, M. (2015). *Waardering van stedelijk groen en blauw - Evaluatie van het gebruik van de TEEB-Stad tool*. Retrieved from https://www.pbl.nl/sites/default/files/downloads/PBL-2015-Waardering-van-Stedelijk-Groen-en-Blauw-1761.pdf

Victoria University and University of Melbourne. (2018). *Quantifying the benefits of green infrastructure in Melbourne - Literature review and gap analysis*. Retrieved from https://www.melbourne.vic.gov.au/SiteCollectionDocuments/quantifying-benefits-green.pdf

WWF. (2018). *Living Planet Report - 2018: Aiming Higher*. Retrieved from https://c402277.ssl.cf1.rackcdn.com/publications/1187/files/original/LPR2018_Full_Report_Spreads.pdf

Web pages

Berrisford, K. (2021). A Simple and Visual Definition of Biodiversity. Retrieved from https://nbs.net/articles/a-simple-and-visual-definition-of-biodiversity/

Bouw natuurinclusief. (2021). De Omgevingswet en natuurinclusieve maatregelen. Retrieved from https://bouwnatuurinclusief.nl/blogs/natuurinclusief-bouwen-en-de-omgevingswet

CAS, S. (2022). NAS-adaptatietool. Retrieved from https://klimaatadaptatienederland.nl/overheden/nas/adaptatietool/

European Commission. (2022). The Economics of Ecosystems and Biodiversity. Retrieved from https://ec.europa.eu/environment/nature/biodiversity/economics/

Imarticus Learning. (2019). The difference between financial analysis and economic analysis. Retrieved from https://blog.imarticus.org/the-difference-between-financial-analysis-and-economic-analysis/

IUCN. (2016). Nature-based Solutions. Retrieved from https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Kennisportaal Klimaatadaptatie. (2022). Kaartviewer - Klimaateffectatlas. Retrieved from https://www.klimaateffectatlas.nl/nl/

Montjoy, V. (2022). Can exterior green walls contribute to a carbon neutral architecture? Retrieved from https://www.archdaily.com/978695/can-exterior-green-walls-contribute-to-a-carbon-neutral-architecture

Nature-based Solutions Initiative. (2022). What are Nature-based Solutions? Retrieved from https://www.naturebasedsolutionsinitiative.org/what-are-nature-based-solutions/

Nielsen, j. (2000). Why you only need to test with 5 users. Retrieved from https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

Nielsen, J. (2012). How Many Test Users in a Usability Study? Retrieved from https://www.nngroup.com/articles/how-many-test-users/

Respyre. (2022). Respyre. Retrieved from https://www.gorespyre.com/

Rijksoverheid. (2020). Handreiking decentrale regelgeving klimaatadaptief bouwen en inrichten. Retrieved from https://www.rijksoverheid.nl/documenten/brochures/2020/04/30/handreiking-regelgeving-klimaat-adaptief-bouwen-en-inrichten

Sweco. (2020). Tien tips voor een natuurinclusieve stad. Retrieved from https://www.sweco.nl/actueel/verhalen/10-tips-voor-een-natuurinclusieve-stad/

Sweco. (2021). Biodiversiteit eenvoudig berekenen met de natuurpuntencalculator. Retrieved from https://www.sweco.nl/portfolio/natuurpuntencalculator/

The World Bank. (2022). World Development Indicators. Retrieved from https://databank.worldbank.org/reports.aspx?source=world-development-indicators

United Nations. (2018). 68% of the world population projected to live in urban areas by 2050, says UN. Retrieved from https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

United Nations. (2021). Secretary-General's statement on the IPCC Working Group 1 Report on the Physical Science Basis of the Sixth Assessment. Retrieved from https://www.un.org/sg/en/content/secretary-generals-statement-the-ipcc-working-group-1-report-the-physical-science-basis-of-the-sixth-assessment

Vesteda. (2022). Wonen in Paradium 3. Retrieved from https://www.vesteda.com/nl/huurwoningen-dordrecht/paradium-3

WorldGBC. (2021). WorldGBC Net Zero Carbon Buildings Commitment expands to include embodied carbon. Retrieved from https://worldgbc.org/news-media/commitment-includes-embodied-carbon

WUR. (2022). Multiple Values of Nature. Retrieved from https://www.wur.nl/en/Research-Results/Themes/Biodiversity/Multiple-Values-of-Nature.htm

Interviews, meetings and personal communication

Ottelé, M. (2022). [Meeting with Dr.ir. Marc Ottelé (TU Delft, research expertise in the field of sustainable building envelopes)].

Rotteveel, M. (2022). [Meeting with Mark Rotteveel (Ambassador for a liveable city and project advisor at Koninklijke Ginkel Groep)].

Sweco expert knowledge (2022). [Sweco's internal expertise, conversations and documents].

Appendices

From this page onwards, the appendices of this thesis work are attached.

A

Elaborated research methodology

In this appendix, more detailed substantiations of intermediate objectives/questions and considerations are provided, which should be answered regarding the current state of the art for the thesis subjects.

Theoretic background and general knowledge with regards to thesis topic

- What are Nature-based Solutions (NBS) in an urban context, how can they be implemented on buildings and how can they help to design an enhanced living environment?
- What are vertical greening systems, which different types exist and what are their prime characteristics and pros and cons? Which type will be used for the further elaboration of this research?
- What are the technical (and structural) attention points with regards to the implementation of the different vertical greening systems on existing structures? Which vertical greening system(s) would be most feasible for implementation in transformation projects? Are there major differences with new development projects?
- What are the different types of costs and benefits of vertical greening systems that can be identified?
- How can the different types of costs and benefits of vertical greening systems be categorised/thematised (while also taking into account ecosystem services)?
- Which effects of vertical greening systems are measurable and hence quantifiable at this moment in time?
- What are ecosystem services and derived benefits or potential values at risk in the built environment, and what do they entail?
- Which ecosystem services and derived benefits apply to, or are provided by, vertical greening systems and which values at risk in the built environment can be reduced?
- What are (different types of) green roof systems and what links can be made with vertical greening systems? What are common values or mutual ecosystem services that can be delivered?
- What knowledge from green roof systems can be used in order to gain additional insight into the effects of vertical greening systems, especially in areas where substantial literature regarding the latter systems is lacking?

Quantitative/Monetary data

- What are the costs of implementing different vertical greening systems on buildings? I.e. investment costs (engineering, production, installation, permit fees, etc.), maintenance and replacement costs, disposal costs. Aside from financial costs, also the environmental costs (shadow costs) of the systems should be taken into account.
- What numerical and monetary values are present in literature with regards to the effects of ecosystem services and derived benefits, delivered by vertical greening systems?
- With previous information, data and boundary/control conditions of studies, an orderly overview (table) will be created of all values found in literature.

- For which ecosystem services or derived benefits are quantitative/monetary values missing at this moment in time? What can be done in order to overcome the present knowledge gap for this research?
- Which type of vertical greening system will be used to develop the valuation framework and hence be incorporated in the monetary valuation study? Sufficient data should be found for this/these system(s) in order to proceed with a comprehensive evaluation.
- What is relevant data regarding the surroundings in which an evaluated project/case is located? What is this data or where can it be found?
- Are there any additional (technical) difficulties, other than lagging knowledge and executed research, with regards to quantifying and monetizing the values delivered by vertical greening systems as compared to other urban NBS? If so, what are these and how can one cope with these difficulties?
- What knowledge/data from green roof systems can be used in order to gain additional insight in quantitative/monetary values of vertical greening systems, and why? Can assumptions or estimated guesses be made for certain effects of vertical greening systems through knowledge present for green roof systems?

Pricing techniques and valuation analysis methods

- What is Ecosystem Services Valuation (ESV) and which studies have previously been conducted for vertical greening systems?
- How does the SCBA exactly work and what data is needed to perform this analysis? Are there any potential alternatives for SCBA that are worthy for consideration as economic analysis method?
- What pricing techniques are available and previously used? How do these techniques work? Which one can be used for the quantification/monetization of what ecosystem service or derived benefit?
- What is an appropriate way of evaluating and comparing the added value for the biodiversity, delivered by the implementation of a vertical greening system?
- What level of detail or precision should be strived for according to literature review, or what are the costs of increasing precision for ESV studies?
- In what ways can the proposed calculation model be validated and/or verified?

Stakeholders

- Who are the different stakeholders involved/considered and how do they relate to vertical greening systems or urban NBS in general?
- What do the ecosystem services and derived benefits of vertical greening systems entail for different stakeholders or how are their delivered values perceived per group? E.g. what is the difference in value for a real estate investor/property manager (client organisation) and society at large? Hence, what effects of the vertical greening systems are relevant (or have value) for whom?
- Given the importance of understanding the fundamental differentiation in value for stakeholders, it should be considered whether different analysis methods should be used to monetize the values for these groups. E.g. SCBA vs. PCBA (financial business case).
- What are the preferences of stakeholders (especially decision-makers), looking from a utilization focussed perspective, with regards to a comprehensive economic valuation model for vertical greening systems?

B
Literature review - Nature-based Solutions

In this appendix, based on preliminary literature research some background information regarding Nature-based Solutions (NBS) is presented. Vertical greening systems, the main topic of this research, form a sub-category of NBS in the urban environment.

First, the appendix will deal with the concept of NBS and their presence and relevance in the urban fabric. Also, vertical greening systems (VGS) are placed within the context of NBS. Later, the link between NBS and (urban) biodiversity is explored and the current place of NBS in legislation, guides and labels in the Netherlands are touched upon.

B.1 Concept of Nature-based Solutions

The first important topic to address is the aspect of what the concept of a Nature-based Solution (NBS) exactly entails. Generally speaking, the International Union for Conservation of Nature defined NBS as "Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human health & well-being and biodiversity benefits" IUCN (2016). More specifically aimed at urban applications of NBS, Langergraber et al. (2020) defined them as concepts that bring nature into cities, which in many cases include ideas for urban design that are derived or inspired from nature. Simply stated, NBS can be viewed upon as an umbrella term for solutions to societal challenges that are based on an ecosystem-related approach, and which address these challenges through delivery of 'ecosystem services' (Figure B.1). For more information on ecosystem services (ES), reference is made to appendix C.

Figure B.1: NBS as an umbrella term for ecosystem-related approaches (IUCN, 2016)

Some examples of NBS in rural areas are reforestation, restoration of wetlands and coastal habitat restorations like e.g. mangroves, reefs and salt marshes. These NBS contribute to ES like securing and regulating water supplies, food production, protection from floods or storm surges, soil erosion and landslides, and the sequester of carbon. In order to bring nature into cities and create urban NBS, among others the following measures comply: implementation of blue-green roofs and green façades/walls, planting trees or flowerbeds in streets or on balconies, gardens, urban forests, creation of constructed wetlands, helophyte filters, bioswales, ponds and the construction of permeable pavements and parking lots. (Nature-based Solutions Initiative, 2022; P. Pereira & Baró, 2022)

These last types, the NBS in urban environments, form the basis for this thesis work. In particular VGS, which are NBS that can be applied directly on buildings. Therefore, the implementation of different typologies of (smart) blue/green/yellow roofs or gardens and vertical greening systems (façades/walls) will be elaborated during the research, with the main goal to increase the knowledge on vertical greening systems.

For green roofs, a distinction can be made between extensive, semi-intensive and intensive green roofs (Figure B.2), all possible in combination with a blue roof or to be extended to bio-solar roofs (yellow roofs). The main difference lies in the intensity of vegetation (and hence the thickness of the substrate layer), the required maintenance and different ways of construction. Extensive roofs contain less mass and have a thinner substrate layer, which means they can be easier realised on existing buildings. Usually the vegetation exists of sedum, mosses or herbs. Intensive roofs can vary from watered grasses or herb roofs to city parks on a building's rooftop. They have a larger substrate thickness and thus contain more mass, which makes them less suitable for existing buildings. Blue roofs expand the water storing capacity of roof surfaces and enable reuse of rainwater. Yellow roofs facilitate the combination of both providing renewable energy (increased solar panel efficiency due to cooling effect and reduced particulate matter accumulation) as well as an increased biodiversity, since shading of the panels reduces the evaporation rates and drought stress, thereby contributing to plant species richness (Catalano & Baumann, 2017).

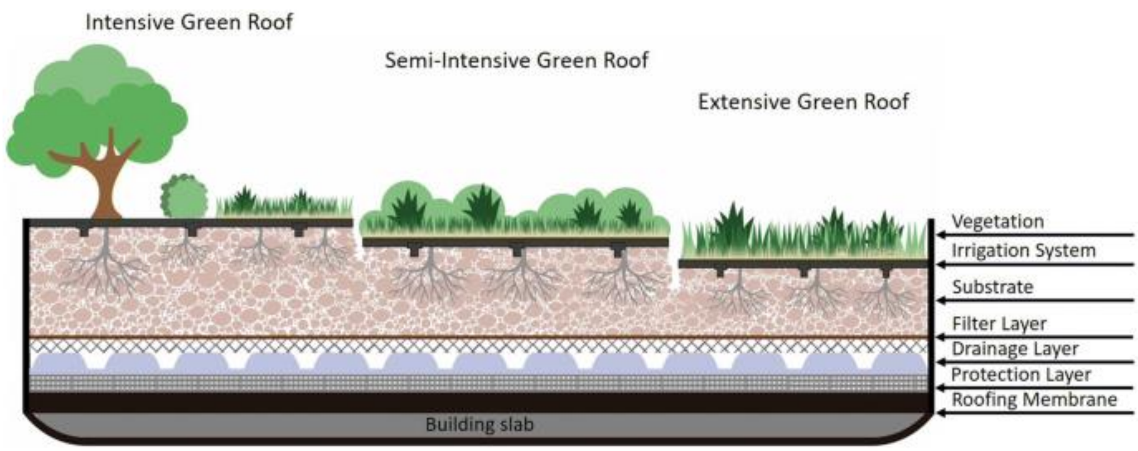


Figure B.2: Different typologies of green roof systems (Calheiros & Stefanakis, 2021)

For vertical greening systems, the main distinction can be made between green façade systems and green/living wall systems (Figure B.3). Green façade systems often cover a façade partially, while living wall systems cover the entire surface and are usually installed in modules. In addition to these systems, nowadays also the research into bio-receptive surfaces is starting to take its flight due to technological advancements in the field of development of bio-receptive materials. Vertical greening systems are further elaborated in Chapter 2.

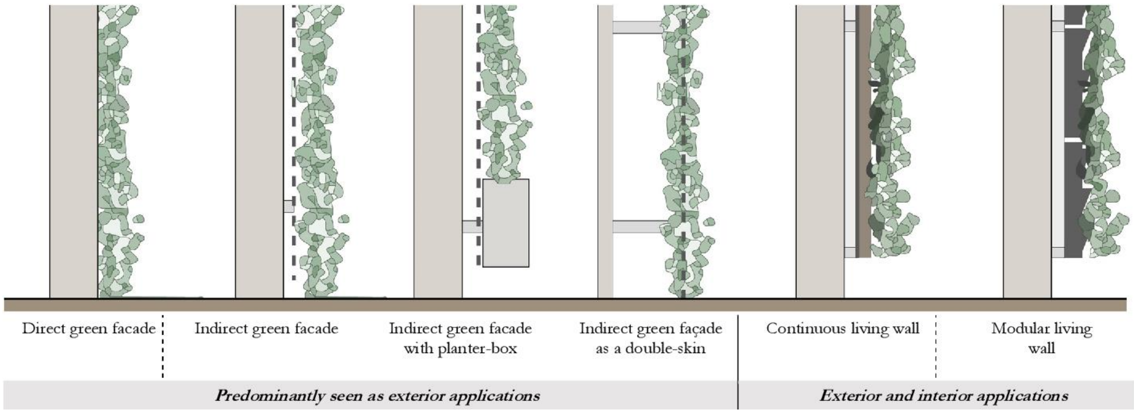


Figure B.3: Different typologies of vertical greening systems (Gunawardena & Steemers, 2019)

B.2 Biodiversity in Nature-based Solutions

In order to elaborate on the connection between urban Nature-based Solutions and biodiversity, first it has to be clear what is meant with the term biodiversity. The UN Convention on Biological Diversity (UNCBD) defines biodiversity as follows: "The variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species (genetic), between species, and of ecosystems." (IPCC, 2002).

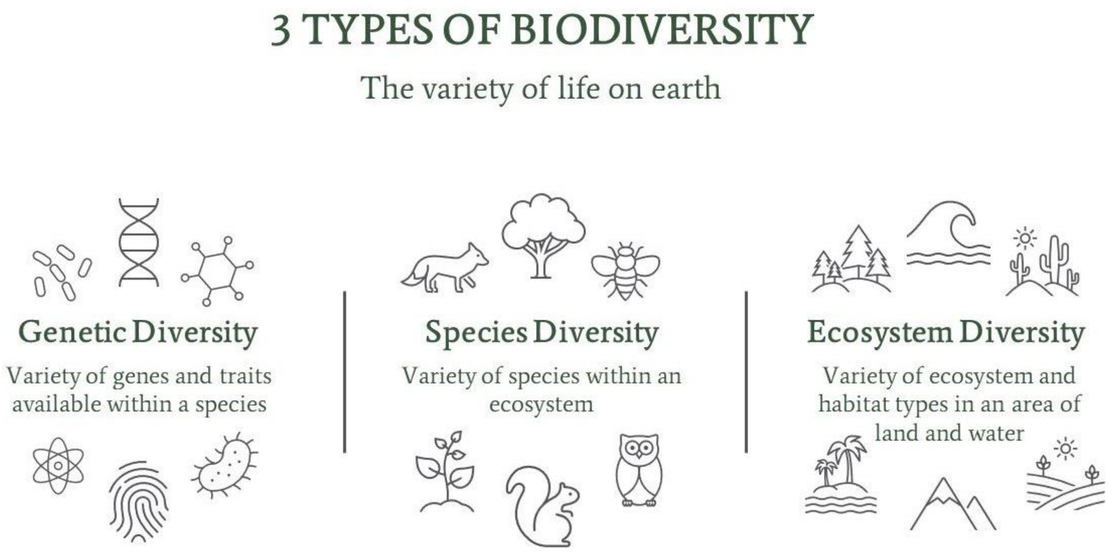


Figure B.4: 3 Types of biodiversity (Berrisford, 2021)

According to the United Nations' Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the health of natural ecosystems, hence biodiversity, is deteriorating more rapidly than ever (Ojala & Campbell, 2020). The lack of (urban) vegetation exposes us to pollutants, heat waves, vector-borne diseases and other negative effects of climate change. This causes to affect the foundations of our economies, livelihoods, food security, health and quality of life.

Rich, healthy and biodiverse ecosystems however, could provide us with many commodities and are vital to our survival. For example, it can contribute to coping with climate adaptation, climate mitigation, health & well-being, and many more benefits (environmental, social and economic) that add value to the living environment. According to e.g. Kirk et al. (2021), urban biodiversity is a key component for human well-being and successful nature conservation within cities. This in the way of

supplying ecosystem services, thus providing regulating, provisioning, cultural and supporting services (P. Pereira & Baró, 2022).
Since urbanisation is increasing, in their current form expanding cities impose a great challenge to overall biodiversity and climate change (Kirk et al., 2021; P. Pereira & Baró, 2022). Buildings and other impervious surfaces alter natural areas into artificial environments. The geographical location of cities, often concentrated in biodiversity hotspots like along coastal areas and rivers, increases this threat. (Ojala & Campbell, 2020)

However, opportunities for the presence of biodiversity and nature in urban spaces are often underrated and P. Pereira and Baró (2022), among others, state that NBS can be used to restore urban ecosystems and increase biodiversity. Existing of a variety of building structures and façade typologies, cities are able to create multiple microclimates that are used by generalist flora and fauna, thus mimicking natural environments. This enables opportunities for flora and fauna to thrive in urban areas, even more so than in rural areas where monocultural farming is mainstream, leading to reduced protection from surroundings.

Ensuring that cities can thrive as ecosystems lies in providing an adequate habitat design for specialist species as well. Nowadays mostly generalist species are attracted by urban areas. This holds that through urban planning natural diversity should be supported. Since higher biodiversity levels enhance ecosystem functioning, thus providing ecosystem services more effectively, original and indigenous (specialist) species should be given a more prominent place in the urban fabric. (Ojala & Campbell, 2020)

Additionally, in order to create rich and healthy ecosystems, enabling the presence of high biodiversity levels and supporting ecosystem services on multiple urban planning scales is essential. I.e. at a city scale, neighbourhood and street scale and building scale (Figure B.5). This can be achieved by maintaining existing biodiversity values, restoration of biodiversity in less favourable conditions and via the creation of new biodiverse habitats. In this thesis, the focus is mainly on the last principle. With vertical greening systems, a type of urban NBS is proposed that enables the opportunity for new natural and biodiverse vertical surfaces. This at locations that were previously inaccessible for vegetation without harming the underlying construction.

Scale	Key Advice for Helping Ecosystems Services (for Health and Climate)	Who Should be Involved?
City scale	1 **Mental and Physical Health.** Connect nature in cities with local ecosystems in suburban and rural areas to create blue-green corridors. Save natural areas for recreation. 2 **Water Regulation, Water Purification and Waste Treatment.** Create blue-green backbones / structure in the city consisting of parks and connecting green structures. Connect urban and rural areas using forests, rivers and by creating green wedges and corridors. Protect natural waterways. 3 **Soil Formation. Nutrient Cycling.** Use permeable materials and native species, save biogeographical characteristics like plant and animal species and habitats typical for the area. Compensate for the damages.	- Local planning authorities - Town planners - Transport planners - Engineers - Landscape architects - Ecologists
Neighbourhood and street	1 **Pollination, Disease and Pest Regulation.** Structural and species variation in green space design. Favour pollinator-friendly species in gardens and public areas. Avoid monocultures and pesticides. 2 **Recreation and Tourism.** Integrate natural habitats into play areas, garden walks and schoolyards for recreation and connect to local ecosystems within the wider landscape. Easy access routes for recreation. 3 **Climate Regulation. Air Quality Regulation. Moderation of Extreme Events.** Age and species variation of urban trees – protecting semi-mature and mature trees. Permeable surfaces and wetlands for water regulation.	- Local planning authorities - Town planners - Engineers - Architects - Landscape architects - Ecologists - Local conservation groups - Local businesses - Constructers
Building/ garden	1 **Air Quality Regulation. Food and Water Provisioning.** Nature-based solutions included within design of buildings (include bird and bat houses, green facades etc). Use roof tops as available spaces to enhance nature and produce food. Save and plant trees and bushes. 2 **Mental and Physical Health.** Adopt nature-friendly garden management techniques. Community gardens. Volunteer work. 3 **Soil Formation. Nutrient Cycling. Pollination.** Use native and pollinator-friendly species and connect to the local ecosystems. Use natural fertilizers. Avoid excess soil preparation. Transform lawns into meadows. Avoid alien species and pesticides.	- Architects - Landscape architects - Local conservation groups - Local businesses - Community-led groups - Individuals - Ecologists

Figure B.5: Sweco experts' recommendations to enhance ecosystems and biodiversity on different urban planning scales (Ojala & Campbell, 2020)

B.3 NBS in the Netherlands: legislation, codes, guidelines and labels

In the Netherlands, no centralised legislation or standards are applicable yet with regards to climate adaptive and nature-inclusive building. However, the national government does stimulate climate adaptation through 2 programs: 'Deltaprogramma Ruimtelijke Adaptatie' and 'Nationale Adaptatiestrategie'. In these programs, the central government cooperates with water boards, provinces and municipalities.

The current legal system offers many possibilities for legally securing climate adaptive construction and design. Municipalities in particular can already lay down and regulate a great deal in their policies and spatial plans. In practice, however, little use is made of these possibilities. One of the reasons for this is that knowledge of what is and is not legally possible is not always available. For this reason, a working group has taken the initiative to develop a guide on decentralised regulation for climate adaptive building and design: 'Handreiking decentrale regelgeving klimaatadaptief bouwen en inrichten'. (Rijksoverheid, 2020)

With regards to nature-inclusive buildings, opportunities arise with the implementation of the new Dutch Environment and Planning Act (EPA, Omgevingswet). With this EPA, municipalities, provinces and water boards have opportunities to encourage or legally enforce nature-inclusive building and management through decentralised regulation. At the moment of writing however, no legally binding measures are applicable. Currently, the only option is for decentralised governments to include nature-inclusive measures as wishes in their tenders, rather than as requirements. This is the case, as there are only limited legal possibilities to include hard requirements that exceed the Buildings Decree (Bouwbesluit 2012) in a request for proposal or in the assessment of a permit application. (Bouw natuurinclusief, 2021) (Mommers et al., 2021)

Besides legally binding legislation or codes, there are some acknowledged authorities that distribute sustainability certificates, hereby also taking into account categories that can be positively affected by nature-inclusive building. These certificates can influence the image of a certain building or their proprietor, since the certificates relate to sustainability scores and a healthy or productive working and living environment. Some of these certificates or authorities are listed below:

- BREEAM-NL – issued by DGBC, focus on several sustainability aspects
- WELL Building Standard – primarily focussed on health and well-being in buildings
- LEED – used/applicable in United States
- GPR Gebouw – 'Gemeentelijke Praktijk Richtlijn'
- GRESB – Global Real Estate Sustainability Benchmark
- NL Greenlabel – labels for green, sustainable and climate adaptive living environment

Additionally, there are some tools and regulations from the European Union (EU) which help or demand the real estate sector to become more sustainable, energy efficient and climate adaptive. Some examples of these tools and regulations are listed below:

- CRREM – Carbon Risk Real Estate Monitor, allows investors and property owners to assess the exposition of their assets to stranding risks based on energy and emission data and the analysis of regulatory requirements
- SFDR – Sustainable Finance Disclosure Regulation, obliges managers of alternative investment funds and managers of collective investment undertakings to specify information regarding sustainability in the prospectuses of the (sub)funds they manage
- EU-Taxonomy – Tool created by the EU in line with the EU Green Deal, to facilitate the classification of activities that are sustainable. The purpose of this classification system is to facilitate the movement of financial capital towards sustainable activities whilst being transparent and avoid greenwashing. The EU taxonomy regulation is obligatory for publicly traded companies that have more than 500 employees and for financial market participants.

The latter group includes e.g. investment firms, asset managers, pension providers and insurance-based investors.

With respect to the EU-taxonomy regulation, the economic valuation of NBS can be an important instrument for investment firms or companies in the real estate sector to showcase the contributions of their investments in sustainable measures and demonstrate their worth. To be taxonomy aligned, economic activity needs to contribute substantially to one of the six environmental objectives defined in the regulation, while not causing significant harm to other objectives. These objectives include (1) climate change mitigation, (2) climate change adaptation, (3) sustainable use and protection of water and marine resources, (4) transition to a circular economy, waste prevention and recycling, (5) pollution prevention and control and (6) protection and restoration of biodiversity and healthy ecosystems. (Busuttil, 2021)

Hence, the implementation of NBS could prove to be valuable for the real estate sector. This in the fields of transitioning towards taxonomy aligned investments, securing access to finance, increasing company reputation among stakeholders and generating positive social impact.

C

Literature review - Ecosystem services, derived benefits and biodiversity

In this appendix, based on preliminary literature research some background information regarding Ecosystem Services (ES) and derived benefits is presented. Vertical greening systems, the main topic of this research, deliver value and goods to society in the form of these benefits.

First, the appendix will deal with Ecosystem Services and their place within the 'Triple-Green design and build concept'. Also, a breakdown of the Ecosystem Services as listed in literature is provided. Subsequently, the importance of Biodiversity for the delivery of Ecosystem Services is stressed and the phrase 'Biodiversity as priority' is adopted as guiding principle throughout this thesis work. Finally, starting points, requirements and boundary conditions with regards to biodiversity in VGS are denoted and Sweco's 'Natuurpuntencalculator' is briefly discussed.

C.1 Concept of Ecosystem Services

The Sustainability Research Group of the Materials & Environment section, Faculty of Civil Engineering and Geosciences of the Delft University of Technology, has developed a design and build concept in which functional performance, service life and socio-environmental impact of constructions are integrated. This is called the 'Triple-Green design and build concept' (Figure C.1). The concept focuses not only on the minimization of the environmental impact of constructions, but it goes one step further by requiring constructions to deliver added value to the environment in which it is placed. In their view, these 3 complementary levels of sustainability should be met in order to deliver a sustainable project. (Jonkers, 2020)

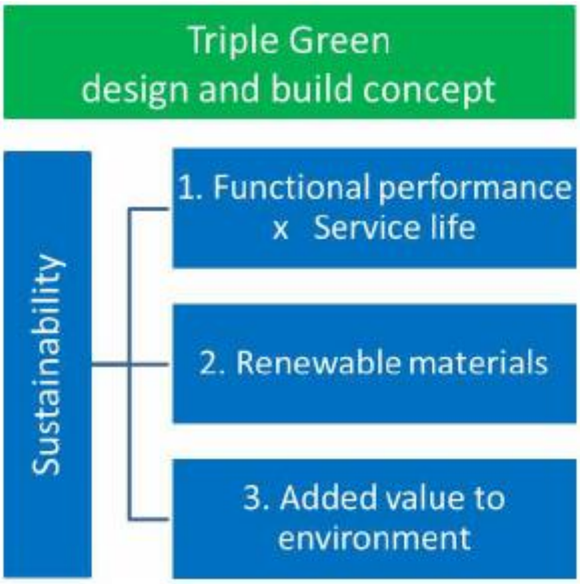


Figure C.1: 'Triple-Green design and build concept', representing sustainability at three complementary levels (Jonkers, 2020)

The third level, providing added value to the direct environment in which a project is located, is what links this concept to the scope of the thesis. Currently, most constructions and projects still have a net negative environmental effect because they consume finite resources and emit harmful substances over their entire life cycle. With the third level of the 'Triple-Green' concept, the potential arises to elevate from these net negative effects towards net positive effects. This can be achieved by implementing ecosystem functionality in the construction, e.g. through the use of NBS. As highlighted before, nature (ecosystems and biodiversity) can provide both products as well as processes which are useful to society 'for free'. The intersection of building engineered constructions and implementing nature is called 'Ecological Engineering'. (Jonkers, 2020)

During this thesis research we will follow the definition of 'ecosystems' and 'ecosystem services' as they were drawn by the Millennium Ecosystem Assessment (MA). MA recalled an ecosystem as "A dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit", while ecosystem services (ES) were simply defined as "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005). In line with this definition, a list of ES is provided in Table C.1.

The ES listed in Table C.1 also contribute to benefits regarding reduced vulnerability of real estate as consequences of climate change. This implies that climate adaptation values are included in these ES, called adaptation services (AS) (Lavorel, Locatelli, Colloff, & Bruley, 2020). Some important and highly topical climate adaptation benefits are reduced urban heat stress around buildings (14: Climate regulation – regional and local) and reduced risks to flooding (15: Water regulation).

Table C.1: Overview of ecosystem services delivered by ecosystems (Millennium Ecosystem Assessment, 2005)

Nr.	Type	Description of ecosystem service
1	Provisioning	Food (crops)
2		Food (livestock)
3		Food (capture fisheries)
4		Food (aquaculture)
5		Food (wild foods)
6		Fiber (timber)
7		Fiber (cotton, hemp, silk)
8		Fiber (wood fuel)
9		Genetic resources
10		Biochemical, natural medicines, pharmaceuticals
11		Fresh water
12	Regulating	Air quality regulation
13		Climate regulation – global
14		Climate regulation – regional and local
15		Water regulation
16		Erosion regulation
17		Water purification and waste treatment
18		Disease regulation
19		Pest regulation
20		Pollination
21		Natural hazard regulation
22	Cultural	Spiritual and religious values
23		Aesthetic values
24		Recreation and ecotourism
(25)	Supporting	Soil formation
(26)	*(not directly used*	Photosynthesis
(27)	*by people)*	Nutrient cycling

Figure C.2 presents a visual overview of the ecosystem services, as adopted from the *Living Planet Report* by WWF (2018). Here, coherent services are grouped into more generic categories, reducing the total number of different ES. As for the types of ES, provisioning services deliver products which are obtained from ecosystems. Regulating services comprise benefits that are obtained from the regulation of ecosystem processes, whereas cultural services contain nonmaterial benefits that people experience from ecosystems. Finally, supporting services are necessary for the creation and preservation of all other ES.

Benefits for humans can be derived from ecosystems and ecosystem services in an urban context and these are not directly captured within the 24 primary ES as provided in Table C.1 or the categories as displayed in Figure C.2. Benefits and values resulting from these benefits follow from the pathway as displayed in Figure 3.3. Some can be regarded as a mix or sub-category of one of the services listed. Others are not directly related to the natural capital itself, but result from human perception or financial/commercial consequences of the natural surroundings. The latter can be viewed upon as a result of the arrangement of the contemporary economic system. Gómez-Baggethun and Barton (2013) stated that: “Urban ecosystems are especially important in providing services with direct impact on health and security”. From the same researchers, a classification of important ecosystem functions and services in an urban context was adopted in

Table C.2. Contradictory, they also listed some examples of potential Ecosystem Disservices (ESD) in urban areas (Table C.3), which have been defined as 'functions of ecosystems that are perceived as negative for human well-being' (Gómez-Baggethun & Barton, 2013).

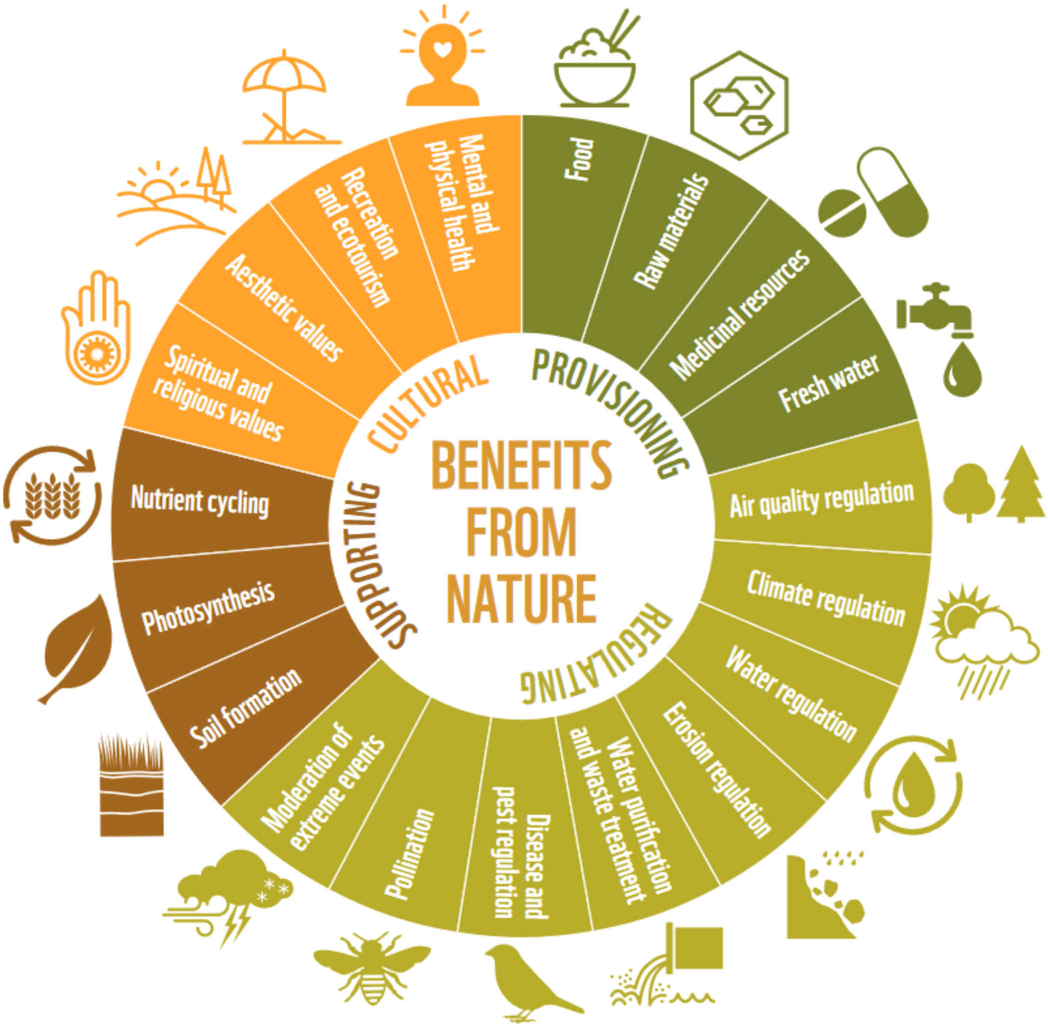


Figure C.2: Benefits from nature, adopted from Living Planet Report (WWF, 2018)

Table C.2: Classification of important ecosystem services in an urban context (Gómez-Baggethun & Barton, 2013)

Nr.	Description of urban ecosystem service
1	Food supply
2	Water flow regulation and runoff mitigation
3	Urban temperature regulation
4	Noise reduction
5	Air purification
6	Moderation of environmental extremes
7	Waste treatment
8	Climate regulation
9	Pollination and seed dispersal
10	Recreation and cognitive development
11	Animal sighting

Table C.3: Examples of potential ecosystem disservices in an urban context (Gómez-Baggethun & Barton, 2013)

Nr.	Description of potential ecosystem disservice
1	Air quality problems (due to emissions from some trees/bushes)
2	View blockage
3	Allergies
4	Accidents
5	Fear and stress (dark green areas perceived as unsafe in night-time)
6	Damages on infrastructure
7	Habitat competition with humans

C.2 Biodiversity as VGS priority, rather than as resulting value

Important direct drivers affecting Ecosystem functioning and delivery of Ecosystem Services are environmental factors (e.g. soil type, position in the landscape, climate and water availability), land-use and the presence of rich and abundant biodiversity in multiple trophic levels. The trophic level is the position an organism occupies in the food chain.

Many experiments have shown that loss of biodiversity reduces the capacity of ecosystems to provide the multiple services on which humans depend (Cardinale et al., 2012; Naeem, Duffy, & Zavaleta, 2012). This is further acknowledge by e.g. Kirk et al. (2021), who state that many of the human benefits following from urban nature arise from “interaction with structurally-complex and biodiverse green spaces, with a higher diversity of species delivering greater health, well-being and social benefits”. Moreover, Soliveres et al. (2016) concluded that high species richness, especially in multiple trophic groups, has positive effects on Ecosystem Services. Even more so than richness in any individual trophic group.

Therefore, in order to create rich, healthy, appealing and future-proof living environments for both human society as well as animals and other species, nature should be given a full place in the design of new buildings, redevelopment projects and public spaces. Supported by literature research, the author beliefs that biodiversity should therefore not only be valued in hindsight, after implementation of a VGS.

In the contrary, it should be a key priority during the planning and design of buildings, or more specifically the VGS. This way the opportunity arises to facilitate and provide for a (local) environment where biodiversity can thrive, cross-pollinate and maintain and enhance ecosystem functioning (van 't Hoff et al., 2022). This view is furthermore supported by several experts in the field of green solutions and ecology (Rotteveel, 2022; Sweco expert knowledge, 2022), who additionally state that biodiversity is at the base of all Ecosystem Services we need. This could partially be achieved by the implementation of vitally healthy VGS.

C.2.1 Biodiversity as priority

For this thesis, the starting principle is taken that whenever nature is implemented in the design of a building or public space, it should have significant and proven added value for (urban) biodiversity. This means not only there should be more green space, but also a better thinking about how to design that green space. This enhances the ability to contribute to a more climate resilient built environment, also it enables ecosystem conservation and functioning, which provides many commodities that are vital to our survival (Ojala & Campbell, 2020). For example Synchroon, a Dutch real estate development firm, claim to have already adopted this principle for their future projects.

Hence, improved biodiversity should be a requirement from the start, rather than merely an assessable outcome of implementing urban nature. This implies that in this thesis, no direct economic valuation will be performed for biodiversity, meaning biodiversity as a category won’t get a (direct) monetary value. In this case, increased biodiversity is viewed upon as a fundamental and intrinsic value of nature (Nature for Nature, see section 3.2.1). However, qualitative benefits or values resulting from biodiversity are stated in the framework and tool. Like displayed in Figure C.3, other assessable (co-) benefits, e.g. delivered through ecosystem services and following from ecosystem structure and functioning, can then be economically valued (Nature for Society). These benefits are assessed with so-called value indicators. Value indicators are essentially used to express the benefits resulting from ecosystem services in monetary terms.

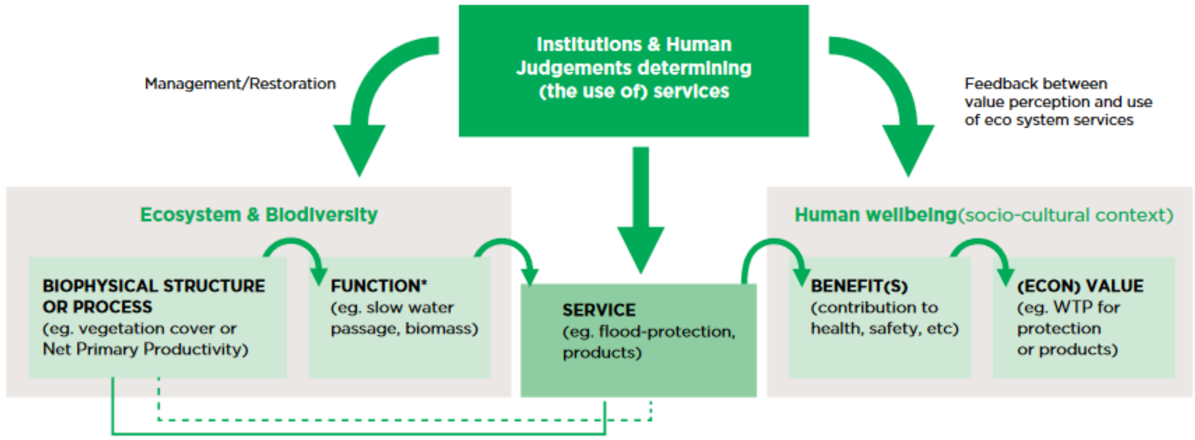


Figure C.3: Pathway from ecosystem structure and biodiversity to economic value for human well-being (de Groot et al., 2010; Victoria University and University of Melbourne, 2018)

C.2.2 Standards, starting points, requirements and boundary conditions with regards to biodiversity

The delivered ecosystem services and derived benefits are also inherently dependent on the extent of biodiversity that is present in the vertical greening system (Kirk et al., 2021). Hence, this means that (the level of) biodiversity will indirectly be valued through other value indicators, relating to e.g. the categories of Health & Well-being, Climate adaptation & mitigation, Real Estate or Recreational & Commercial & Social values (see Figure C.3). Therefore, certain standards with respect to biodiversity in the vertical greening system have to be compiled or stated for the economic valuation of the system as a whole.

To integrate nature and biodiversity in projects, some municipalities in the Netherlands use a point system for tenders, meaning development projects should meet a certain point threshold in order to get approval. For example, the city of Amsterdam applies the point system 'Natuurinclusief bouwen', for which a minimum of 30 points should be obtained in order to compete for a project contract. A well designed Living Wall System (LWS) using a circular and sustainable irrigation system and containing over 20 native plant/shrub/tree species, can acquire up to 30 points for the project. This system holds for new development projects in the residential segment (Gemeente Amsterdam, 2021). Similar types of systems are adopted by the municipalities of The Hague, Arnhem and Ede, however the interpretation of point scoring may differ.

Since high biodiversity implies to have a value-added effect in the economic valuation of ecosystem services and derived benefits of VGS, certain assumptions have to be made as to what biodiversity level corresponds to the values derived in the economic valuation model. In order to account for an optimal/sufficient LWS in terms of biodiversity, in the remainder of this sub-section some standards, starting points, requirements and boundary conditions are worked out. Therefore, it is assumed that the values provided by the valuation model are a minimum boundary of what can be achieved, given that the attention points listed below are taken care of in the design of the LWS.

The subsequent list is created based on scientific documents (Gemeente Amsterdam, 2021; Ojala & Campbell, 2020), as well as interviews with Sweco experts and ecologists (Meijer & Mossink, 2021; Rotteveel, 2022; Sweco expert knowledge, 2022).

1. Biodiversity is incorporated as a full-fledged sustainability theme at the front of processes, plans and projects. This by marking it as an integral part of decision-making. As a practical example, by conducting a biodiversity-scan taking into account every project in each phase, chances for biodiversity can be mapped and cashed.

2. Incorporate at least 20 (preferably more) different local/native/indigenous species in the landscaping plan, most favourably target species which are locally in decline and pollinator friendly (Gemeente Amsterdam, 2021; Ojala & Campbell, 2020).
3. No use of invasive/alien species
4. Contract/Consult an ecologist in order to compose a list of desired species and an adequate planting scheme
5. In the planting scheme, not solely the distribution of types of plants, grasses, herbs, ground cover plants and shrubs should be accounted for. Building shape and orientation should be considered as well, e.g. wind-resistant species near the edges of façades where wind loads are most intense.
6. A maintenance management plan should be included as a standard and nature-sensitive or ecological management should be applied, in order to ensure vitality of the VGS and make sure that biodiversity is at its optimum health (Ojala & Campbell, 2020; Rotteveel, 2022; Sweco, 2020)
7. Incorporate habitat and nesting features for birds, bats, insects or other targeted species into the LWS design. Also make use of vegetation that provides sources of food and shelter. This enables the function of a stepping stone in a larger connected network of urban habitats (Ojala & Campbell, 2020). Moreover, this way biodiversity at multiple trophic levels is facilitated, enhancing ecosystem functioning (Soliveres et al., 2016).
8. Prevent and manage the use of chemical pesticides, use natural fertilizers instead
9. Since the substrate layer forms the basis for a healthy development of the vegetation, it should be carefully composed of natural materials such as e.g. lava, bims, humus and clay

For further development of standards, starting points, requirements and boundary conditions regarding implementation of VGS into the urban fabric, additional research (potentially based on existing literature) is proposed. This will be integrated in the future recommendations of this research work in section 9.3 and appendix I, and will warrant ongoing investigation.

C.2.3 'Natuurpuntencalculator' Sweco

For the quantification of biodiversity, Sweco among others already developed a tool called 'Natuurpuntencalculator'. This tool is developed by ecologists and GIS-ICT experts, based on the nature points system of the Dutch Environmental Assessment Agency (PBL – Planbureau voor de Leefomgeving). It generates automated nature point calculations for horizontal nature in a certain region and uses different 2D maps, a database and flora and fauna observations to do so.
A nature point is a uniform measure/size for natural value and biodiversity, with the following formula:

$$Nature\ point = area * quality * weighting\ factor$$

Quality is determined by the completeness of the species composition that belongs to the nature type, while the weighting factor is determined by the species richness and uniqueness of a nature type. Hence, nature points account for the size of a region, the number of target species present and the type of nature observed. This results in a scientifically reliable number/figure that indicates nature's value. (Sweco, 2021)

In order to account for vertical greening and nature in the 'Natuurpuntencalculator', this tool should be developed further to be able to generate adequate results. However, it is not possible to do so merely based on 2D maps and apart from horizontal area. Also (vertical) façade area should be accounted for in the tool. This entails the integration of several different sources of information that are neglected to date. When it is extended to façade areas, the tool would be promising for the scientific quantification of the value for nature delivered by VGS.

D

Background on economic analysis methods and valuation techniques

In order to allow for economic valuation and monetisation of the benefits derived from ecosystem services, different economic analysis methods and valuation techniques are available. These methods in itself are well established and common practice in decision-making processes, for example in the domain of urban planning.

Background knowledge and the methods presented in this appendix are derived from presentations of the courses 'CIE4100 – Materials and Ecological Engineering' and 'CME2300 – Financial Engineering', followed at Delft University of Technology (2020). Also, scientific literature was consulted to get a preliminary insight into the different possibilities for economic valuation strategies, e.g. journal papers by Perini and Rosasco (2013), Rosasco (2018), Teotónio et al. (2021), Manso et al. (2021), Huang et al. (2019), , Bockarjova and Botzen (2017), Farber, Costanza, and Wilson (2002), Pascual et al. (2010), Gómez-Baggethun and Barton (2013) and Victoria University and University of Melbourne (2018).

D.1 Economic analysis methods to evaluate costs and benefits

In this thesis, the effort is made to generate new insights regarding the cost and benefits resulting from the implementation of vertical greening systems. This can be done in several ways (Figure D.1):

- Multi criteria analysis (MCA), an open (qualitative) analysis which models an objectification of political preferences (objectives and criteria) and decides on weights and performance of these;
- Cost-Benefit Analysis (CBA), a more detailed analysis, weighing probable costs against probable benefits to choose the most valuable option;
- Cash Flow Analysis (CFA), an analysis of the financial results by weighing the amount of money made with cash in and outflows (based on transactions).

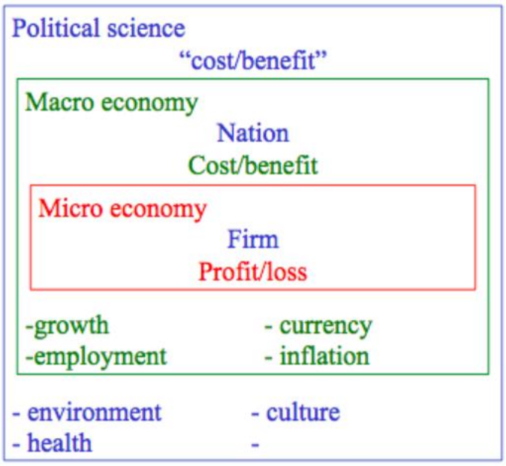


Figure D.1: Potential economic analyses (Vrijling & Verlaan, 2015)

Keeping in mind the research goal of this work (the development of a framework and tool enabling the economic valuation of costs and benefits related to VGS), the focus was placed on CBA and CFA. In the following, the most relevant social- and merely financial analyses are worked out:

- Social result:
  - Social Cost-Benefit Analysis (SCBA):
    - Method that can be used to include social costs and values of benefits derived from ES, as determined with e.g. Contingent Valuation or Hedonic Pricing in project cost-benefit analysis;
    - Can be used to provide economic arguments for applying ES in the built environment, particularly when the costs of implementation are lower than the benefits to society;
    - Requirement is that ES can be economically valued;
  - Total Cost for Society (TCS) model:
    - Combination of Life Cycle Costing (LCC), Life Cycle Analysis (LCA), Life Cycle Circular Value (LCCV) and Life Cycle Added Value (LCAV);
    - Method that can be used for determining the societal value of current and future (infrastructural) assets;
    - Includes value of circular building implementation and environmental impact calculations (LCA module D);
    - Includes values of benefits derived from ES;
    - Represents the 'next generation' LCC tool for calculating and justifying society-inclusive return of investments;
- Financial result:
  - Private Cost-Benefit Analysis (PCBA):
    - E.g. all direct monetary transactions and revenue streams of a company or household related to a certain investment (calculation of NPV).
  - Life Cycle Cost Analysis (LCCA):
    - Estimates the pure financial impact over the lifetime of the investment;
    - LCCA includes the initial cost (capital expenditure) plus the future costs of the asset like operational costs (e.g. utilities), maintenance costs, repair, and replacement.

D.2 Valuation/Pricing techniques for ecosystem services and derived benefits

Most ES do not qualify for market trading since they are not private assets in nature. When no explicit markets for services exist, one should apply indirect means of assessing economic values. A variety of valuation techniques are well established for these cases (Farber et al., 2002). Depicted below, is the classification scheme for potential economic valuation methods by Amadei, De Laurentiis, and Sala (2021).

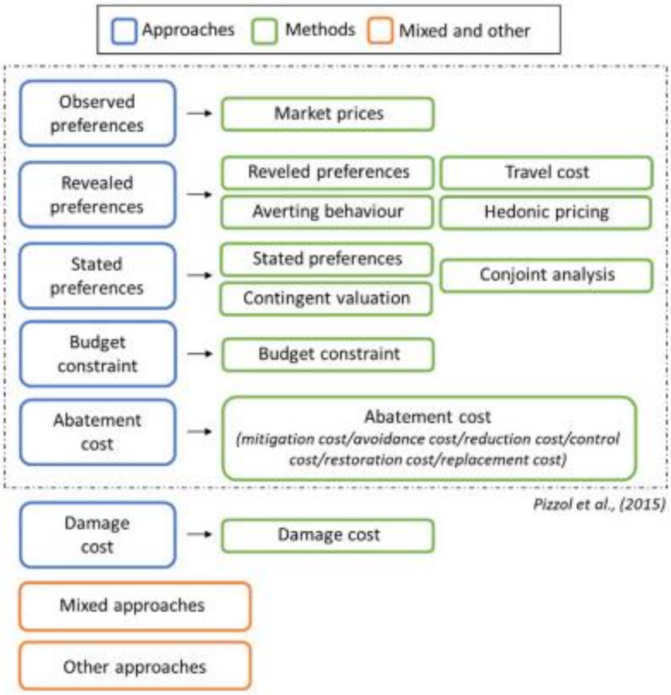


Figure D.2: Overview of the classification of monetary valuation approaches and methods (Amadei et al., 2021)

Observed Preference Methods (based on actual market prices)

- Market Price based Method (MPM):
  - Estimates the economic value of commodities that are bought and sold in markets;
- Factor Income (FI):
  - Estimates values of services based on the enhancement of incomes. E.g. the improvement of water quality in oceans could increase commercial fisheries catch and income.

Revealed Preference Methods (based on actual market prices and behaviour of users)

- Hedonic Pricing Method (HPM):
  - Relies on market transactions for differentiated goods to estimate the economic benefits or costs that are associated with an ecosystem service/environmental quality;
  - Commonly applied to quantitatively value ES that e.g. directly affect market prices for homes;
- Travel Cost Method (TCM):
  - Estimates the value of recreational benefits generated by ecosystems. The method assumes that the value of the site or its recreational services is reflected in how much people are willing to pay to get there;

Abatement Cost methods (based on actual market prices)

- Cost Based Method (CBM):
  - Replacement Cost Method:
    - Estimates values of commodities based on the costs of replacing environmental assets, or the costs of providing substitute goods or services;
  - Avoided Cost Method:
    - Estimates the economic values of benefits delivered by ecosystems and which would not exist if the ecosystem was no longer in place. Hence, the benefit would represent an added cost to society if the ES no longer existed;
  - Mitigation Cost Method
  - Reduction Cost Method
  - Control Cost Method
  - Restoration Cost Method

Stated Preference Methods (based on hypothetical situations)

- Contingent Valuation Method (CVM):
  - Can be used to create a hypothetical market place for public goods (commodities) in which no actual transactions are made;
  - Survey-based technique to determine value based on peoples 'Willingness To Pay' (WTP) for a commodity, or alternatively 'Willingness To Accept' (WTA) loss of a commodity (also known as compensations costs that are demanded);
  - Specifically suitable for valuing commodities for which no economic market exists, e.g. beauty of nature, improvement of water or air quality, presence of national park, reduction in risk of death, days of illness avoided, days spend on recreational activities;
  - Disadvantage: interviewed people need to be involved in the commodity and have basic understanding of the commodity (e.g. an ES) involved;
- Choice Experiment Methods (CEM):
  - Survey-based technique that seeks to discover individual preferences for simultaneous changes in the attributes that compose an environmental good or service, e.g. public preferences for alternative façade appearance.

Other methods

- Benefit Transfer Method (BTM):
  - Adopting values from similar studies or transferring available information from studies already completed in another location or context;
  - Easier, less costly and less time-consuming;
  - Relying on the similarity between studies/literature and the current project. One should acknowledge the limitations.

D.3 Indicators for financial/economic feasibility

- Net Present Value (NPV);
- Benefit-Cost Ratio (BCR);
- Return on Investment (ROI); (when there is no constant revenue flow, it's harder to define ROI)
- Payback Period (PBP);
- Internal Rate of Return (IRR);
- Break-Even-Point (BEP).

E

Literature review - Stakeholders

In this appendix, based on literature research and explorative conversations with Sweco peers, clients and relations, as well as with the graduation committee and TU Delft staff, the relevant stakeholders for the implementation of VGS are qualitatively identified. One of the research gaps is to generate new insights with regards to the distribution of costs and benefits of VGS over stakeholders, and facilitate this distribution in the valuation framework and model. Hence, this appendix provides the information used relating to the stakeholders, their value perspectives and the (different) financial methods suited for valuation of costs and benefits for these stakeholder groups. Also for the sake of feasibility, a demarcation in scope with regards to stakeholders will be presented in this appendix.

E.1 List of important stakeholders for implementation of vertical greening systems

Not all stakeholders that are involved during the implementation of VGS notice all costs and benefits that relate to VGS and often it's difficult to find parties who are willing to pay. According to Posma et al. (2018), the main reasons for this are the following:

- The benefits are not always clear;
- Not all benefits can directly be valued in monetary terms;
- Not all benefits are directly visible to all users, or more importantly, to the payer or investor.

Benefits are in this case delivered through ecosystem services (ES). When the costs and benefits are noticed, their individual values might be perceived differently by specific stakeholder groups since their relation, attitude or concerns are not aligned with regards to the VGS. That is, the costs and benefits are divided, and hence should be distributed over the stakeholders who actually pay and benefit from them. This can have influence on the general acceptance or support for implementation of proposed VGS in the urban fabric. In order to make both the social, as well as the financial, costs and benefits more transparent, this thesis work is performed and a comprehensive valuation model is proposed. (Mommers et al., 2021; Posma et al., 2018; van den Biesen, 2018)

In the Netherlands, a research was conducted regarding the attitudes of stakeholders towards the implementation of *vertical gardens* by van den Biesen (2018). More specifically, the study examined in what way the stakeholders' attitudes towards the effects of vertical gardens, towards other stakeholders and towards critical success factors, constituted their attitude towards the implementation of vertical gardens. All stakeholders regarded the government and municipalities as key players, since their vision, criteria and policies towards the innovation should be stable. Moreover, stakeholders stressed the relevance of detailed quantifications of the benefits of the systems in order to access economic viability, or at least identify calculable effects that support implementation.

Therefore, as result of the study, governmental bodies were recommended to invest in research regarding valuation of the effects of vertical gardens, in order to facilitate tangible tools which support decisions for implementation. Note that in the study, the researcher referred to *vertical gardens* in the same way as this thesis work uses the term *VGS* as description for vertical vegetation. Hence, these words describe the same topic.

In order to conduct his research, van den Biesen (2018) initially identified the stakeholders which relate to VGS (Figure E.1). This was done based on literature review and explorative conversations. In similar fashion, the author of this thesis work had conducted an identification of the stakeholders as well (see Table E.1). Comparing this established list to the formerly conducted study, it was observed that these were nearly identical. Hence, it could be concluded that both efforts led to a matching list. Therefore, the initial list of stakeholders relating to the implementation of VGS was adopted from the elaborate study by van den Biesen (2018) (Figure E.1). The only remark is that a firm stakeholder classification is proposed for the triangulation of real estate investor, resident (owner) and resident (tenant). These parties could perceive different or even contradicting values. Therefore, strict division of these groups is recommended.

Stakeholders		Exploratory conversations					Literature Review			
Code	Stakeholder	EC1	EC2	EC3	EC4	EC5	(Ottelé, 2011)	(Perini et al., 2013)	(Liang et al., 2017)	(Besir et al., 2018)
S1	Municipality	x	x			x	(2011, p. 237)	(2013, p. 117)		
S2	National Government		x			x	(2011, p. 237)	(2013, p. 120)	(2017, p. 9)	(2018, p. 914)
S3	Project Developer	x	x	x		x			(2017, p. 9)	
S4	Neighborhood			x		x				
S5	Architects	x	x		x		(2011, p. 237)		(2017, p. 9)	
S6	Housing Corporation / Real Estate owner	x							(2017, p. 9)	(2018, p. 920)
S7	User/resident	x		x		x			(2017, p. 9)	
S8	Insurance company					x			(2017, p. 9)	
S9	Investor	x		x				(2013, p. 113)	(2017, p. 9)	
S10	Non-governmental organizations				x	x			(2017, p. 9)	
S11	Landscape architect	x	x		x		(2011, p. 237)			
S12	Specialized gardening company	x		x	x		(2011, p. 238)			

Figure E.1: Adopted list of stakeholders, provided by exploratory conversations and literature study as per research of van den Biesen (2018)

Table E.1: Initial list of stakeholders as identified by the author

Nr.	Description of stakeholder
1	Real estate investor
2	(Social) Housing corporation
3	Real estate developer
4	Asset manager
5	Residents (owners)
6	Residents (tenants)
7	Visitors ; Tourists ; Pedestrians ; Bystanders
8	General public ; Society as a whole
9	Municipality ; Government institution ; Policy-makers ; Water board
10	External investors / Investment funds & banks / Mortgage lenders
11	Insurance companies
12	Environmental agencies
13	Architectural-, Engineering-, Consultancy firms
14	General building contractor
15	VGS manufacturer or supplier / Specialized gardener
16	Shops and hospitality services located in the vicinity

Additionally, the study by van den Biesen (2018) provided a general overview of the attitudes and relevance of effects of VGS, according to the different stakeholders (Figure E.2). This information was gathered based on questionnaires and interviews with several interviewees from different stakeholder groups. Unfortunately, due to the anonymization of respondents, from this figure no exact conclusions can be drawn per stakeholder group. Nevertheless, the overview shows a wide range of perceived relevance per effect. This indicates the delicacy of distributing values of benefits over different stakeholder groups.

Respondent code	Verbetering luchtkwaliteit	Vergroting biodiversiteit	Bescherming gebouw tegen neerslag en zonnestraling	Temperatuur regulatie en isolatie & stedelijke hittestress	Waardevergroting gebouw	Vergroening van de stad in algemene zin	Geluid absorberende werking	Draagt bij aan welzijn bewoners/gebruikers	Draagt bij aan welzijn van buurtbewoners	Esthetische bijdrage aan stadslandschap
Q01S03R11	3	4	4	4	3	4	4	5	5	3
Q02S12R10	3	4	5	5	1	5	4	4	3	5
Q03S03R08	4	2	4	4	5	4	4	5	4	3
Q04S11R09	5	3	3	5	4	5	4	5	3	4
Q05S12R07	2	4	3	4	4	5	4	5	5	5
Q06S05R00	2	4	4	4	2	5	3	4	4	5
Q07S05R00	4	5	4	5	4	5	4	5	5	5
Q08S05R00	5	5	2	3	4	5	3	5	4	4
Q09S00R03	5	5	5	5	4	5	4	5	4	5
Q10S12R00	3	3	3	3	4	4	3	4	4	3
Q11S01R01	1	3	3	3	2	5	2	4	5	5
Q12S06R00	4	2	2	3	5	4	2	4	3	4
Q13S00R00	4	3	3	5	4	4	3	3	5	5
Q14S00R00	4	5	5	5	4	5	5	5	5	5
Q15S00R00	4	2	4	4	1	5	4	5	5	5
Q15S06R00	4	3	4	5	3	5	5	4	5	4
Q16S12R00	4	4	3	5	3	5	4	5	5	4
Q17S01R00	5	5	4	5	4	5	4	4	4	4
Q18S01R00	3	4	4	4	4	5	3	4	4	4
Q19S01R00	3	3	5	5	3	3	2	2	3	3
Q20S01R02	4	4	2	4	2	4	2	5	5	4
Q21S00R00	5	5	3	5	3	4	5	5	3	4
Q22S11R06	3	4	2	4	4	5	3	4	5	3
Average	3,7	3,7	3,5	4,3	3,3	4,6	3,5	4,4	4,3	4,2

Figure E.2: Relevance of effects of vertical gardens according to stakeholders (van den Biesen, 2018)

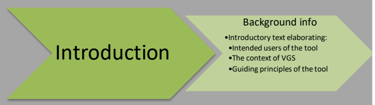
F

Design and infrastructure of VGS Valuation Tool

In this appendix, the final design and lay-out of the current version of the VGS Valuation Tool is displayed. Zooming in to the screenshots allows for a focussed and sharp view, however reference is made to the supplemented MS-Excel file *'VGS_Valuation_Tool_V.1.01'* in order to get a clear and true overview of the tool.

F.1 Introduction sections

Tab 1.1: Background info



Introduction to the VGS Valuation Tool

Welcome to the VGS Valuation Tool!

Are you a consultant and exploring options to create nature-inclusive and climate resilient real estate through the implementation of vertical greening systems (VGS)? Do you want to advise your clients (e.g. policy-makers, real estate investors/owners or residents) based on substantive and rational facts and figures? This tool allows you to gain insight into both the pure Financial Business Case, as well as the total Costs & Benefits for society regarding VGS!

Vertical greening systems and context

VGS are vertical structures covered with vegetation and can be implemented as e.g. the outer skin of a building's façade systems. Essentially, it is a living cladding system. There are 2 main categories of vertical greening systems: Green façade systems and Green/Living wall systems.

- Green façade systems are composed of climbing plants, usually rooted from the subsoil. However, they may also grow from substrates embedded in elevated planter-boxes.
- Living wall systems (LWS) provide a vertical growing surface, consisting from e.g. modular panels, tray systems or felt systems. The greenery is then planted in a growing medium (packed soil, fiber mats or other substrates) and the system features an integrated irrigation and nutrition system.

VGS are a type of urban Nature-based Solutions (NBS). NBS are defined as: "Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human health & well-being and biodiversity benefits" (International Union for Conservation of Nature, 2016).

This is done through the generation of Ecosystem Services (ES) and accompanying co-benefits: "The benefits that people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005).

At the base of Ecosystem Services are environmental factors and rich and abundant biodiversity in multiple trophic levels (the position an organism occupies in the food chain). Many experiments have shown that loss of biodiversity reduces the capacity of ecosystems to provide the multiple services on which humans depend. However, high species richness in multiple trophic groups has positive effects on ecosystem services, even more so than richness in any individual trophic group (Soliveres et al., 2016).

Hence, when realising VGS in the built environment, always the emphasis should be at facilitating high standards for biodiversity in order to stimulate ecosystem functioning.

The benefits obtained by implementation of VGS and through delivery of Ecosystem Services and co-benefits are manyfold. They include:

- Improved physical and mental health & well-being
- Improved productivity and stress relief
- Reduction of urban heat island (UHI) effect, heat stress and related diseases
- Improved air quality through sequestration of substances and particulate matter (fine dust particles)
- Production of oxygen
- Sequestration of carbon and other greenhouse gases (climate mitigation)
- Improved rainwater regulation and quality (minor effect and only applicable for green façade systems rooted in subsoil)
- Reduced drought effects (minor effect and only applicable for green façade systems rooted in subsoil)
- Improved thermal insulation and reduced energy consumption
- Reduced noise hindrance and improved acoustic insulation
- Increased building/construction integrity and lifespan
- Increased resident satisfaction level
- Increased property values
- Legislative, tax and subsidy benefits for companies and individuals
- Food production and urban argiculture, either for humans or other animal species (e.g. birds and insects)
- Recreational values
- Social values
- Aesthetic values
- Commercial values (e.g. marketing)
- Increased biodiversity levels and natural animal habitat in surroundings
- Preservation or improvement of ecosystem functioning

Life Cycle Cost Analysis & Social Cost-Benefit Analysis

In this tool we distinguish between 2 economic analysis frameworks. The mere financial business case, hence the financial analysis, is captured in the LCCA (Life Cycle Cost Analysis), while the total spectrum of costs and benefits are analysed in the Social Cost-Benefit Analysis (SCBA). This distinction in analyses types results from different stakeholders involved with VGS implementation.

- In the LCCA, the financial business case shows the pure financial costs and direct financial earnings for the investor over the lifetime of the VGS, based on actual (and avoided negative) transactions and cash flows. Based on future research, it might be concluded that other stakeholders relate to this analysis framework as well. These might be integrated in subsequent versions of the VGS Valuation Tool.
- In the SCBA, an effort is made to also quantify and monetize costs and benefits that don't have a true financial origin and were no direct cash flows are involved. These are the indirect and/or intangible costs and benefits. Here, values of the environmental and social costs and benefits are included, regardless of who pays or benefits. Hence, the stakeholder group for this analysis is society as a whole.
  Additionally, qualitative potential Ecosystem Disservices, implying costs, and benefits of VGS are included in this document. These are deemed unquantifiable values or aren't expressed and valued in monetary terms (yet). However, they are scientifically proven to affect or benefit certain stakeholders or society at large. Effort should be made to integrate and develop these within the tool in the future.

Based on the various costs and benefits considered per analysis and distinctive 'Discount rates' per analysis, value (cost and benefit) calculations are performed. The 'Discount rate' is the rate with which the 'Time value of money' and riskiness of an investment are accounted for. A discount rate is deducted from future costs and benefits to provide its present value. It is related to the rate of return that investors/stakeholders expect, or the cost of borrowing money (opportunity cost of capital).

- As a baseline, for both LCCA and SCBA a 'Zero discount rate' analysis is performed. This entails the valuation of all costs and benefits corresponding to an analysis framework for the case in which the 'Time value of money' is neglected.
- For the LCCA, subsequently an analysis is performed with a certain governing 'investor discount rate' (to be determined by the consultant and client)
- For the SCBA, aside from the 'Zero discount rate', a 'Social discount rate' for green investments is applied to the analysis framework.

These different kind of analyses and applied discount rates generate insights into both the different costs and benefits taken into account for the framework, as well as the influence of the time value of money for distinct stakeholders on costs and benefits of VGS.

Initial tool development based on Living Wall Systems

Please note that this document forms the first version of a generic and comprehensive valuation tool for VGS. It is aimed at the development of a valuation framework for delivered Ecosystem Services and accompanying co-benefits of VGS. The tool will remain a work in progress with the potential to add more functionalities and substantiated values. In order to design and develop the framework and this first version of the tool, the thesis work focusses on Living Wall Systems (LWS). This is done since these systems:

- Can be composed from a wide range of different (native) plant species. Hence, for a given façade area they are expected to offer greater potential for the stimulation of, or contribution to, biodiversity as compared to green façade systems.
- Contain a more extensive façade system (secondary support system) that exists of a multitude of building materials. Hence, they allow for the extensive elaboration and integration of environmental 'shadow costs' in this version of the tool already. This enables the development of a more comprehensive valuation model.
- Are usually more costly than green façade systems. Hence this complicates the development of a viable financial business case. With this VGS Valuation Tool it is aimed to initiate and facilitate an (economic) discussion relating the implementation of these urban greening systems. In turn, this should allow for rational decision-making based on scientifically substantiated values.
- Can be installed at higher altitudes since they do not rely on implant in the subsoil. Moreover, these systems can cover the full façade area within one year of installation, while green façade systems can take years or decades to grow, densify, mature and cover large areas.
- Have the tendency to appeal to the eyes of the public at large, due to their artistic designed appearance.

Hopefully the tool helps you, the user, to generate new insights and to start a discussion that leads to rational decision-making with regards to the implementation of VGS in urban projects!

Colophon

This first version of the VGS Valuation Tool was developed during a MSc. Thesis project. This served as a partial fulfilment for the degree of Master of Science in Civil Engineering (track: Building Engineering) at the Delft University of Technology. For this thesis project, a collaboration was initiated with Sweco Nederland, part of Sweco: Europe's leading and largest architectural & engineering-consultancy firm.

It was developed through comprehensive literature research and cooperation with firms from the industry of VGS (supplier and engineering/consultancy firm). An initial pilot case that is used to develop this tool stems from a real estate client of Sweco Nederland B.V.

For more information regarding the academic and scientific background underlying to this tool, reference is made to the thesis report which accompanies this Excel file. This thesis report can be found at the TU Delft Repository and goes by the title: "Towards a more nature-inclusive and climate resilient built environment - A method for the economic valuation of the costs and benefits associated with the implementation of vertical greening systems on buildings". (Weblink: https://repository.tudelft.nl/)

Graduate Student: Guy Janssen (E: guyjanssen97@gmail.com ; M: +31 6 51 98 80 83)

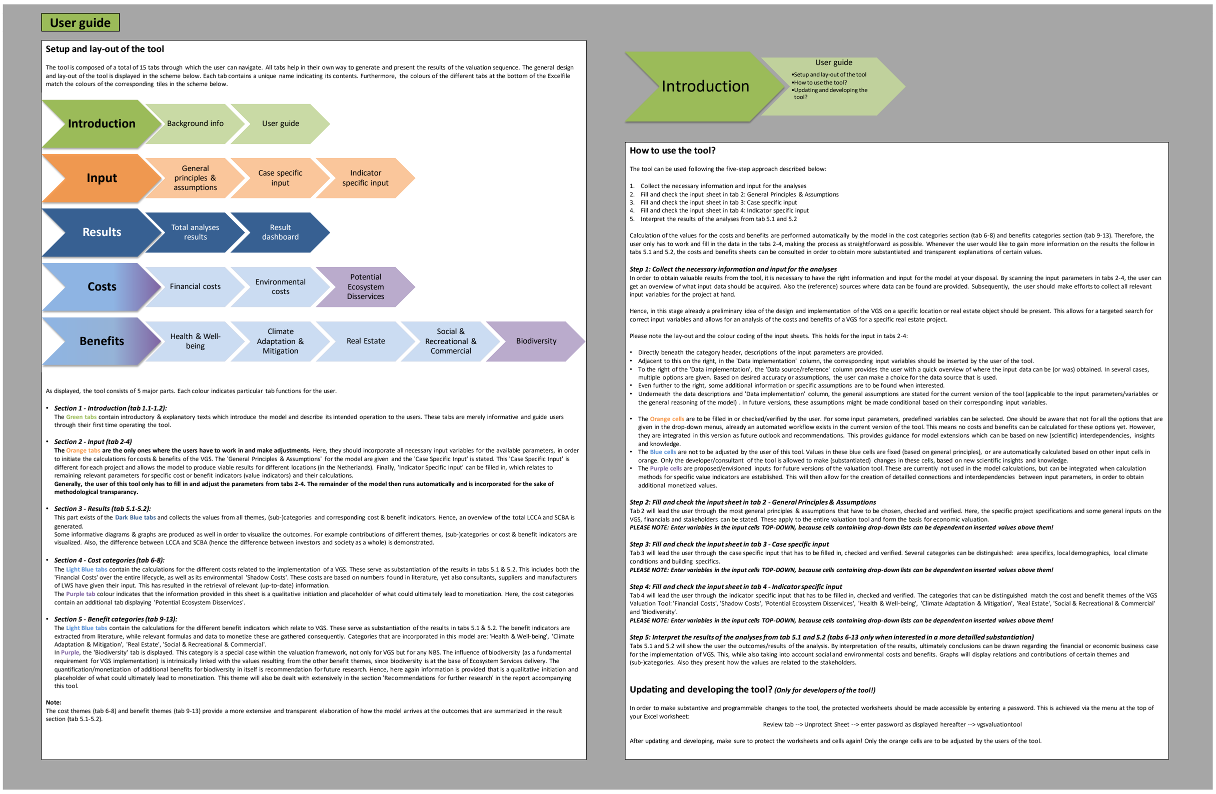
Projectteam Delft University of Technology: Prof.dr. Henk Jonkers (MAIL, PHONE) / Dr. Daan Schraven (MAIL, PHONE) / Ir. Roy Crielaard (MAIL, PHONE)

Projectteam Sweco Nederland: MSc. Jelmer van de Ridder (MAIL, PHONE) / MSc. Gijs Meijer (MAIL, PHONE) / MSc. Jeroen van Eekelen (MAIL, PHONE)

VGS Valuation Tool: Version 1.01

TUDelft Delft University of Technology   SWECO

Tab 1.2: User guide



User guide

Setup and lay-out of the tool

The tool is composed of a total of 15 tabs through which the user can navigate. All tabs help in their own way to generate and present the results of the valuation sequence. The general design and lay-out of the tool is displayed in the scheme below. Each tab contains a unique name indicating its contents. Furthermore, the colours of the different tabs at the bottom of the Excelfile match the colours of the corresponding tiles in the scheme below.

As displayed, the tool consists of 5 major parts. Each colour indicates particular tab functions for the user.

- ***Section 1 - Introduction (tab 1.1-1.2):***
  The Green tabs contain introductory & explanatory texts which introduce the model and describe its intended operation to the users. These tabs are merely informative and guide users through their first time operating the tool.
- ***Section 2 - Input (tab 2-4)***
  The Orange tabs are the only ones where the users have to work in and make adjustments. Here, they should incorporate all necessary input variables for the available parameters, in order to initiate the calculations for costs & benefits of the VGS. The 'General Principles & Assumptions' for the model are given and the 'Case Specific Input' is stated. This 'Case Specific Input' is different for each project and allows the model to produce viable results for different locations (in the Netherlands). Finally, 'Indicator Specific Input' can be filled in, which relates to remaining relevant parameters for specific cost or benefit indicators (value indicators) and their calculations.
  Generally, the user of this tool only has to fill in and adjust the parameters from tabs 2-4. The remainder of the model then runs automatically and is incorporated for the sake of methodological transparancy.
- ***Section 3 - Results (tab 5.1-5.2):***
  This part exists of the **Dark Blue tabs** and collects the values from all themes, (sub-)categories and corresponding cost & benefit indicators. Hence, an overview of the total LCCA and SCBA is generated.
  Some informative diagrams & graphs are produced as well in order to visualize the outcomes. For example contributions of different themes, (sub-)categories or cost & benefit indicators are visualized. Also, the difference between LCCA and SCBA (hence the difference between investors and society as a whole) is demonstrated.
- ***Section 4 - Cost categories (tab 6-8):***
  The Light Blue tabs contain the calculations for the different costs related to the implementation of a VGS. These serve as substantiation of the results in tabs 5.1 & 5.2. This includes both the 'Financial Costs' over the entire lifecycle, as well as its environmental 'Shadow Costs'. These costs are based on numbers found in literature, yet also consultants, suppliers and manufacturers of LWS have given their input. This has resulted in the retrieval of relevant (up-to-date) information.
  The Purple tab colour indicates that the information provided in this sheet is a qualitative initiation and placeholder of what could ultimately lead to monetization. Here, the cost categories contain an additional tab displaying 'Potential Ecosystem Disservices'.
- ***Section 5 - Benefit categories (tab 9-13):***
  The Light Blue tabs contain the calculations for the different benefit indicators which relate to VGS. These serve as substantiation of the results in tabs 5.1 & 5.2. The benefit indicators are extracted from literature, while relevant formulas and data to monetize these are gathered consequently. Categories that are incorporated in this model are: 'Health & Well-being', 'Climate Adaptation & Mitigation', 'Real Estate', 'Social & Recreational & Commercial'.
  In Purple, the 'Biodiversity' tab is displayed. This category is a special case within the valuation framework, not only for VGS but for any NBS. The influence of biodiversity (as a fundamental requirement for VGS implementation) is intrinsically linked with the values resulting from the other benefit themes, since biodiversity is at the base of Ecosystem Services delivery. The quantification/monetization of additional benefits for biodiversity in itself is recommendation for future research. Hence, here again information is provided that is a qualitative initiation and placeholder of what could ultimately lead to monetization. This theme will also be dealt with extensively in the section 'Recommendations for further research' in the report accompanying this tool.

Note:
The cost themes (tab 6-8) and benefit themes (tab 9-13) provide a more extensive and transparent elaboration of how the model arrives at the outcomes that are summarized in the result section (tab 5.1-5.2).

How to use the tool?

The tool can be used following the five-step approach described below:

1. Collect the necessary information and input for the analyses
2. Fill and check the input sheet in tab 2: General Principles & Assumptions
3. Fill and check the input sheet in tab 3: Case specific input
4. Fill and check the input sheet in tab 4: Indicator specific input
5. Interpret the results of the analyses from tab 5.1 and 5.2

Calculation of the values for the costs and benefits are performed automatically by the model in the cost categories section (tab 6-8) and benefits categories section (tab 9-13). Therefore, the user only has to work and fill in the data in the tabs 2-4, making the process as straightforward as possible. Whenever the user would like to gain more information on the results the follow in tabs 5.1 and 5.2, the costs and benefits sheets can be consulted in order to obtain more substantiated and transparent explanations of certain values.

Step 1: Collect the necessary information and input for the analyses
In order to obtain valuable results from the tool, it is necessary to have the right information and input for the model at your disposal. By scanning the input parameters in tabs 2-4, the user can get an overview of what input data should be acquired. Also the (reference) sources where data can be found are provided. Subsequently, the user should make efforts to collect all relevant input variables for the project at hand.

Hence, in this stage already a preliminary idea of the design and implementation of the VGS on a specific location or real estate object should be present. This allows for a targeted search for correct input variables and allows for an analysis of the costs and benefits of a VGS for a specific real estate project.

Please note the lay-out and the colour coding of the input sheets. This holds for the input in tabs 2-4:

- Directly beneath the category header, descriptions of the input parameters are provided.
- Adjacent to this on the right, in the 'Data implementation' column, the corresponding input variables should be inserted by the user of the tool.
- To the right of the 'Data implementation', the 'Data source/reference' column provides the user with a quick overview of where the input data can be (or was) obtained. In several cases, multiple options are given. Based on desired accuracy or assumptions, the user can make a choice for the data source that is used.
- Even further to the right, some additional information or specific assumptions are to be found when interested.
- Underneath the data descriptions and 'Data implementation' column, the general assumptions are stated for the current version of the tool (applicable to the input parameters/variables or the general reasoning of the model) . In future versions, these assumptions might be made conditional based on their corresponding input variables.

- The Orange cells are to be filled in or checked/verified by the user. For some input parameters, predefined variables can be selected. One should be aware that not for all the options that are given in the drop-down menus, already an automated workflow exists in the current version of the tool. This means no costs and benefits can be calculated for these options yet. However, they are integrated in this version as future outlook and recommendations. This provides guidance for model extensions which can be based on new (scientific) interdependencies, insights and knowledge.
- The Blue cells are not to be adjusted by the user of this tool. Values in these blue cells are fixed (based on general principles), or are automatically calculated based on other input cells in orange. Only the developer/consultant of the tool is allowed to make (substantiated) changes in these cells, based on new scientific insights and knowledge.
- The Purple cells are proposed/envisioned inputs for future versions of the valuation tool. These are currently not used in the model calculations, but can be integrated when calculation methods for specific value indicators are established. This will then allow for the creation of detailled connections and interdependencies between input parameters, in order to obtain additional monetized values.

Step 2: Fill and check the input sheet in tab 2 - General Principles & Assumptions
Tab 2 will lead the user through the most general principles & assumptions that have to be chosen, checked and verified. Here, the specific project specifications and some general inputs on the VGS, financials and stakeholders can be stated. These apply to the entire valuation tool and form the basis for economic valuation.
PLEASE NOTE: Enter variables in the input cells TOP-DOWN, because cells containing drop-down lists can be dependent on inserted values above them!

Step 3: Fill and check the input sheet in tab 3 - Case specific input
Tab 3 will lead the user through the case specific input that has to be filled in, checked and verified. Several categories can be distinguished: area specifics, local demographics, local climate conditions and building specifics.
PLEASE NOTE: Enter variables in the input cells TOP-DOWN, because cells containing drop-down lists can be dependent on inserted values above them!

Step 4: Fill and check the input sheet in tab 4 - Indicator specific input
Tab 4 will lead the user through the indicator specific input that has to be filled in, checked and verified. The categories that can be distinguished match the cost and benefit themes of the VGS Valuation Tool: 'Financial Costs', 'Shadow Costs', 'Potential Ecosystem Disservices', 'Health & Well-being', 'Climate Adaptation & Mitigation', 'Real Estate', 'Social & Recreational & Commercial' and 'Biodiversity'.
PLEASE NOTE: Enter variables in the input cells TOP-DOWN, because cells containing drop-down lists can be dependent on inserted values above them!

Step 5: Interpret the results of the analyses from tab 5.1 and 5.2 (tabs 6-13 only when interested in a more detailled substantiation)
Tabs 5.1 and 5.2 will show the user the outcomes/results of the analysis. By interpretation of the results, ultimately conclusions can be drawn regarding the financial or economic business case for the implementation of VGS. This, while also taking into account social and environmental costs and benefits. Graphs will display relations and contributions of certain themes and (sub-)categories. Also they present how the values are related to the stakeholders.

Updating and developing the tool? ***(Only for developers of the tool!)***

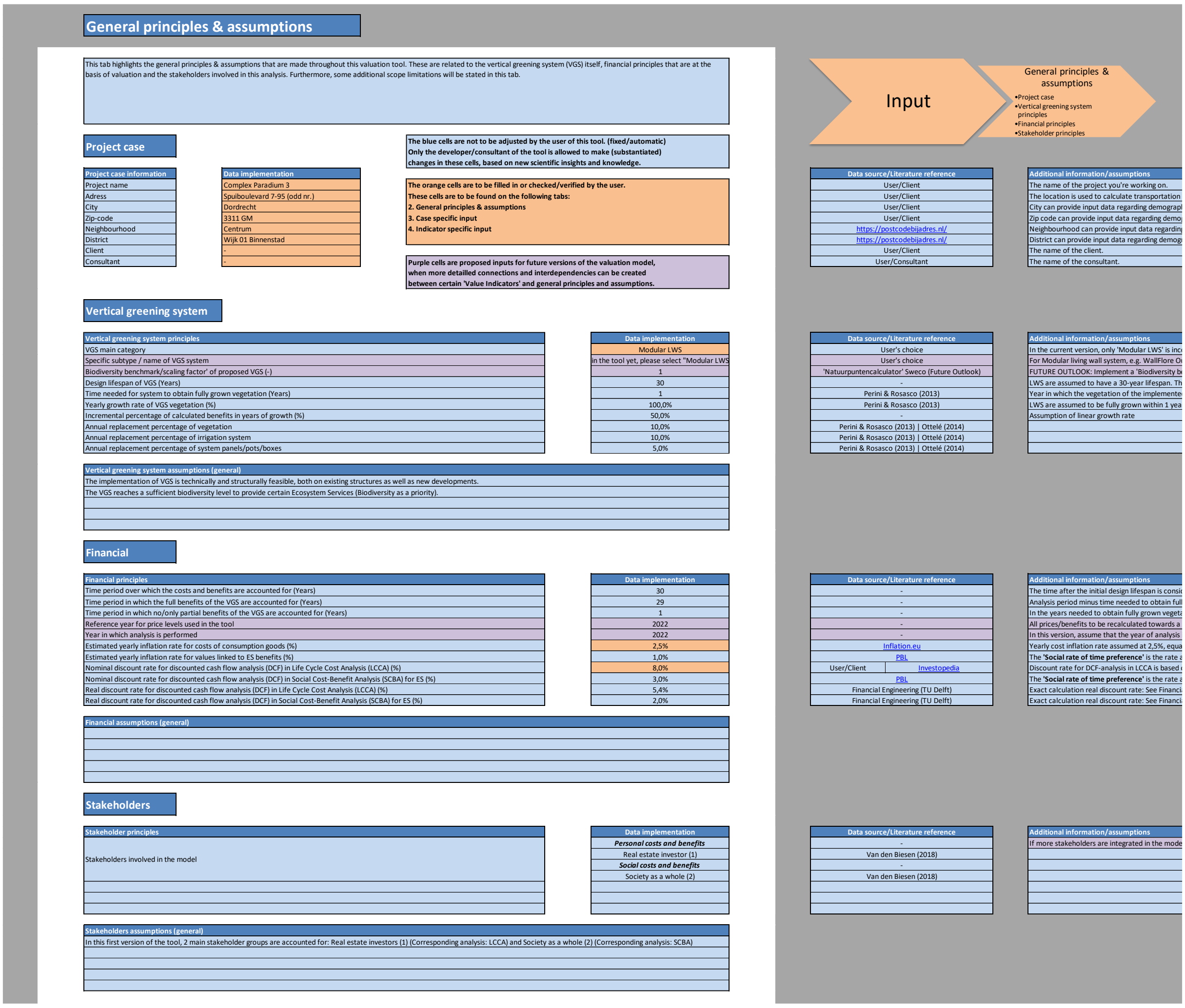
In order to make substantive and programmable changes to the tool, the protected worksheets should be made accessible by entering a password. This is achieved via the menu at the top of your Excel worksheet:
Review tab --> Unprotect Sheet --> enter password as displayed hereafter --> vgsvaluationtool

After updating and developing, make sure to protect the worksheets and cells again! Only the orange cells are to be adjusted by the users of the tool.

F.2 Input sections

In the VGS Valuation Tool, for the input tabs only the orange cells have to be adjusted by the user. The blue cells are fixed by the developer of the tool or are dependent and linked to selection of certain general principles or certain case specific inputs. The purple cells in the input tabs are future outlook, and comprise foreseen input variables needed to quantify and monetarise values of costs and benefits of VGS. These are given in this report for comprehensiveness, but not yet integrated in the workflow or valuation methods comprised in the model.

Tab 2: General principles & assumptions



General principles & assumptions

This tab highlights the general principles & assumptions that are made throughout this valuation tool. These are related to the vertical greening system (VGS) itself, financial principles that are at the basis of valuation and the stakeholders involved in this analysis. Furthermore, some additional scope limitations will be stated in this tab.

The blue cells are not to be adjusted by the user of this tool. (fixed/automatic) Only the developer/consultant of the tool is allowed to make (substantiated) changes in these cells, based on new scientific insights and knowledge.

The orange cells are to be filled in or checked/verified by the user. These cells are to be found on the following tabs:
2. General principles & assumptions
3. Case specific input
4. Indicator specific input

Purple cells are proposed inputs for future versions of the valuation model, when more detailled connections and interdependencies can be created between certain 'Value Indicators' and general principles and assumptions.

Project case

Project case information	Data implementation	Data source/Literature reference	Additional information/assumptions
Project name	Complex Paradium 3	User/Client	The name of the project you're working on.
Adress	Spuiboulevard 7-95 (odd nr.)	User/Client	The location is used to calculate transportation
City	Dordrecht	User/Client	City can provide input data regarding demograp
Zip-code	3311 GM	User/Client	Zip code can provide input data regarding demo
Neighbourhood	Centrum	https://postcodebijadres.nl/	Neighbourhood can provide input data regarding
District	Wijk 01 Binnenstad	https://postcodebijadres.nl/	District can provide input data regarding demog
Client	-	User/Client	The name of the client.
Consultant	-	User/Consultant	The name of the consultant.

Vertical greening system

Vertical greening system principles	Data implementation	Data source/Literature reference	Additional information/assumptions
VGS main category	Modular LWS	User's choice	In the current version, only 'Modular LWS' is inc
Specific subtype / name of VGS system	in the tool yet, please select "Modular LWS	User's choice	For Modular living wall system, e.g. WallFlore O
Biodiversity benchmark/scaling factor' of proposed VGS (-)	1	'Natuurpuntencalculator' Sweco (Future Outlook)	FUTURE OUTLOOK: Implement a 'Biodiversity b
Design lifespan of VGS (Years)	30	-	LWS are assumed to have a 30-year lifespan. Th
Time needed for system to obtain fully grown vegetation (Years)	1	Perini & Rosasco (2013)	Year in which the vegetation of the implemente
Yearly growth rate of VGS vegetation (%)	100,0%	Perini & Rosasco (2013)	LWS are assumed to be fully grown within 1 yea
Incremental percentage of calculated benefits in years of growth (%)	50,0%	-	Assumption of linear growth rate
Annual replacement percentage of vegetation	10,0%	Perini & Rosasco (2013) | Ottelé (2014)	
Annual replacement percentage of irrigation system	10,0%	Perini & Rosasco (2013) | Ottelé (2014)	
Annual replacement percentage of system panels/pots/boxes	5,0%	Perini & Rosasco (2013) | Ottelé (2014)	

Vertical greening system assumptions (general)
The implementation of VGS is technically and structurally feasible, both on existing structures as well as new developments.
The VGS reaches a sufficient biodiversity level to provide certain Ecosystem Services (Biodiversity as a priority).

Financial

Financial principles	Data implementation	Data source/Literature reference		Additional information/assumptions
Time period over which the costs and benefits are accounted for (Years)	30	-		The time after the initial design lifespan is consi
Time period in which the full benefits of the VGS are accounted for (Years)	29	-		Analysis period minus time needed to obtain full
Time period in which no/only partial benefits of the VGS are accounted for (Years)	1	-		In the years needed to obtain fully grown veget
Reference year for price levels used in the tool	2022	-		All prices/benefits to be recalculated towards a
Year in which analysis is performed	2022	-		In this version, assume that the year of analysis
Estimated yearly inflation rate for costs of consumption goods (%)	2,5%	Inflation.eu		Yearly cost inflation rate assumed at 2,5%, equa
Estimated yearly inflation rate for values linked to ES benefits (%)	1,0%	PBL		The **'Social rate of time preference'** is the rate a
Nominal discount rate for discounted cash flow analysis (DCF) in Life Cycle Cost Analysis (LCCA) (%)	8,0%	User/Client	Investopedia	Discount rate for DCF-analysis in LCCA is based
Nominal discount rate for discounted cash flow analysis (DCF) in Social Cost-Benefit Analysis (SCBA) for ES (%)	3,0%	PBL		The **'Social rate of time preference'** is the rate a
Real discount rate for discounted cash flow analysis (DCF) in Life Cycle Cost Analysis (LCCA) (%)	5,4%	Financial Engineering (TU Delft)		Exact calculation real discount rate: See Financi
Real discount rate for discounted cash flow analysis (DCF) in Social Cost-Benefit Analysis (SCBA) for ES (%)	2,0%	Financial Engineering (TU Delft)		Exact calculation real discount rate: See Financi

Financial assumptions (general)

Stakeholders

Stakeholder principles	Data implementation	Data source/Literature reference	Additional information/assumptions
Stakeholders involved in the model	***Personal costs and benefits***	-	If more stakeholders are integrated in the mode
	Real estate investor (1)	Van den Biesen (2018)	
	Social costs and benefits	-	
	Society as a whole (2)	Van den Biesen (2018)	

Stakeholders assumptions (general)
In this first version of the tool, 2 main stakeholder groups are accounted for: Real estate investors (1) (Corresponding analysis: LCCA) and Society as a whole (2) (Corresponding analysis: SCBA)

Vertical greening system principles	Data implementation
VGS main category	Modular LWS
Specific subtype / name of VGS system	Not incorporated in the tool yet, please select "Modular LWS" in the cell above
Biodiversity benchmark/scaling factor' of proposed VGS (-)	1
Design lifespan of VGS (Years)	30
Time needed for system to obtain fully grown vegetation (Years)	1
Yearly growth rate of VGS vegetation (%)	100,0%
Incremental percentage of calculated benefits in years of growth (%)	50,0%
Annual replacement percentage of vegetation	10,0%
Annual replacement percentage of irrigation system	10,0%
Annual replacement percentage of system panels/pots/boxes	5,0%

Financial principles	Data implementation
Time period over which the costs and benefits are accounted for (Years)	30
Time period in which the full benefits of the VGS are accounted for (Years)	29
Time period in which no/only partial benefits of the VGS are accounted for (Years)	1
Reference year for price levels used in the tool	2022
Year in which analysis is performed	2022
Estimated yearly inflation rate for costs of consumption goods (%)	2,5%
Estimated yearly inflation rate for values linked to ES benefits (%)	1,0%
Nominal discount rate for discounted cash flow analysis (DCF) in Life Cycle Cost Analysis (LCCA) (%)	8,0%
Nominal discount rate for discounted cash flow analysis (DCF) in Social Cost-Benefit Analysis (SCBA) for ES (%)	3,0%
Real discount rate for discounted cash flow analysis (DCF) in Life Cycle Cost Analysis (LCCA) (%)	5,4%
Real discount rate for discounted cash flow analysis (DCF) in Social Cost-Benefit Analysis (SCBA) for ES (%)	2,0%

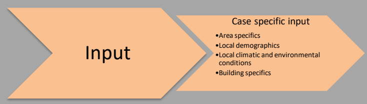
Stakeholder principles	Data implementation
Stakeholders involved in the model	***Personal costs and benefits***
	Real estate investor (1)
	Social costs and benefits
	Society as a whole (2)

Tab 3: Case specific input & assumptions

In appendix F.2, also the case specific input data related to the case study is provided, which was implemented in the VGS Valuation Tool.

Case specific assumptions & input

The case specific assumptions & input is used for the calculations of monetary terms for each cost and benefit theme. The input will be used throughout the entire document and cost or benefit calculations (monetarization formulas) are linked to the input denoted in this tab. The case specific input is distributed over different categories that are relevant to the elaboration of all costs and benefits. For correct use and results of this model, the user should pay attention that adequate input is given in this tab, which aligns with the specific project/case that is analysed. All necessary project/case information is gathered here, before the calculations in the costs and benefits tabs are conducted.



The blue cells are not to be adjusted by the user of this tool. (fixed/automatic) Only the developer/consultant of the tool is allowed to make (substantiated) changes in these cells, based on new scientific insights and knowledge.

The orange cells are to be filled in or checked/verified by the user. These cells are to be found on the following tabs:
2. General principles & assumptions
3. Case specific input
4. Indicator specific input

Purple cells are proposed inputs for future versions of the valuation model, when more detailled connections and interdependencies can be created between certain 'Value Indicators' and general principles and assumptions.

Project case

Project case information	Data implementation
Project name	Complex Paradium 3
Adress	Spuiboulevard 7-95 (odd nr.)
City	Dordrecht
Zip-code	3311 GM
Neighbourhood	Centrum
District	Wijk 01 Binnenstad
Client	-
Consultant	-

Area specifics

Area specific input	Data implementation	Data source/Literature reference	Additional information/assumptions
Location type	Dense city centre	Google Maps	
Type of street adjacent to the building	City centre	Google Maps	Effectivity of e.g. capture of pollutants as a result o
Plot area of the building		Kadasterdata - Kadastrale kaart	
Current level of green in surroundings (% green within neighbourhood)		Basiskaart Groen en Grijs (Klimaateffectatlas)	
Increase level of green in surroundings (% increase green within neighbourhood)			
Local biodiversity levels/conditions		'Natuurpuntencalculator' Sweco (Future Outlook)	FUTURE OUTLOOK: Implement a biodiversity scalin

Area specific assumptions

Local demographics

Local demographics input	Data implementation	Data source/Literature reference	Additional information/assumptions
Number of inhabitants in the neighbourhood (n)	1030	Statline CBS	
Population density (inhabitants/km²)	8209	Statline CBS	
Population density (inhabitants/ha)	82,09	Statline CBS	
Socio-economic status of neighbourhood (low-medium-high)			
Number of households/apartments/dwellings in the neighbourhood (n)	695	Statline CBS	
Average income per capita in neighbourhood (€/year)	31900	Allecijfers.nl	
Age distribution inhabitants - 0-15 years (n)	60	Statline CBS	
Age distribution inhabitants - 15-25 years (n)	95	Statline CBS	
Age distribution inhabitants - 25-45 years (n)	385	Statline CBS	
Age distribution inhabitants - 45-65 years (n)	295	Statline CBS	
Age distribution inhabitants - 65 years and older (n)	200	Statline CBS	

Local demographics assumptions
Inhabitants are assumed to be evenly distributed over the entire neighbourhood in which the building/project is situated.

Local climatic and environmental conditions

Local climatic and environmental conditions input	Data implementation	Data source/Literature reference	Additional information/assumptions
Climate in general			
Climate type	Temperate climate		Netherlands is temperate climate
Bruto surrounding conditions			
Local temperature conditions			
Maximum local temperature			
Maximum perceived local temperature			
Local precipitation conditions			
Local air quality: concentration in μg/m3 for e.g. CO2, Particulate matter (PM10, PM2.5), NOx, SOx, O3		https://geodata.rivm.nl/gcn/	
Local concentration of PM10 (μg/m3)	18,87	Geodata RIVM	Local concentration can be obtained through acces
Local soil saturation			
		https://data.overheid.nl/	

Local climatic and environmental conditions assumptions

Building specifics

Building specific input	Data implementation	Data source/Literature reference		Additional information/assumptions
Structural/Architectural features				
Building type	Residential (Multi-family housing)	User/Client		The building type can have influence on e.g. averag
Year of construction	1967	User/Client	Atlas Leefomgeving	The year of construction can act as starting principl
Current existing façade type	Brick façade (masonry wall)	User/Client	Googlemaps	
Façade area for VGS in South-orientation (m²)	898,30	Building plans	Spotr.ai	
Façade area for VGS in East-orientation (m²)	585,70	Building plans	Spotr.ai	
Façade area for VGS in West-orientation (m²)	183,10	Building plans	Spotr.ai	
Façade area for VGS in North-orientation (m²)	190,90	Building plans	Spotr.ai	
Total façade area for VGS in project (m²)	1858,00	-		Sum of all façade orientations
Residual lifetime of current façade (years)		-		
Thermal insulation value (Rc-value) existing façade (m²K/W)	0,43	User/Client	HandelBouwadvies	Initially, the thermal insulation value of the façade
Thermal insulation value increase due to VGS (Rc-value) (m²K/W)	0,09	Ottelé (2011)		
Sound insulation value (Rw-value) existing façade (dB)				
Sound insulation value increase due to VGS (Rw-value) (dB)				
Properties				
Number of dwellings in the building complex (n)	45	User/Client		
Average area of the properties (m²)	100	User/Client		
Total area of the communal spaces (m²)	1000	User/Client		
Total area of the entire building complex (m²)	5500	-		
Number of inhabitants in the building complex (n)	66,69	User/Client	Statline CBS	Based on average number of inhabitants per dwelli
Average number of inhabitants per dwelling in the building complex (n)	1,48			Based on number of inhabitants in the neighbourho
Average property value ('WOZ'-value) in neighbourhood or of the property (€)	193000	User/Client	Statline CE WOZ-waarde Loket	Average property value can be deducted from 'Kerr
Total property value of the complex (€)	8685000	-		Based on number of dwellings in the building compl
Average monthly rent per area in the city (€/m²)	14,82	Pararius		
Average monthly base rent per dwelling in the building complex (€)	1482	User/Client	-	Initially, the average monthly base rent per dwelling
Average yearly base rent per dwelling in the building complex (€)	17784	-		
Total monthly base rent for the entire building complex (€)	66690	-		
Total yearly base rent for the entire building complex (€)	800280	-		
Energy consumption				
Price for electricity (euro/kWh)	0,80			
Price for gas (euro/m3)	2,00			
Average yearly electricity consumption per dwelling in the building complex (kWh)	1940	User/Client	Allecijfers.nl	
Total yearly electricity consumption in the building complex (kWh)	87300	-		
Average yearly natural gas consumption per dwelling in the building complex (m³)	810	User/Client	Allecijfers.nl	
Total yearly natural gas consumption in the building complex (m³)	36450	-		
Average percentage of gas consumption for heating (%)	75%	Essent		
Potential energy saving for heating (%)	6,3%	Ottelé (2011)		Year round average
		-		

Building specific assumptions
Current façade is intact, in good condition and suitable for implementation of VGS. Hence, technical feasibility is assumed.
The building type (real estate object) is a major influence for the (total) cost price of the VGS, due to the differences in façade composition/built-up.
The entire façade area can be covered with a VGS, with exceptions of course for the areas of windows and doors.

Area specific input	Data implementation
Location type	Dense city centre
Type of street adjacent to the building	City centre
Plot area of the building	
Current level of green in surroundings (% green within neighbourhood)	
Increase level of green in surroundings (% increase green within neighbourhood)	
Local biodiversity levels/conditions	

Local demographics input	Data implementation
Number of inhabitants in the neighbourhood (n)	1030
Population density (inhabitants/km^2)	8209
Population density (inhabitants/ha)	82,09
Socio-economic status of neighbourhood (low-medium-high)	
Number of households/apartments/dwellings in the neighbourhood (n)	695
Average income per capita in neighbourhood (€/year)	31900
Age distribution inhabitants - 0-15 years (n)	60
Age distribution inhabitants - 15-25 years (n)	95
Age distribution inhabitants - 25-45 years (n)	385
Age distribution inhabitants - 45-65 years (n)	295
Age distribution inhabitants - 65 years and older (n)	200

Local climatic and environmental conditions input	Data implementation
Climate in general	
Climate type	Temperate climate
Bruto surrounding conditions	
Local temperature conditions	
Maximum local temperature	
Maximum perceived local temperature	
Local precipitation conditions	
Local air quality: concentration in μg/m3 for e.g. CO2, Particulate matter (PM10, PM2.5), NOx, SOx, O3	
Local concentration of PM10 (μg/m3)	18,87
Local soil saturation	

Building specific input	Data implementation
Structural/Architectural features	
Building type	Residential (Multi-family housing)
Year of construction	1967
Current existing façade type	Brick façade (masonry wall)
Façade area for VGS in South-orientation (m^2)	898,30
Façade area for VGS in East-orientation (m^2)	585,70
Façade area for VGS in West-orientation (m^2)	183,10
Façade area for VGS in North-orientation (m^2)	190,90
Total façade area for VGS in project (m^2)	1858,00
Residual lifetime of current façade (years)	
Thermal insulation value (Rc-value) existing façade (m^2K/W)	0,43
Thermal insulation value increase due to VGS (Rc-value) (m^2K/W)	0,09
Sound insulation value (Rw-value) existing façade (dB)	
Sound insulation value increase due to VGS (Rw-value) (dB)	
Properties	
Number of dwellings in the building complex (n)	45
Average area of the properties (m^2)	100
Total area of the communal spaces (m^2)	1000
Total area of the entire building complex (m^2)	5500
Number of inhabitants in the building complex (n)	66,69
Average number of inhabitants per dwelling in the building complex (n)	1,48
Average property value ('WOZ'-value) in neighbourhood or of the property (€)	193000
Total property value of the complex (€)	8685000
Average monthly rent per area in the city (€/m^2)	14,82
Average monthly base rent per dwelling in the building complex (€)	1482
Average yearly base rent per dwelling in the building complex (€)	17784
Total monthly base rent for the entire building complex (€)	66690
Total yearly base rent for the entire building complex (€)	800280
Energy consumption	
Price for electricity (euro/kWh)	0,80
Price for gas (euro/m3)	2,00
Average yearly electricity consumption per dwelling in the building complex (kWh)	1940
Total yearly electricity consumption in the building complex (kWh)	87300
Average yearly natural gas consumption per dwelling in the building complex (m^3)	810
Total yearly natural gas consumption in the building complex (m^3)	36450
Average percentage of gas consumption for heating (%)	75%
Potential energy saving for heating (%)	6,3%

Tab 4: Indicator specific input & assumptions

In appendix F.2, finally the indicator specific input data related to the case study is provided, which was implemented in the VGS Valuation Tool.

Theme: Financial costs

Financial costs input	Data implementation		
Cost factor 'economy of scale': in case of large scale VGS project (-)	**1,00**		
Complexity cost factor: in case of high complexity VGS project (-)	**1,00**		
Initial costs	**Total (Sum of individual cost items (when known))**	**Total (manual)**	**Final**
Total sum of initial costs of VGS (€/m²) ***(Sum of individual costs (FUTURE OUTLOOK) vs. Manually implemented costs)***	**0**	**750**	**750,00**
Initial costs	**Exact**	**% of total**	**Final**
Engineering & Consultancy (€/m2)		**4%**	**30,00**
Study, design, engineering of construction and planting scheme ('Fixed costs') (€)			**0,00**
Permit application ('Fixed costs') (€)			**0,00**
Initialisation (off-site) & installation (on-site) (€/m2)		**87%**	**652,50**
Manpower cost: salary of workers for taking care of plants in nursery stage and preparing system components (€/m2)			**0,00**
Material cost: VGS components (structure, plants, pot/panel/module, growing media, irrigation system, drainage system and buffer tank, technical room, fertilizers) (€/m2)			**0,00**
Utilities cost: electricity and water for initialisation (€/m2)			**0,00**
Equipment cost: for nursing plants, preparing system, etc. (€/m2)			**0,00**
Repair works on existing façade (€/m2)			**0,00**
Manpower cost: salary of workers for transporting and installing the system on-site (€/m2)			**0,00**
Material cost: transport for materials (€/m2)			**0,00**
Equipment cost: for installation of the system (aerial lift, telescopic handler, etc.) (€/m2)			**0,00**
First year aftercare (€/m2)		**9%**	**67,50**
Follow-up/Aftercare (€/m2)			
Costs occuring at later moment			
Operations, maintenance & replacement (€/m2/year) (Reference costs)	**50**		**50,00**
Manpower cost: salary of workers for maintaining the system on regular schedule (pruning and panels adjustment, irrigation system and fertilization, monitoring) (€/m2/year)			**0,00**
Material cost: annual replacement cost of materials (mainly plants (10%), irrigation system (10%) and panels (5%)) and transportation (€/m2/year)			**0,00**
Utilities cost: electricity and water (€/m2/year)			**0,00**
Equipment cost: for maintenance work (€/m2/year)			**0,00**
Disposal (€/m2) (Reference costs)	**150**		**150,00**
Manpower cost: salary of workers for dismantling and disposal (€/m2)			**0,00**
Material cost: transport for materials minus potential residual value of the system (reuse) (€/m2)			**0,00**
Equipment cost: for disposal of the system (€/m2)			**0,00**

Theme: Environmental costs

Shadow costs input	Data implementation
Location of VGS manufacturer	Utrecht
Transportation distance (manufacturer - project site) (km)	63
Mode of transportation	Truck, trailer, 24 t (EURO 6, 16-32 t)
Number of hours of crane operation (installation)	100

Shadow Costs Category & components	Material / Process / Transport	Amount of material input for VGS per m2	Unit
Product Stage			
A1+A2+A3 - Raw material supply, transport and manufacturing			
Modular LWS - Planter boxes			
Bolts	Construction steel (S235)	0,27	kg/m2
Spacer brackets	Construction steel (S235)	0,32	kg/m2
Air cavity	-		
Supporting U-section	Construction steel (S235)	4,62	kg/m2
Planter boxes	High-density polyethelyne (HDPE)	13,20	kg/m2
Growing material	Potting soil	75,60	kg/m2
Vegetation	Ferns/shrubs	8,00	kg/m2
Watering system	Polyethylene (PE), beter PVC	0,26	kg/m2
Construction Process Stage			
A4 - Transport			
VGS Supplier - Project site (materials) (Fossil fuel)	Truck, trailer, 24 t (EURO 6, 16-32 t)	6,44	tkm/m2
VGS Supplier - Project site (materials) (Fossil fuel)	Truck, container, 28 t (EURO 5, 16-32 t)		tkm/m2
VGS Supplier - Project site (materials) (Fossil fuel)	Van		m
A5 - Construction-installation process			
Mounting equipment - Project site (Fossil)	Crane	100,00	u
Use Stage			
Energy demand for operating and monitoring VGS	Electricity consumption (average)		kWh/year/m2
	Natural gas consumption (average)		m^3/year/m2
B7 - Operational water use			
Water demand	Tap water (average)	365,00	l/year/m2
	Grey water (average)		l/year/m2
	Recycled rain water (average)		l/year/m2
End of Life Stage			
	verbranden steenwol		kg/m2
	verbranden staalschroot		kg/m2
	verbranden kunststoffen		kg/m2
	breken steen		kg/m2
Benefits and Loads			
	recycling aluminium		kg/m2
	recycling PE		kg/m2
	recycling PVC		kg/m2
	recyclage staal		kg/m2

Theme: Health & well-being benefits

1.2.1 - Reduction of healthcare costs due to deposition of Particulate Matter (PM10) input	Data implementation
Deposition rate for VGS (cm/m)	0,64
Wall Leaf Area Index (WLAI) (-)	5,00
Resuspension fraction PM10 (-)	0,50
Conversion factor (-)	3,1536
Inhabitants per ha (number of people)	82,09
Value of Particulate Matter (PM10), related to population density (€/kg PM10)	161,63

Theme: Real estate benefits

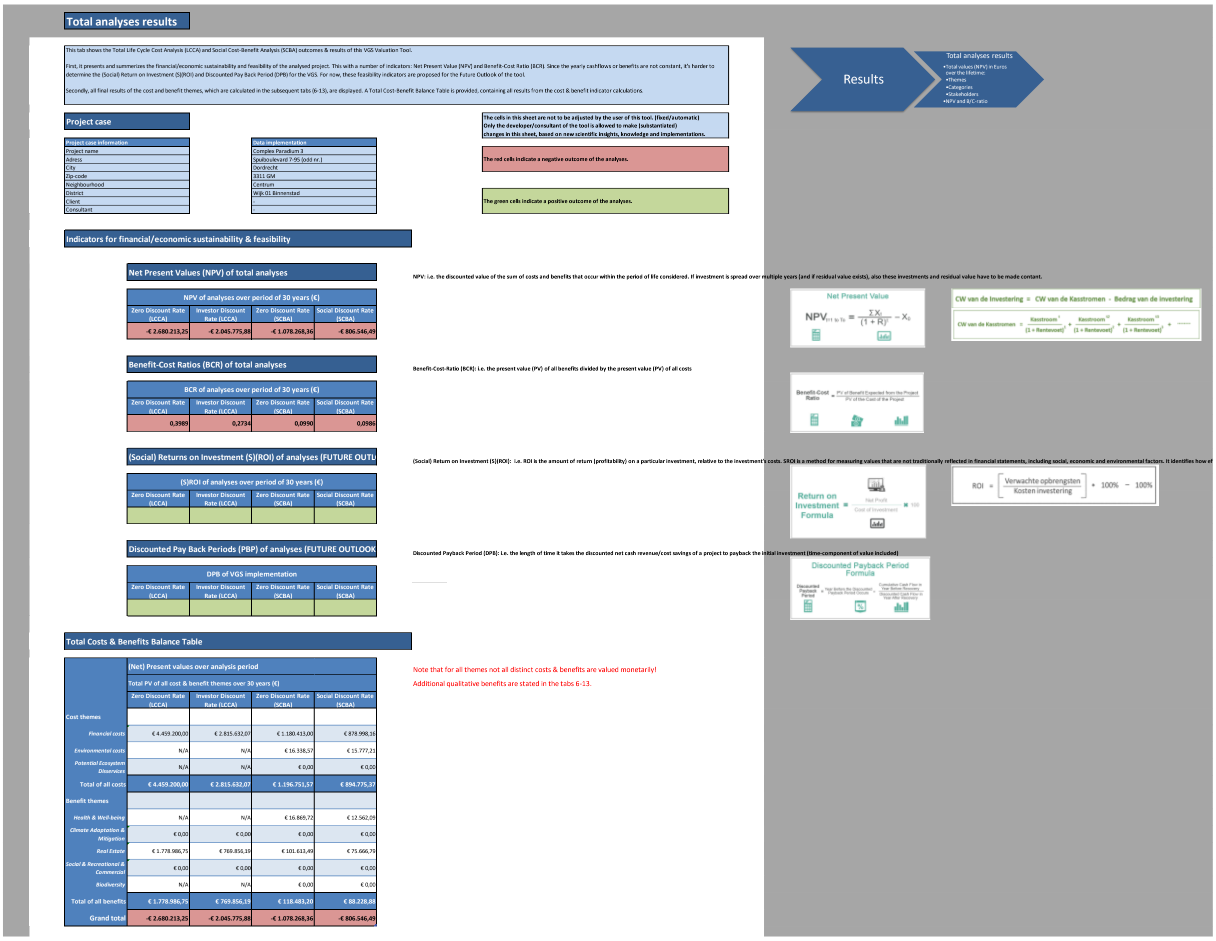
1.1 Increase of real estate value for the real estate investor/owner (increased rental incomes) (financial cost component for residents) input	Data implementation
Assumed increase in rental price for property (%)	5,0%

3.2 Tax incentives MIA input	Data implementation
Tax percentage for profit (%)	25,00%
Tax benefits MIA: percentage of investment in VGS that is tax deductible (%)	45,00%

3.3 Tax incentives VAMIL input	Data implementation
Tax benefits Vamil: average net benefit of total invested sum (%)	3,00%

F.3 Result sections

Tab 5.1: Total analyses results



Total analyses results

This tab shows the Total Life Cycle Cost Analysis (LCCA) and Social Cost-Benefit Analysis (SCBA) outcomes & results of this VGS Valuation Tool.

First, it presents and summerizes the financial/economic sustainability and feasibility of the analysed project. This with a number of indicators: Net Present Value (NPV) and Benefit-Cost Ratio (BCR). Since the yearly cashflows or benefits are not constant, it's harder to determine the (Social) Return on Investment (S)(ROI) and Discounted Pay Back Period (DPB) for the VGS. For now, these feasibility indicators are proposed for the Future Outlook of the tool.

Secondly, all final results of the cost and benefit themes, which are calculated in the subsequent tabs (6-13), are displayed. A Total Cost-Benefit Balance Table is provided, containing all results from the cost & benefit indicator calculations.

Project case

Project case information	Data implementation
Project name	Complex Paradium 3
Adress	Spuiboulevard 7-95 (odd nr.)
City	Dordrecht
Zip-code	3311 GM
Neighbourhood	Centrum
District	Wijk 01 Binnenstad
Client	-
Consultant	-

The cells in this sheet are not to be adjusted by the user of this tool. (fixed/automatic)
Only the developer/consultant of the tool is allowed to make (substantiated) changes in this sheet, based on new scientific insights, knowledge and implementations.

The red cells indicate a negative outcome of the analyses.

The green cells indicate a positive outcome of the analyses.

Results → Total analyses results
- Total values (NPV) in Euros over the lifetime:
  - Themes
  - Categories
  - Stakeholders
- NPV and B/C-ratio

Indicators for financial/economic sustainability & feasibility

Net Present Values (NPV) of total analyses

NPV of analyses over period of 30 years (€)			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
-€ 2.680.213,25	-€ 2.045.775,88	-€ 1.078.268,36	-€ 806.546,49

NPV: i.e. the discounted value of the sum of costs and benefits that occur within the period of life considered. If investment is spread over multiple years (and if residual value exists), also these investments and residual value have to be made contant.

Net Present Value

$$NPV_{t=1\ to\ T_0} = \frac{\sum X_t}{(1+R)^t} - X_0$$

CW van de Investering = CW van de Kasstromen - Bedrag van de investering

CW van de Kasstromen = Kasstroom / (1 + Rentevoet) + Kasstroom / (1 + Rentevoet) + Kasstroom / (1 + Rentevoet) + ...

Benefit-Cost Ratios (BCR) of total analyses

BCR of analyses over period of 30 years (€)			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
0,3989	0,2734	0,0990	0,0986

Benefit-Cost-Ratio (BCR): i.e. the present value (PV) of all benefits divided by the present value (PV) of all costs

Benefit-Cost Ratio = PV of Benefit Expected from the Project / PV of the Cost of the Project

(Social) Returns on Investment (S)(ROI) of analyses (FUTURE OUTL

(S)ROI of analyses over period of 30 years (€)			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)

(Social) Return on Investment (S)(ROI): i.e. ROI is the amount of return (profitability) on a particular investment, relative to the investment's costs. SROI is a method for measuring values that are not traditionally reflected in financial statements, including social, economic and environmental factors. It identifies how ef

Return on Investment Formula = Net Profit / Cost of Investment × 100

ROI = [Verwachte opbrengsten / Kosten investering] • 100% − 100%

Discounted Pay Back Periods (PBP) of analyses (FUTURE OUTLOOK

DPB of VGS implementation			
Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)

Discounted Payback Period (DPB): i.e. the length of time it takes the discounted net cash revenue/cost savings of a project to payback the initial investment (time-component of value included)

Discounted Payback Period Formula

Total Costs & Benefits Balance Table

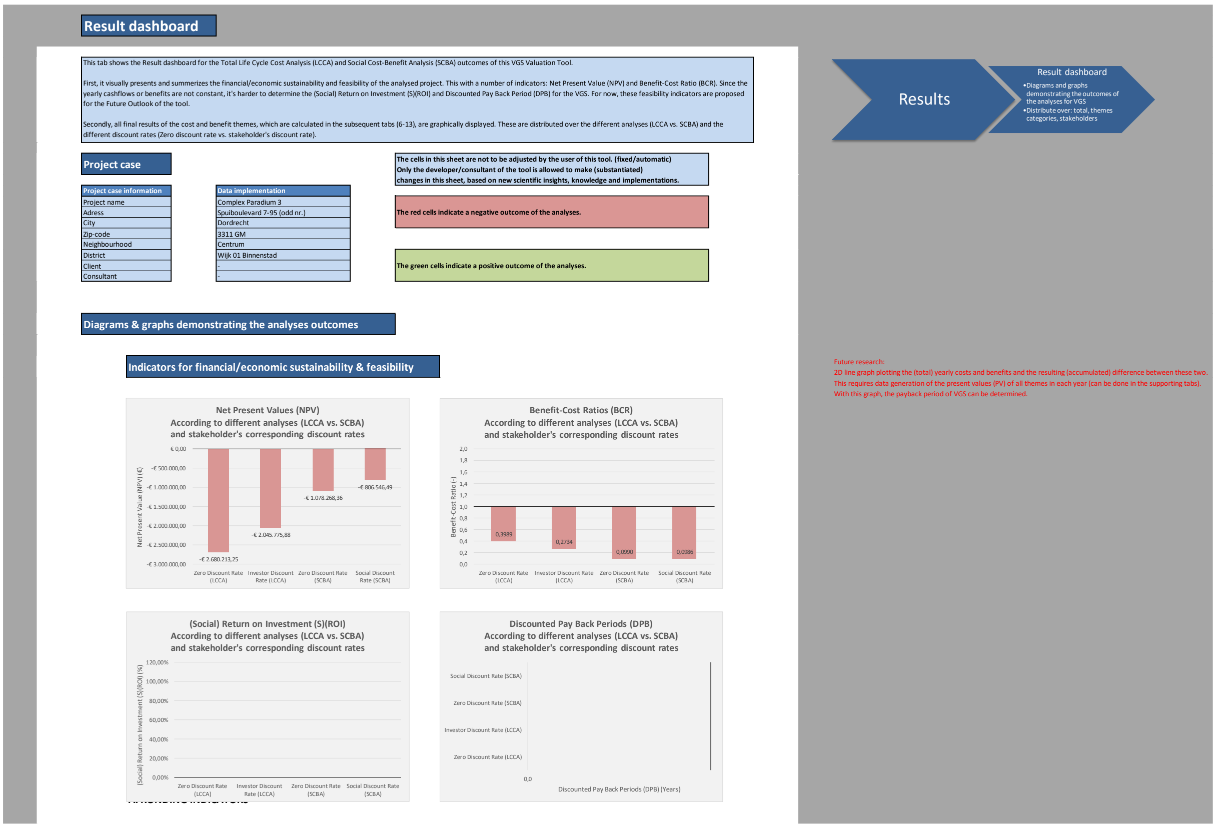
	(Net) Present values over analysis period			
	Total PV of all cost & benefit themes over 30 years (€)			
	Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
Cost themes				
Financial costs	€ 4.459.200,00	€ 2.815.632,07	€ 1.180.413,00	€ 878.998,16
Environmental costs	N/A	N/A	€ 16.338,57	€ 15.777,21
Potential Ecosystem Disservices	N/A	N/A	€ 0,00	€ 0,00
Total of all costs	€ 4.459.200,00	€ 2.815.632,07	€ 1.196.751,57	€ 894.775,37
Benefit themes				
Health & Well-being	N/A	N/A	€ 16.869,72	€ 12.562,09
Climate Adaptation & Mitigation	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Real Estate	€ 1.778.986,75	€ 769.856,19	€ 101.613,49	€ 75.666,79
Social & Recreational & Commercial	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Biodiversity	N/A	N/A	€ 0,00	€ 0,00
Total of all benefits	€ 1.778.986,75	€ 769.856,19	€ 118.483,20	€ 88.228,88
Grand total	-€ 2.680.213,25	-€ 2.045.775,88	-€ 1.078.268,36	-€ 806.546,49

Note that for all themes not all distinct costs & benefits are valued monetarily!

Additional qualitative benefits are stated in the tabs 6-13.

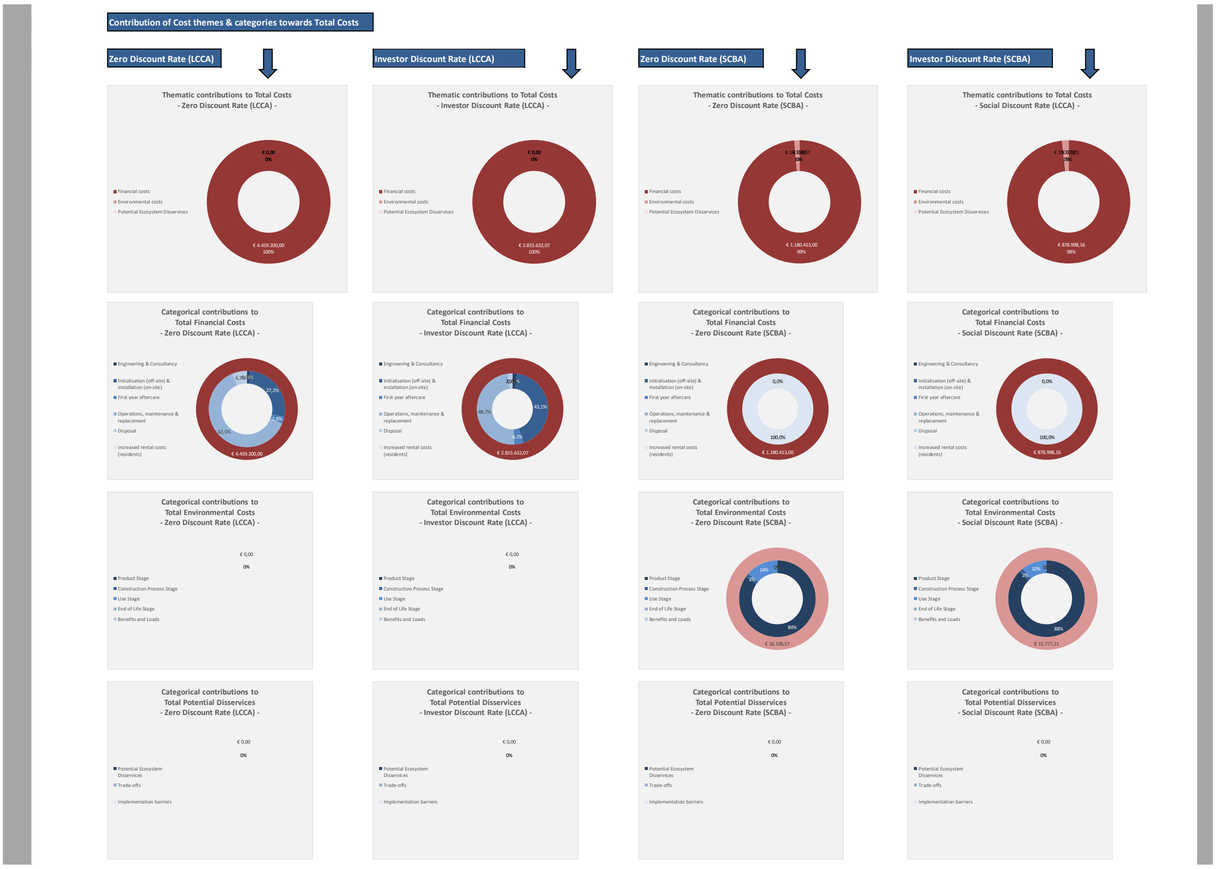
Tab 5.2: Result dashboard

Economic & financial feasibility indicators: NPV & B/C-ratio



Costs vs. Benefits: Total & Distributed over impact themes

Contribution of Cost themes & categories towards Total Costs



Contribution of Benefit themes & categories towards Total Benefits

F.4 Cost sections

Tab 6: Financial costs

Financial costs

In this tab, an analysis of the financial costs related to the vertical greening system is performed and an overview of these is given. The analysis is divided over several categories, based on literature research and information provided by suppliers.

Furthermore, some backgrounds on financing options for 'green' climate adaptation measures are provided. For the client, these can be a starting point from which the financing options for the VGS can be investigated.

Cost indicators & Cost Balance Table

Purple cells are proposed inputs for future versions of the valuation model, when more detailled connections and interdependencies can be created between certain 'Value Indicators' and general principles and assumptions.

Cost indicators		Occurance and prices		Present values over analysis period			
Item	Categories & cost indicators	Time frame	Value (€ ; €/year)	Total PV of financial costs over 30 years (€)			
				Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
1.	**Engineering & Consultancy**	**One time - Initial**	**€ 55.740,00**	€ 55.740,00	€ 55.740,00	N/A	N/A
1.1	Study, design, engineering of construction and planting scheme	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
1.2	Permit application	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
	Total of Engineering & consultancy			€ 55.740,00	€ 55.740,00	€ 0,00	€ 0,00
2.	**Initialisation (off-site) & installation (on-site)**	**One time - Initial**	**€ 1.212.345,00**	€ 1.212.345,00	€ 1.212.345,00	N/A	N/A
2.1	Manpower cost: salary of workers for taking care of plants in nursery stage and preparing system components	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.2	Material cost: VGS components (structure, plants, pot/panel/module, growing media, irrigation system, drainage sy	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.3	Utilities cost: electricity and water for initialisation	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.4	Equipment cost: for nursing plants, preparing system, etc.	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.5	Repair works on existing façade	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.6	Manpower cost: salary of workers for transporting and installing the system on-site	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.7	Material cost: transport for materials	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
2.8	Equipment cost: for installation of the system (aerial lift, telescopic handler, etc.)	One time - Initial	€ 0,00	N/A	N/A	N/A	N/A
	Total of initialisation & installation			€ 1.212.345,00	€ 1.212.345,00	€ 0,00	€ 0,00
3.	**First year aftercare**	**One time - Year 1**	**€ 125.415,00**	€ 125.415,00	€ 119.028,13	N/A	N/A
3.1	Follow-up/Aftercare	One time - Year 1	€ 0,00	N/A	N/A	N/A	N/A
	Total of First year aftercare			€ 125.415,00	€ 119.028,13	€ 0,00	€ 0,00
4.	**Operations, maintenance & replacement**	**Annual - Year 1-30**	**€ 92.900,00**	€ 2.787.000,00	€ 1.370.423,75	N/A	N/A
4.1	Manpower cost: salary of workers for maintaining the system on regular schedule (pruning and panels adjustment, i	Annual - Year 1-30	€ 0,00	N/A	N/A	N/A	N/A
4.2	Material cost: annual replacement cost of materials (mainly plants (10%), irrigation system (10%) and panels (5%)) a	Annual - Year 1-30	€ 0,00	N/A	N/A	N/A	N/A
4.3	Utilities cost: electricity and water	Annual - Year 1-30	€ 0,00	N/A	N/A	N/A	N/A
4.4	Equipment cost: for maintenance work	Annual - Year 1-30	€ 0,00	N/A	N/A	N/A	N/A
	Total of Operations, maintenance & replacement			€ 2.787.000,00	€ 1.370.423,75	€ 0,00	€ 0,00
5.	**Disposal**	**One time - Year 30**	**€ 278.700,00**	€ 278.700,00	€ 58.095,20	N/A	N/A
5.1	Manpower cost: salary of workers for dismantling and disposal	One time - Year 30	€ 0,00	N/A	N/A	N/A	N/A
5.2	Material cost: transport for materials minus potential residual value of the system (reuse)	One time - Year 30	€ 0,00	N/A	N/A	N/A	N/A
5.3	Equipment cost: for disposal of the system	One time - Year 30	€ 0,00	N/A	N/A	N/A	N/A
	Total of Disposal			€ 278.700,00	€ 58.095,20	€ 0,00	€ 0,00
6.	**Increased rental costs (residents)**	**Annual - Year 1-30**	**€ 40.014,00**	N/A	N/A	€ 1.180.413,00	€ 878.998,16
	Total of Increased rental costs (residents)			€ 0,00	€ 0,00	€ 1.180.413,00	€ 878.998,16
	Grand total			**€ 4.459.200,00**	**€ 2.815.632,07**	**€ 1.180.413,00**	**€ 878.998,16**

Additional information regarding financing climate adaptation measures

In the Netherlands, RVO identified 29 different financing options that might offer a solution for financing climate adaptation measures:

Funds
1. BIZ-fonds
2. NWB Waterinnovatiefonds
3. Fonds gesmeden schade verzekeraars

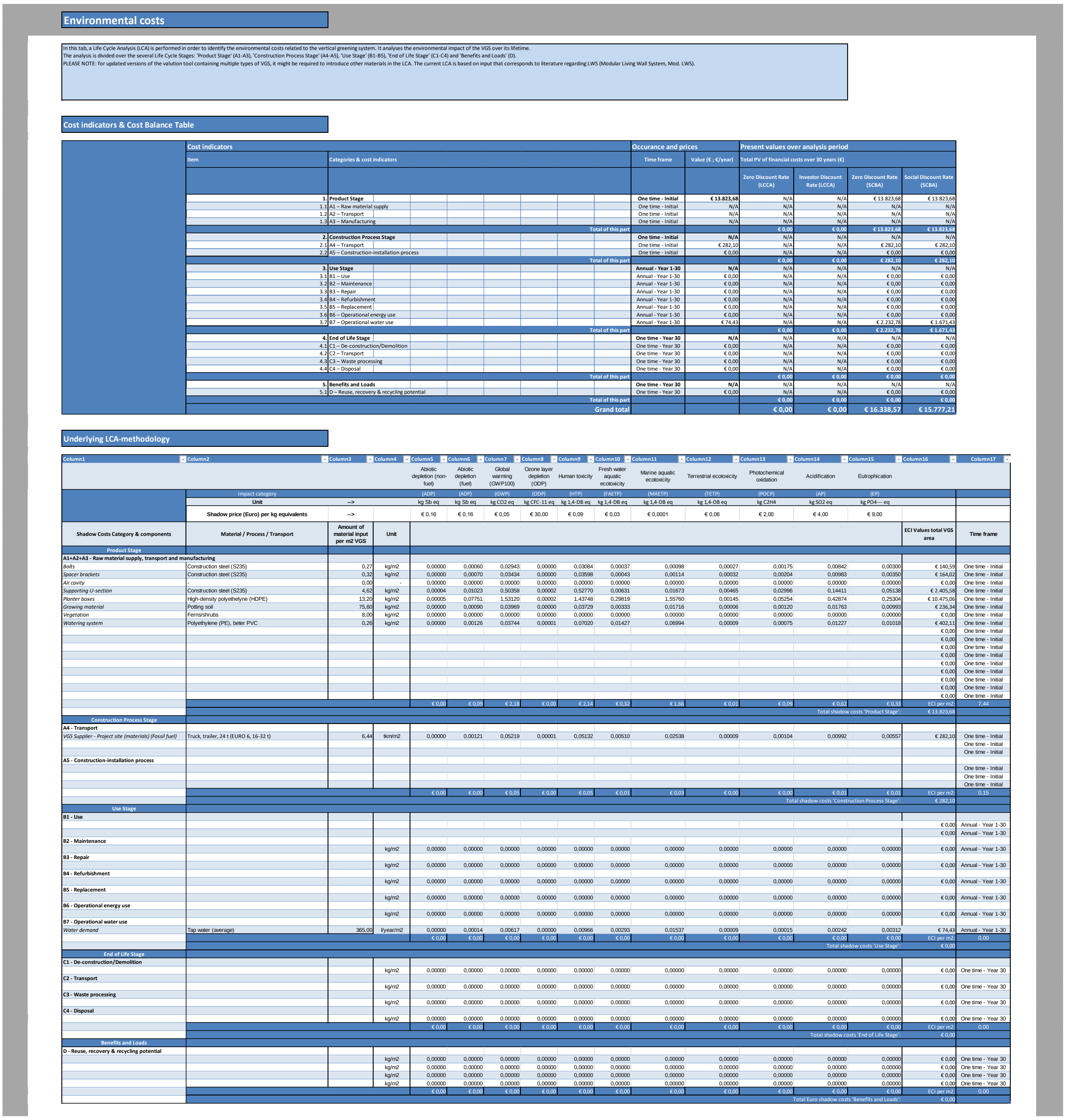
Subsidies/Grants
4. Diensten en producten in natura
5. Impulsregeling klimaatadaptatie
6. Maatwerksubsidie voor woningcorporaties
7. Subsidie door decentrale overheden

Loans
8. Duurzaamheidslening
9. Hypotheekrente-differentiatie
10. Impactlening
11. Regeling groenprojecten

Tax benefits
12. Differentiatie van de waterschapsbelasting
13. Duurzame rioolheffing
14. Duurzame WOZ-waarde
15. Groene leges
16. Investeringsaftrek MIA\Vamil

Financing structures
17. Anterieure overeenkomst
18. Besparen op beheer en onderhoud
19. Crowdfunding
20. Energieprestatievergoeding
21. Environmental impact bond
22. Green bond
23. Hogere vastgoedwaarde door vergroening
24. Inkoopkorting
25. Klimaatadaptatie in de grondexploitatie
26. Meekoppelkansen
27. Residuele grondwaarde
28. Toekenning bovenwijks
29. Woningabonnement

Tab 7: Environmental costs



Environmental costs

In this tab, a Life Cycle Analysis (LCA) is performed in order to identify the environmental costs related to the vertical greening system. It analyses the environmental impact of the VGS over its lifetime.
The analysis is divided over the several Life Cycle Stages: 'Product Stage' (A1-A3), 'Construction Process Stage' (A4-A5), 'Use Stage' (B1-B5), 'End of Life Stage' (C1-C4) and 'Benefits and Loads' (D).
PLEASE NOTE: for updated versions of the valution tool containing multiple types of VGS, it might be required to introduce other materials in the LCA. The current LCA is based on input that corresponds to literature regarding LWS (Modular Living Wall System, Mod. LWS).

Cost indicators & Cost Balance Table

Cost indicators		Occurance and prices		Present values over analysis period			
Item	Categories & cost indicators	Time frame	Value (€ ; €/year)	Total PV of financial costs over 30 years (€)			
				Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
1.	**Product Stage**	**One time - Initial**	**€ 13.823,68**	N/A	N/A	€ 13.823,68	€ 13.823,68
1.1	A1 – Raw material supply	One time - Initial	N/A	N/A	N/A	N/A	N/A
1.2	A2 – Transport	One time - Initial	N/A	N/A	N/A	N/A	N/A
1.3	A3 – Manufacturing	One time - Initial	N/A	N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 13.823,68	€ 13.823,68
2.	**Construction Process Stage**	**One time - Initial**	**N/A**	N/A	N/A	N/A	N/A
2.1	A4 – Transport	One time - Initial	€ 282,10	N/A	N/A	€ 282,10	€ 282,10
2.2	A5 – Construction-installation process	One time - Initial	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
	Total of this part			€ 0,00	€ 0,00	€ 282,10	€ 282,10
3.	**Use Stage**	**Annual - Year 1-30**	**N/A**	N/A	N/A	N/A	N/A
3.1	B1 – Use	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.2	B2 – Maintenance	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.3	B3 – Repair	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.4	B4 – Refurbishment	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.5	B5 – Replacement	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.6	B6 – Operational energy use	Annual - Year 1-30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
3.7	B7 – Operational water use	Annual - Year 1-30	€ 74,43	N/A	N/A	€ 2.232,78	€ 1.671,43
	Total of this part			€ 0,00	€ 0,00	€ 2.232,78	€ 1.671,43
4.	**End of Life Stage**	**One time - Year 30**	**N/A**	N/A	N/A	N/A	N/A
4.1	C1 – De-construction/Demolition	One time - Year 30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
4.2	C2 – Transport	One time - Year 30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
4.3	C3 – Waste processing	One time - Year 30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
4.4	C4 – Disposal	One time - Year 30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
5.	**Benefits and Loads**	**One time - Year 30**	**N/A**	N/A	N/A	N/A	N/A
5.1	D – Reuse, recovery & recycling potential	One time - Year 30	€ 0,00	N/A	N/A	€ 0,00	€ 0,00
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
	Grand total			€ 0,00	€ 0,00	€ 16.338,57	€ 15.777,21

Underlying LCA-methodology

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10	Column11	Column12	Column13	Column14	Column15	Column16	Column17
				Abiotic depletion (non-fuel)	Abiotic depletion (fuel)	Global warming (GWP100)	Ozone layer depletion (ODP)	Human toxicity	Fresh water aquatic ecotoxicity	Marine aquatic ecotoxicity	Terrestrial ecotoxicity	Photochemical oxidation	Acidification	Eutrophication		
	Impact category			(ADP)	(ADP)	(GWP)	(ODP)	(HTP)	(FAETP)	(MAETP)	(TETP)	(POCP)	(AP)	(EP)		
	Unit	-->		kg Sb eq	kg Sb eq	kg CO2 eq	kg CFC-11 eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kg C2H4	kg SO2 eq	kg PO4--- eq		
	Shadow price (Euro) per kg equivalents	-->		€ 0,16	€ 0,16	€ 0,05	€ 30,00	€ 0,09	€ 0,03	€ 0,0001	€ 0,06	€ 2,00	€ 4,00	€ 9,00		
Shadow Costs Category & components	Material / Process / Transport	Amount of material input per m2 VGS	Unit												ECI Values total VGS area	Time frame
Product Stage																
A1+A2+A3 - Raw material supply, transport and manufacturing																
Bolts	Construction steel (S235)	0,27	kg/m2	0,00000	0,00060	0,02943	0,00000	0,03084	0,00037	0,00098	0,00027	0,00175	0,00842	0,00300	€ 140,59	One time - Initial
Spacer brackets	Construction steel (S235)	0,32	kg/m2	0,00000	0,00070	0,03434	0,00000	0,03598	0,00043	0,00114	0,00032	0,00204	0,00983	0,00350	€ 164,02	One time - Initial
Air cavity	-	0,00	-	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Initial
Supporting U-section	Construction steel (S235)	4,62	kg/m2	0,00004	0,01023	0,50358	0,00002	0,52770	0,00631	0,01673	0,00465	0,02996	0,14411	0,05138	€ 2.405,58	One time - Initial
Planter boxes	High-density polyethelyne (HDPE)	13,20	kg/m2	0,00005	0,07751	1,53120	0,00002	1,43748	0,29819	1,55760	0,00145	0,05254	0,42874	0,25304	€ 10.475,06	One time - Initial
Growing material	Potting soil	75,60	kg/m2	0,00000	0,00090	0,03969	0,00000	0,03729	0,00333	0,01716	0,00006	0,00120	0,01763	0,00993	€ 236,34	One time - Initial
Vegetation	Ferns/shrubs	8,00	kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Initial
Watering system	Polyethylene (PE), beter PVC	0,26	kg/m2	0,00000	0,00126	0,03744	0,00001	0,07020	0,01427	0,06994	0,00009	0,00075	0,01227	0,01018	€ 402,11	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
															€ 0,00	One time - Initial
				€ 0,00	€ 0,09	€ 2,18	€ 0,00	€ 2,14	€ 0,32	€ 1,66	€ 0,01	€ 0,09	€ 0,62	€ 0,33	ECI per m2:	7,44
														Total shadow costs 'Product Stage':	€ 13.823,68	
Construction Process Stage																
A4 - Transport																
VGS Supplier - Project site (materials) (Fossil fuel)	Truck, trailer, 24 t (EURO 6, 16-32 t)	6,44	tkm/m2	0,00000	0,00121	0,05219	0,00001	0,05132	0,00510	0,02538	0,00009	0,00104	0,00992	0,00557	€ 282,10	One time - Initial
																One time - Initial
																One time - Initial
A5 - Construction-installation process																
																One time - Initial
																One time - Initial
																One time - Initial
				€ 0,00	€ 0,00	€ 0,05	€ 0,00	€ 0,05	€ 0,01	€ 0,03	€ 0,00	€ 0,00	€ 0,01	€ 0,01	ECI per m2:	0,15
														Total shadow costs 'Construction Process Stage':	€ 282,10	
Use Stage																
B1 - Use																
															€ 0,00	Annual - Year 1-30
															€ 0,00	Annual - Year 1-30
B2 - Maintenance																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	Annual - Year 1-30
B3 - Repair																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	Annual - Year 1-30
B4 - Refurbishment																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	Annual - Year 1-30
B5 - Replacement																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	Annual - Year 1-30
B6 - Operational energy use																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	Annual - Year 1-30
B7 - Operational water use																
Water demand	Tap water (average)	365,00	l/year/m2	0,00000	0,00014	0,00617	0,00000	0,00966	0,00293	0,01537	0,00009	0,00015	0,00242	0,00312	€ 74,43	Annual - Year 1-30
				€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	ECI per m2:	0,00
														Total shadow costs 'Use Stage':	€ 0,00	
End of Life Stage																
C1 - De-construction/Demolition																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
C2 - Transport																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
C3 - Waste processing																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
C4 - Disposal																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
				€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	ECI per m2:	0,00
														Total shadow costs 'End of Life Stage':	€ 0,00	
Benefits and Loads																
D - Reuse, recovery & recycling potential																
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
			kg/m2	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	€ 0,00	One time - Year 30
				€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	ECI per m2:	0,00
														Total Euro shadow costs 'Benefits and Loads':	€ 0,00	

Tab 8: Potential Ecosystem Disservices

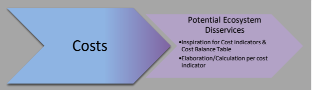
Potential Ecosystem Disservices, trade-offs & implementation barriers

In this tab, the potential Ecosystem Disservices, trade-offs & implementation barriers with regards to the integration of vertical greening systems in the urban fabric are displayed.

These disservices, trade-offs & implementation barriers are qualitatively stated (supported by potential literature references), however they are not (yet) worked out as monetarised values. If one would be able to do so, these effects could be an additional category at the cost spectrum of the Total Cost-Benefit Balance Sheet.

Firstly, all governing potential value indicators are listed, accompanied by placeholders for their resulting values in the 'Cost indicators & Cost Balance table'. In this table, in the future also the values can be distributed over the different analyses types, with their corresponding stakeholder group.

Secondly, the detailed elaborations and calculations of the monetary values per value indicator can be provided, which are at the basis of the values that are presented in the 'Cost indicators & Cost Balance table'.
For transparancy, also the applicable literature and other sources used for the elaboration of the particular cost indicator can be given.

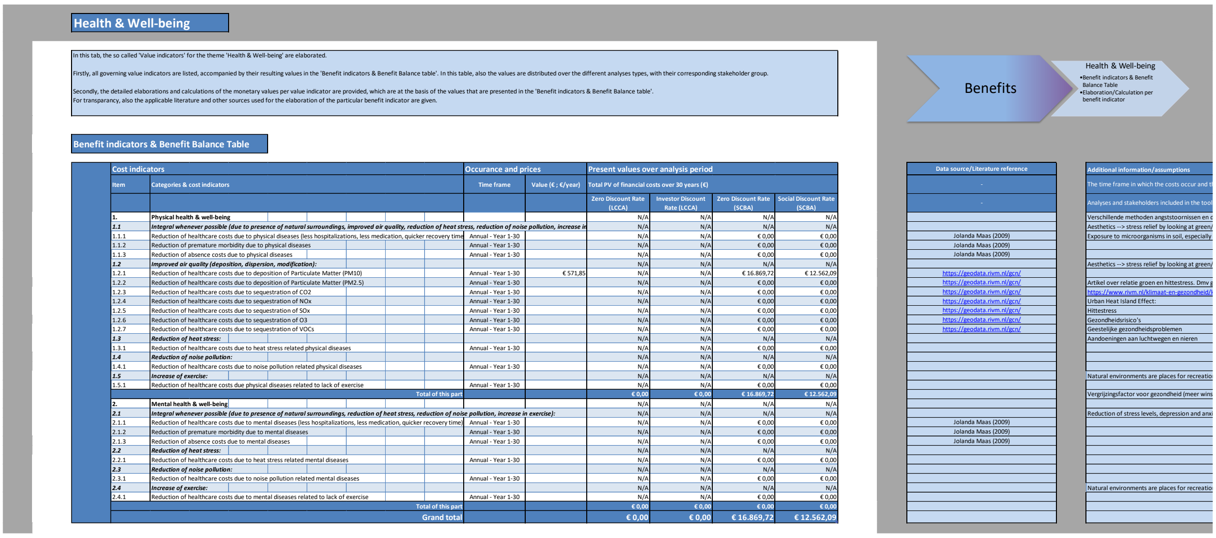


Inspiration for Cost indicators & Cost Balance Table

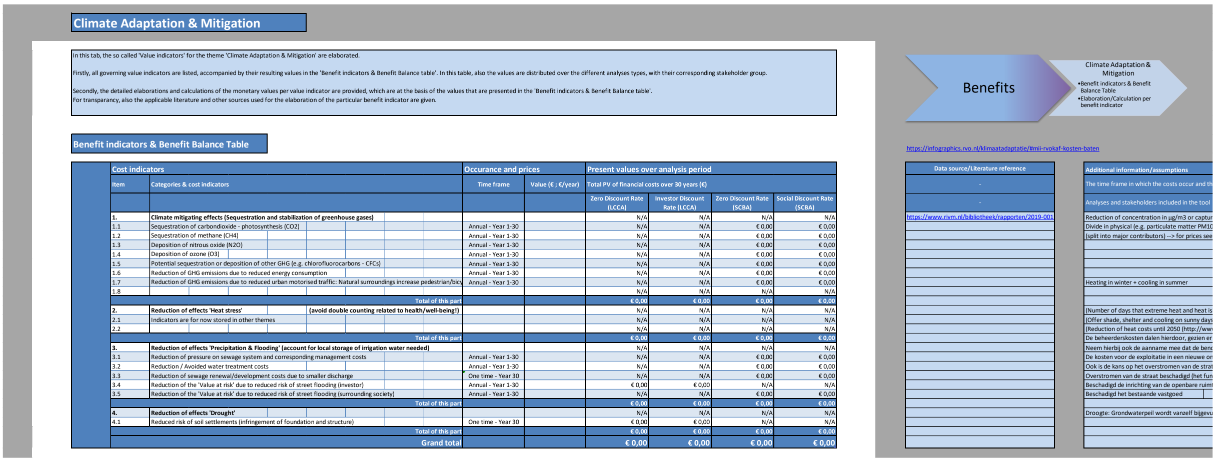
Inspiration for cost indicators		Occurance and prices		Present values over analysis period				Data source/Literature reference	Additional information/assumptions
Item	Categories & inspiration for cost indicators	Time frame	Value (€ ; €/year)	Total PV of financial costs over 30 years (€)				-	The time frame in which the costs occur
				Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)	-	Analyses and stakeholders included in th
1.	**Potential Ecosystem Disservices**			N/A	N/A	N/A	N/A		
1.1	Plant allergies or poisoning (value through increase of medication costs)		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.2	Emission of biogenic volatile organic compounds (BVOCs)		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.3	Unpleasant smells/odours from dead plants		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.4	Development of diseases		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.5	People might dislike birds and insects		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.6	Potential undesirable increase of humidity		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.7			Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
1.8			Qualitative: Not mone	N/A	N/A	N/A	N/A		
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00		
2.	**Trade-offs**			N/A	N/A	N/A	N/A		
2.1	Potential of green gentrification (disservice for people with lower incomes)		Qualitative: Not mone	N/A	€ 0,00	€ 0,00	€ 0,00		
2.2	Increased water consumption		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.3	Increased risk of fire spread due to excessive urban vegetation development / Risk of pyromania		Qualitative: Not mone	N/A	€ 0,00	€ 0,00	€ 0,00		
2.4	Associated management costs		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.5	Use of agrochemicals in urban green space management may increase soil pollution, produce offsite effects and induce hea		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.6	People don't like maintenance		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.7	Vision obstruction		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.8	Potential of green-washing with unsustainable, non-biodiverse VGS, that are not tailored to the building's need or functionin		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.9			Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
2.10			Qualitative: Not mone	N/A	N/A	N/A	N/A		
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00		
3.	**Implementation barriers**			N/A	N/A	N/A	N/A		
3.1	Political motivation		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		Lobby costs or hours spend on working a
3.2	Lack of knowledge		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.3	Time and workload		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.4	Municipal organization		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.5	Legislation		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.6	Economic factors		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.7	Uncertainty about roles and responsibilities		Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.8			Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00		
3.9			Qualitative: Not mone	N/A	N/A	N/A	N/A		
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00		
	Grand total			€ 0,00	€ 0,00	€ 0,00	€ 0,00		

F.5 Benefit sections

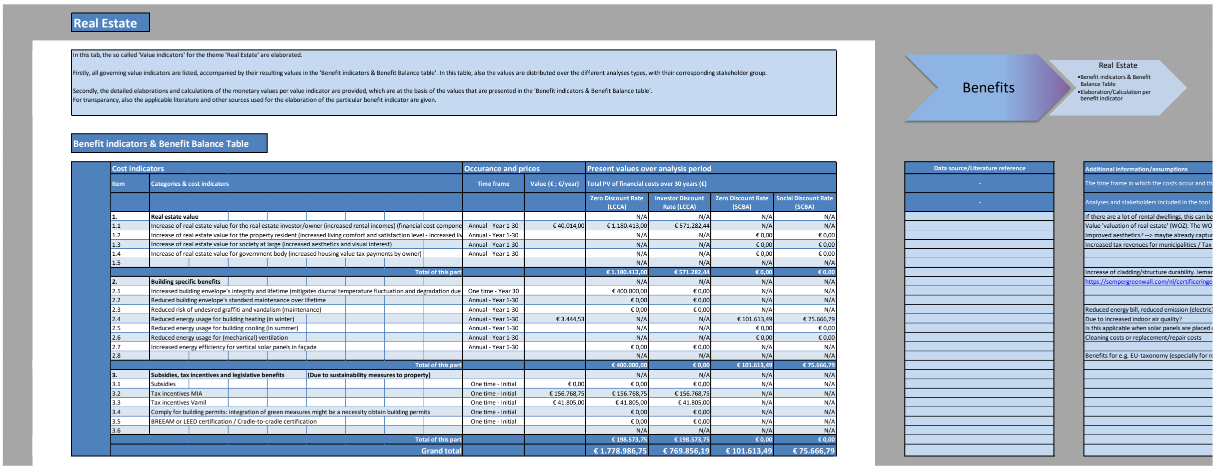
Tab 9: Health & Well-being benefits



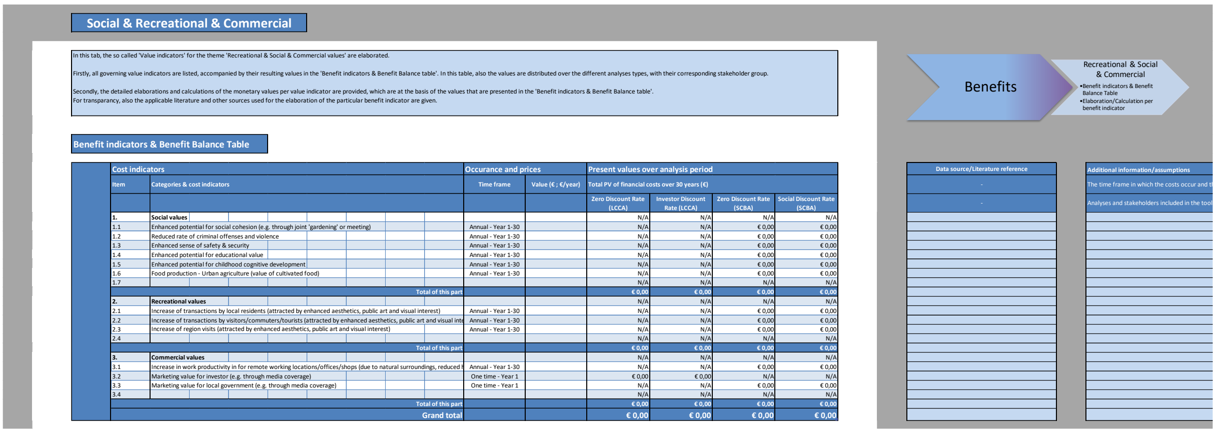
Tab 10: Climate Adaptation & Mitigation benefits



Tab 11: Real Estate benefits



Tab 12: Social & Recreational & Commercial benefits



Social & Recreational & Commercial

In this tab, the so called 'Value indicators' for the theme 'Recreational & Social & Commercial values' are elaborated.

Firstly, all governing value indicators are listed, accompanied by their resulting values in the 'Benefit indicators & Benefit Balance table'. In this table, also the values are distributed over the different analyses types, with their corresponding stakeholder group.

Secondly, the detailed elaborations and calculations of the monetary values per value indicator are provided, which are at the basis of the values that are presented in the 'Benefit indicators & Benefit Balance table'.
For transparancy, also the applicable literature and other sources used for the elaboration of the particular benefit indicator are given.

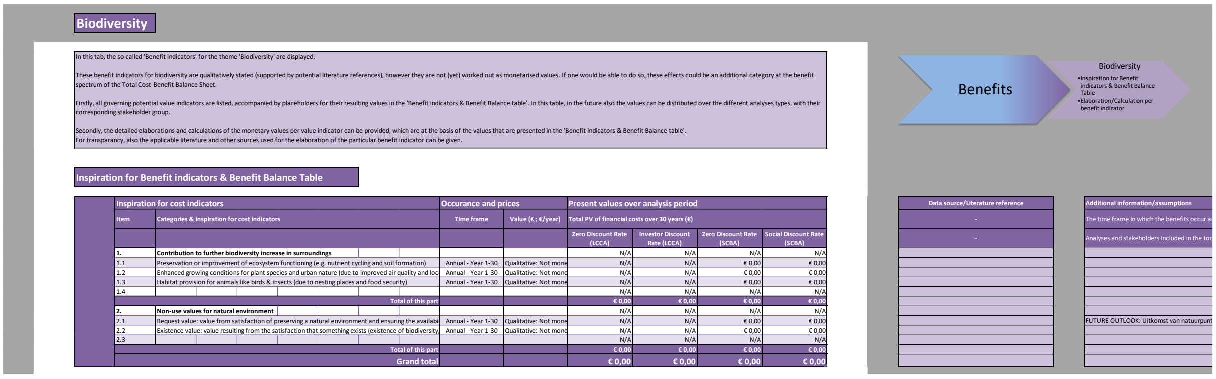
Benefit indicators & Benefit Balance Table

Cost indicators		Occurance and prices		Present values over analysis period			
Item	Categories & cost indicators	Time frame	Value (€ ; €/year)	Total PV of financial costs over 30 years (€)			
				Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
1.	**Social values**			N/A	N/A	N/A	N/A
1.1	Enhanced potential for social cohesion (e.g. through joint 'gardening' or meeting)	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.2	Reduced rate of criminal offenses and violence	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.3	Enhanced sense of safety & security	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.4	Enhanced potential for educational value	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.5	Enhanced potential for childhood cognitive development	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.6	Food production - Urban agriculture (value of cultivated food)	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
1.7				N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
2.	**Recreational values**			N/A	N/A	N/A	N/A
2.1	Increase of transactions by local residents (attracted by enhanced aesthetics, public art and visual interest)	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
2.2	Increase of transactions by visitors/commuters/tourists (attracted by enhanced aesthetics, public art and visual inte	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
2.3	Increase of region visits (attracted by enhanced aesthetics, public art and visual interest)	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
2.4				N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
3.	**Commercial values**			N/A	N/A	N/A	N/A
3.1	Increase in work productivity in for remote working locations/offices/shops (due to natural surroundings, reduced h	Annual - Year 1-30		N/A	N/A	€ 0,00	€ 0,00
3.2	Marketing value for investor (e.g. through media coverage)	One time - Year 1		€ 0,00	€ 0,00	N/A	N/A
3.3	Marketing value for local government (e.g. through media coverage)	One time - Year 1		N/A	N/A	€ 0,00	€ 0,00
3.4				N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
	Grand total			€ 0,00	€ 0,00	€ 0,00	€ 0,00

Data source/Literature reference
-
-

Additional information/assumptions
The time frame in which the costs occur and t
Analyses and stakeholders included in the tool

Tab 13: Biodiversity benefits



Biodiversity

In this tab, the so called 'Benefit indicators' for the theme 'Biodiversity' are displayed.

These benefit indicators for biodiversity are qualitatively stated (supported by potential literature references), however they are not (yet) worked out as monetarised values. If one would be able to do so, these effects could be an additional category at the benefit spectrum of the Total Cost-Benefit Balance Sheet.

Firstly, all governing potential value indicators are listed, accompanied by placeholders for their resulting values in the 'Benefit indicators & Benefit Balance table'. In this table, in the future also the values can be distributed over the different analyses types, with their corresponding stakeholder group.

Secondly, the detailed elaborations and calculations of the monetary values per value indicator can be provided, which are at the basis of the values that are presented in the 'Benefit indicators & Benefit Balance table'.
For transparancy, also the applicable literature and other sources used for the elaboration of the particular benefit indicator can be given.

Inspiration for Benefit indicators & Benefit Balance Table

Inspiration for cost indicators		Occurance and prices		Present values over analysis period			
Item	Categories & inspiration for cost indicators	Time frame	Value (€ ; €/year)	Total PV of financial costs over 30 years (€)			
				Zero Discount Rate (LCCA)	Investor Discount Rate (LCCA)	Zero Discount Rate (SCBA)	Social Discount Rate (SCBA)
1.	**Contribution to further biodiversity increase in surroundings**			N/A	N/A	N/A	N/A
1.1	Preservation or improvement of ecosystem functioning (e.g. nutrient cycling and soil formation)	Annual - Year 1-30	Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00
1.2	Enhanced growing conditions for plant species and urban nature (due to improved air quality and loc	Annual - Year 1-30	Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00
1.3	Habitat provision for animals like birds & insects (due to nesting places and food security)	Annual - Year 1-30	Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00
1.4				N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
2.	**Non-use values for natural environment**			N/A	N/A	N/A	N/A
2.1	Bequest value: value from satisfaction of preserving a natural environment and ensuring the availabil	Annual - Year 1-30	Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00
2.2	Existence value: value resulting from the satisfaction that something exists (existence of biodiversity,	Annual - Year 1-30	Qualitative: Not mone	N/A	N/A	€ 0,00	€ 0,00
2.3				N/A	N/A	N/A	N/A
	Total of this part			€ 0,00	€ 0,00	€ 0,00	€ 0,00
	Grand total			€ 0,00	€ 0,00	€ 0,00	€ 0,00

Data source/Literature reference
-
-

Additional information/assumptions
The time frame in which the benefits occur a
Analyses and stakeholders included in the too
FUTURE OUTLOOK: Uitkomst van natuurpunt

G

User Experiment VGS Valuation Tool

The manual for the user experiment of the VGS Valuation Tool is displayed starting at the next page, in the form as it was presented to the participants in the test panel.

Subsequently, the results of this user experiment are given to provide full transparency into the outcome of this experiment. Hence, the results of the questionnaire are displayed. Also, the results obtained by the participants of the experiment from inserting input in the VGS Valuation Tool are illustrated. From these results, conclusions for the user experiment are drawn in section 7.3.

G.1 Manual of the user experiment

Manual: User Test Experiment VGS Valuation tool

-

A method for the economic valuation of the costs and benefits associated with the implementation of vertical greening systems on buildings

TU Delft Delft University of Technology

SWECO

1. Introductie User Test Experiment (3 min)

Beste collega/contact/deelnemer,

Allereerst wil ik u alvast hartelijk danken voor uw deelname aan dit 'User Test Experiment' en daarmee ook voor uw bijdrage aan mijn Master Thesis.

Achtergrond

Voor u ligt de handleiding van het 'User Test Experiment' m.b.t. de **VGS Valuation Tool**, ontwikkeld als onderdeel van de Building Engineering Master Thesis aan de TU Delft. Deze tool moet het in de toekomst mogelijk maken om alle kosten en baten van verschillende groene gevelsystemen (vertical greening systems, VGS) inzichtelijk te maken. Zodoende kan een afgewogen keuze gemaakt worden op basis van de verschillende problemen die spelen op een locatie, de gemaakte kosten voor het gevelsysteem en de baten (waarden van de geleverde ecosysteemdiensten of andere bijkomende voordelen) omtrent implementatie van VGS in de fysieke leefomgeving.

Probleemstelling

Literatuuronderzoek heeft aangetoond dat een alomvattend framework dat een dergelijke analyse mogelijk maakt voor VGS, een van de 'missing links' is als het gaat om stimulering van hiervan. Bovendien is inzicht in de verdeling van kosten en baten over verschillende stakeholders relevant om gesprekken met belanghebbenden te initiëren en begeleiden. Tot op heden is er, voor zover bekend, nog geen andere tool of methode die dit alomvattend en inzichtelijk faciliteert voor VGS en waar 'iedereen' gebruik van kan maken. Hierdoor sneeuwen de voordelen vaak onder t.o.v. de relatief hoge kosten van VGS in vergelijking met andere groene maatregelen in steden. Echter kunnen VGS duidelijk voordelen bieden in dichtbevolkte of binnenstedelijke gebieden, zeker op locaties waar minder of geen ruimte is voor inpassing van voldoende horizontaal groen.

Doel van het onderzoek

De focus gedurende het onderzoek was gericht op het ontwikkelen van een alomvattend framework en tool, dat het waarderen van alle kosten en baten van VGS in de toekomst mogelijk maakt. Dit is gedaan middels het opzetten van een MS Excel tool. Deze tool is slechts een eerste aanzet.
Gezien de noodzaak en tijd die nodig was om eerst een volledig framework op te zetten dat monetarisatie van voordelen (semi-)geautomatiseerd mogelijk dient te maken, zal in de nasleep van dit onderzoek moeite moeten worden gestoken in het toevoegen van meerdere waarden en berekeningen van verschillende zogenaamde 'Value indicators' in het model. Zodoende kan uiteindelijk steeds een completer overzicht worden geboden omtrent mogelijkheden en kunnen rationele en afgewogen beslissingen worden genomen over het al dan niet inpassen van een VGS.

Doel van deze test sessie

Middels deze handleiding met bijbehorende casus en vragenlijst wil ik wel alvast de voorziene toekomstige functionaliteit, gebruikservaring, intuïtiviteit en waarde van de ontwikkelde tool testen. Dit door jullie, als test panel van beoogde gebruikers, een casus in te laten vullen in de tool tot nu toe. Hiermee dient ook duidelijk te worden of het gebruikersperspectief (één van de geïdentificeerde onderzoeksproblemen voor deze thesis) voldoende in acht wordt genomen, waardoor een tool als deze daadwerkelijke meerwaarde kan gaan bieden bij het maken van afgewogen keuzes. Dit dus vooral wanneer meerdere 'Value indicators' in het model zijn geïntegreerd en een completer overzicht gegeven kan worden van de totale kosten en baten van VGS.

Nogmaals hartelijk dank voor uw medewerking,
Guy Janssen

2. Introductie casus Paradium 3, Dordrecht (2 min)

De casus die gekozen is om te fungeren als ondergrond voor de ontwikkeling van de tool en die tevens wordt voorgelegd aan het test panel is het Complex Paradium 3 te Dordrecht. Deze huurappartementen (bouwjaar 1967) zijn ter beschikking gesteld door een klant van Sweco en zijn gelegen aan de Spuiboulevard 7 t/m 95 (oneven nummers), aan de rand van het historische centrum van Dordrecht.

Door deze binnenstedelijke ligging en het verharde straatbeeld wordt voldaan aan de aanname dat op deze locatie weinig ruimte is voor inpassing van horizontaal groen. De klimaat effect atlas toont aan dat deze buurt een groenpercentage heeft van minder dan 10%. Hierdoor kan uitwerking van deze casus uiteindelijk een daadwerkelijke maatschappelijke meerwaarde hebben, wat betekent dat ook direct gewerkt wordt aan een praktische en relevante casus.

Figuur 1: Appartementencomplex Paradium 3, Spuiboulevard te Dordrecht

Figuur 2: Groenpercentage per buurt volgens de klimaat effect atlas. In rood de contouren van het appartementencomplex.

De locatie, het gebouw, het type vastgoed en verschillende omgevingsfactoren bepalen onder andere de kosten en geleverde baten door een groen gevelsysteem. Relevante waarden, specifiek voor de voorgenoemde onderdelen, dienen daarom als input te fungeren in de waarderingstool. In deze test sessie worden relevante input waarden meegeleverd in de gebruikshandleiding vanaf de volgende pagina. Zo kan na afloop worden onderzocht of de beoogde gebruiker (u als consultant) de tool op een intuïtieve manier kon gebruiken.

In praktijk zou de gebruiker van de tool deze waarden zelf moeten verzamelen aan de hand van de informatiebronnen (o.a. hyperlinks) die in de tool zijn opgenomen. Echter, omwille van beperkt beschikbare tijd en om de test sessie behapbaar te houden (dit is immers een eerste kennismaking van beoogde gebruikers met de tool), wordt daar in dit geval vanaf gezien.
Afhankelijk van de informatiebronnen kan het namelijk een tijdrovende klus zijn alle input data correct boven tafel te krijgen. Daarnaast kan het zijn dat door technische (project-)achtergronden niet alle inputwaarden direct door het test panel bepaald kunnen worden.

Het primaire doel van de test sessie is om te beoordelen of de input op de juiste plekken en op een juiste manier wordt ingevuld *(en in de toekomst goed kan worden geïnterpreteerd)*. Het is in deze fase niet van belang om te bepalen of deelnemers (onder tijdsdruk) de juiste inputwaarden kunnen achterhalen middels de gegeven bronnen.

N.B.: De hoeveelheid in te vullen input is in deze fase van ontwikkeling van de tool nog vrij gelimiteerd/beperkt. Gezien de tool een levend document blijft, wordt hier in de toekomst meer input voor verwacht. Verwachting van de onderzoeker is wel dat het achterhalen en invullen van data steeds sneller gaat, naarmate gebruikers vaker met de tool werken en er een 'project database' wordt opgebouwd.

3. User Test experiment: Gebruikshandleiding (30 min)

Doormiddel van het doorlopen van de volgende stappen wordt u door de VGS Valuation Tool geleid. Indien u vragen/opmerkingen heeft, noteer deze kort en neem ze mee naar de vragenlijst of de plenaire reflectie later tijdens deze sessie. Dringende vragen mag u uiteraard direct stellen in de meeting of chat via MS Teams.

1. **Open de VGS Valuation Tool:** deze heeft u als Excel file ontvangen via email.

2. **Navigatie:** In deze tool ziet u 15 tabbladen in totaal. Door op de tabbladen beneden in het scherm te klikken kunt u navigeren door de tool.

3. **Vul op de oranje tabbladen de verkregen informatie in:** Om de tool te laten fungeren/werken hoeft u alleen op de oranje gekleurde tabbladen (tabblad 2 t/m 4) informatie aan te vullen. Alle overige tabbladen omvatten andere informatie en functionaliteiten. Hieronder vind u gemakkelijk de functie van elk tabblad terug.

Tabblad kleuren (functie per kleur):

- Groen: Introductie en gebruiksgids (m.n. van belang bij eerste maal gebruik van de tool).
- Oranje: Input tabbladen, enkel deze sheets zijn van belang voor de gebruiker als het gaat om het invullen van data.
- Donkerblauw: Overzicht van totale resultaten in tabelvorm en grafieken dashboard.
- Blauw: Overzicht, berekeningen en 'placeholders' voor berekeningen van kosten en baten per thema, (sub-)categorie en indicator. Deze sheets zijn voor de gebruiker mogelijk interessant ter onderbouwing en transparantie van gebruikte methodieken, echter niet direct noodzakelijk om door te nemen wanneer men enkel geïnteresseerd is in het uiteindelijke resultaat. Berekeningen in deze sheets worden automatisch uitgevoerd op basis van ingevoerde data in de oranje sheets. De verkregen resultaten worden vervolgens weer teruggekoppeld naar de donkerblauwe resultaten-sheets.
- Paars: Sheets met enkel kwalitatieve inhoud. 'Placeholders' voor berekeningen die mogelijk volgen uit 'Recommendations for Future Research'.

4. **Vul op de oranje tabbladen alleen de oranje velden in:** Alleen de oranje gekleurde cellen dienen te worden ingevuld of aangepast. Indien reeds geïntegreerd in de tool, vullen de (blauwe) gelinkte cellen automatisch aan.

5. **Vergrendeling van overige informatie:** Geen zorgen, alle overige tabbladen/cellen zijn vergrendeld. Als het goed is kunt u dus geen ongewenste aanpassingen doen.

Invullen en aansporing deelnemers:
Op de volgende pagina staan de meegeleverde relevante input waarden voor de tool op dit moment. U dient deze input zometeen stapsgewijs op de juiste locaties in te vullen in de tool.

Bekijk ter info tijdens het invullen van de inputwaarden in de tool ook de overige informatie en gegeven bronnen. O.a. de volgende vragen komen terug in de vragenlijst achteraf:

- Zijn alle financiële en milieukosten (en evt. andere kosten) volgens u opgenomen in de tool?
- Geldt dit ook voor alle baten (ecosysteemdiensten en bijkomende voordelen) in de verschillende thema's en zijn deze naar uw mening logisch onderverdeeld?
- Welke kosten/baten van groene gevelsystemen missen naar uw mening eventueel nog?

6. Neem ter inleiding de sheets ***'1.1_Introduction'*** en ***'1.2_User_Guide'*** door in de tool. Dit hoeft enkel als achtergrond te gebeuren voor het eerste maal gebruik. ***(10 min)***

7. **Vul enkel onderstaande input aan in de tool (overige zaken reeds ingevuld of gelinkt):**

Sheet '2_Gen._Principles&Assumptions'

Projectnaam:	Complex Paradium 3
Adres:	Spuiboulevard 7-95 (odd nr.)
Stad:	Dordrecht
Buurt:	Centrum
Wijk:	Wijk 01 Binnenstad
Klant:	*{optionele eigen inbreng}*
Consultant:	*{optionele eigen inbreng}*

Na overleg blijkt dat de klant zich oriënteert op een verticaal groensysteem van de categorie ***'Modulair LWS'***;

De klant (vastgoed investeerder) wil een rendement van ***6,0%*** halen met zijn investeringen;

De maatschappij als geheel ziet voor inspanningen en investeringen in 'groene initiatieven' graag een rendement van ***2,0%*** tegemoet;

Sheet '3_Case_specific_input'

Aantal inwoners in de wijk:	1030
Bevolkingsdichtheid:	8209
Gebouwtype:	Residentieel appartementencomplex
Bouwjaar:	1967
Huidig geveltype:	Metselwerk
Geveloppervlak zuid:	898,30
Geveloppervlak oost:	585,70
Geveloppervlak west:	183,10
Geveloppervlak noord:	190,90
Gemiddelde vastgoedwaarde (WOZ):	193000

Sheet '4_Indicator_specific_input'

Thema: 'Financial costs'
Totale initiële kosten van VGS: 750
Overige (aannamen) van kosten zijn reeds ingevuld.

Zie voor een overzicht van de resultaten sheet '6_Financial_costs'

Thema: 'Health & Well-being'
Indicator: '5.1 - Less healthcare costs due to capture of Particulate Matter (PM10)'
Lokale concentratie fijnstof (PM10): 18,87
Depositie snelheid: 0,33

Zie de uitwerking van deze indicator op sheet '9_Health&Well-being'
Als het goed is komt hier een waarde uit van 294,86 euro per jaar

Sheet '5.1_Total_analyses_results'

In deze sheet zal in tabelvorm een volledig overzicht worden gegeven van de uitkomsten van alle thema's (zowel kosten als baten). Afgaand op de einduitkomst en enkele economische haalbaarheidsindicatoren kan de klant, in overleg met de consultant, een afweging maken voor het al dan niet implementeren van VGS.

Sheet '5.2_Result_dashboard'

In deze sheet zal in grafieken en diagrammen een volledig overzicht worden gegeven van de uitkomsten van alle thema's (zowel kosten als baten). Hierdoor kunnen inzichten ontstaan in welke thema's bijdragen aan de kosten en baten zijde van de analyse.

8. **Ter info:**
   Waarden voor Netto Contante Waarde berekeningen (Net Present Value calculations) worden altijd uitgezet in een aparte Excel sheet, volgend op de sheet waar deze op van toepassing zijn. Aangezien in deze sheets door u als gebruiker niets ingevoerd of aangepast hoeft te worden, zijn deze sheets verborgen in de Excel navigatie van het gebruikersdocument.

9. U bent aan het einde gekomen van het invullen van de input.

10. Stuur uw ingevulde versie van het Excel document retour en ga door naar de vragenlijst.

    E: guy.janssen@sweco.nl

4. Vragenlijst (15 min, evt. direct na afloop plenaire sessie invullen)

Tot slot wil ik u verzoeken een vragenlijst door te nemen en te beantwoorden.

De vragen in deze enquête hebben met name betrekking op uw ervaring met de VGS Valuation Tool, toekomstige resultaten en het test experiment zelf. Deze hebben als doel om inzicht te verschaffen in de voorziene praktische waarde van de tool in de toekomst. Hierbij is de gebruikerservaring, gebruiksvriendelijkheid en intuïtiviteit bij het invullen van de tool van belang.

In totaal bevat de vragenlijst 17 vragen.
De meerkeuzevragen kunnen worden beoordeeld met een score van 1-10 (geheel getal). Tevens is er ruimte voor het geven van een eventuele toelichting met gerichte feedback.
Daarnaast zijn er nog een aantal open vragen waarbij een kort en bondig antwoord voldoende is.

Vergeet niet uw antwoorden te verzenden voordat u de vragenlijst sluit!

Hieronder vind u de link naar de vragenlijst*:

https://forms.gle/1A4S9ucaMuZYPMES6

* Kopiëren en plakken in browser indien de link niet direct werkt.

5. Vragen

Vragen in te vullen via 'Google Forms'!

Algemene opinie omtrent VGS Valuation Tool en resultaten

1. Hoe heeft u de algehele opbouw en structuur van het framework en de tool (inclusief indeling in thema's/categorieën) ervaren? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

Cijfer: [*1 = Totaal niet goed* | *10 = Zeer goed*]
Toelichting:

2. Hoe zou u de gebruiksvriendelijkheid of het gebruiksgemak van deze tool beoordelen? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

Cijfer: [*1 = Totaal niet goed* | *10 = Zeer goed*]
Toelichting:

3. Hoe zou u de intuïtiviteit (overzichtelijkheid, duidelijkheid, logisch invullen) tijdens het gebruik van deze tool beoordelen? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

Cijfer: [*1 = Totaal niet goed* | *10 = Zeer goed*]
Toelichting:

4. Hoe zou u de educatieve/wetenschappelijke waarde van deze tool beoordelen, rekening houdend met het feit dat een dergelijk alomvattend framework voor VGS voor zover bekend nog niet bestaat? Geef evt. een korte toelichting, of geef indien nodig aan wat naar uw mening zou bijdragen aan meer educatieve/wetenschappelijke waarde.

Cijfer: [*1 = Zeer lage waarde* | *10 = Zeer hoge waarde*]
Toelichting:

5. Hoe zou u de (toekomstige) praktische waarde van deze tool voor het vakgebied van VGS en potentiële klanten beoordelen? Geef evt. een korte toelichting, of geef indien nodig aan wat naar uw mening zou bijdragen aan meer praktische waarde in de toekomst.

Cijfer: [*1 = Zeer lage waarde* | *10 = Zeer hoge waarde*]
Toelichting:

6. Is de tool naar uw mening compleet en alomvattend? Zijn er evt. andere kosten of baten van groene gevelsystemen die u nog mist in de tool? Zo ja, welke en bij welk thema? (Ofwel kwalitatief, dan wel kwantitatief)
   Momenteel nog niet veel kwantitatief verwerkt.

Cijfer: [*1 = Zeer incompleet | 10 = Alomvattend*]
Toelichting:

7. Hebben de toekomstige resultaten van de tool de potentie om nieuwe inzichten te verschaffen omtrent verschillende (gemonetariseerde) kosten en baten van VGS? Zo ja, welke? Zo niet, hoe zou dit verbeterd kunnen worden?

Cijfer: [*1 = Geen nieuwe inzichten | 10 = Zeer veel nieuwe inzichten*]
Toelichting:

8. Worden de resultaten van de tool op een heldere en logische manier gepresenteerd? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

Cijfer: [*1 = Totaal niet helder en logisch | 10 = Zeer helder en logisch*]
Toelichting:

9. Waren er bepaalde fouten/bugs/glitches waar u tegenaan liep tijdens het invullen van de tool? Zo ja, op welk tabblad en welke cel? Wat was het ervaren probleem?

Antwoord:

10. Indien u een klant zou moeten adviseren omtrent de eventuele implementatie van groene gevels: zou u deze (of een soortgelijke) tool dan willen gebruiken? Wie zou u anders aanraden deze tool te gebruiken en waarom?

Cijfer: [*1 = Totaal niet | 10 = Heel graag*]
Toelichting:

11. Indien bekend met de uit te voeren handelingen, maakt het feit dat dit model in Excel is gecreëerd het naar uw mening toegankelijk voor 'iedereen'?

Cijfer: [*1 = Totaal niet toegankelijk | 10 = Zeer toegankelijk*]
Toelichting:

12. Zou u deze tool in de toekomst liever in een ander jasje zien? Zo ja, hoe en waarom?

Antwoord:

Test experiment

13. Hoe heeft u de tijdslimiet van 30 minuten ervaren voor het doorlopen van alle stappen in de handleiding? Was er voldoende tijd? Zo nee, waar lag dit aan?

Cijfer: [*1 = Tijd totaal niet toereikend* | *10 = Ruim voldoende tijd*]
Toelichting:

14. Hoe heeft u dit test experiment ervaren? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

Cijfer: [*1 = Totaal niet goed* | *10 = Zeer goed*]
Toelichting:

15. Welke voor- en nadelen ziet u in de opzet/aanpak van dit test experiment? D.w.z. het plenair inplannen van een moment via MS Teams en vervolgens individueel de casus input invullen in de tool?

Antwoord:

16. Hoe zou deze opzet/aanpak naar uw mening invloed kunnen hebben op de uitkomsten van het user experiment?

Antwoord:

17. Heeft u nog additionele opmerkingen of zaken die u kwijt wilt en die nog niet aan de orde zijn gekomen?

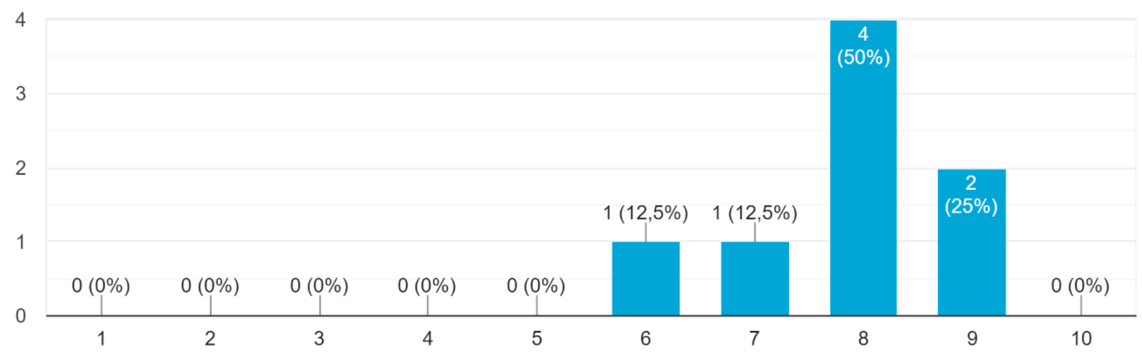
Antwoord:

G.2 Results questionnaire

The results as obtained from the questionnaires via Google Forms are displayed here. Per question, all grades, the average grade and the explanation or response to the open questions are provided.

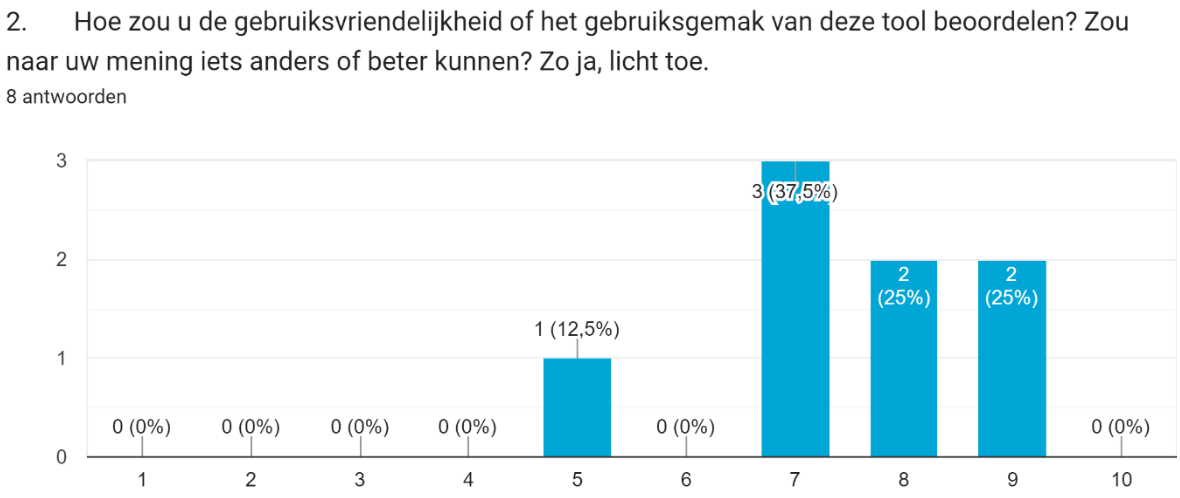
1. Hoe heeft u de algehele opbouw en structuur van het framework en de tool (inclusief indeling in thema's/categorieën) ervaren? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

8 antwoorden



Average grade: 7.9
Toelichting:

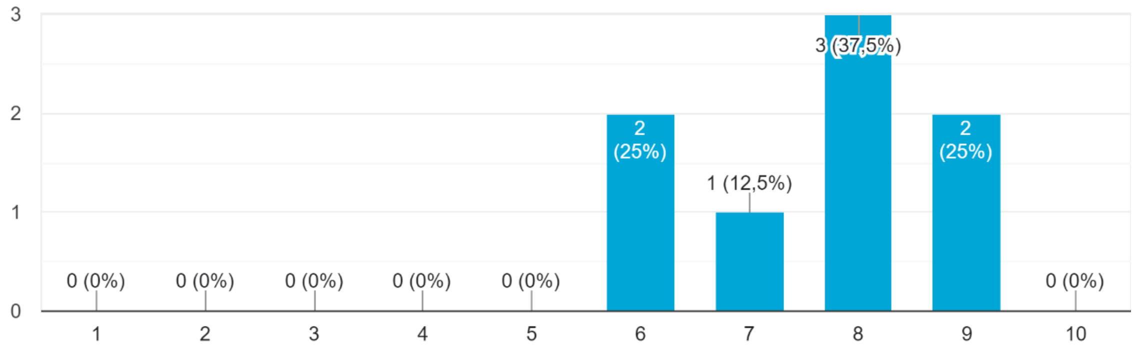
- Heldere structuur door naamgeving, nummering en kleurcodering. Ik zou overwegen om de lege kolommen tussen data-naam en data zelf weg te laten, dit kan verwarrend lijken.
- Professioneel, geeft vertrouwen. Thema's zie ik vaker terugkomen in rapporten en eigen werkzaamheden, lijken op het eerste oog geschikt. Wellicht voor een gebruiker wel teveel informatie. Wellicht voor een gebruiker wel teveel informatie.
- Erg onder de indruk van je vormgeving in Excel. Het is helder, duidelijk en ik heb zelden getwijfeld waar ik moest zijn. De kleuren bieden een duidelijke verdeling van taken en dit zorgt voor overzicht. Het is wel een groot document met veel tekst. Dit is ons nu gemakkelijk gemaakt door de handleiding, maar gaat dit ook gelden voor klanten? Je user-guide is hierin het meest belangrijk. Je stapaanduiding vind ik top, met wederom de kleuren. De grote afbeelding zorgt daarentegen misschien voor afleiding en laat deze sheet als 'heel veel' ogen.
- De andere sheets zijn namelijk heel overzichtelijk en laten meteen zien wat wel en niet te doen. Daarmee kan je misschien je user-guide korter houden.
- Als je de tool opent krijg je gelijk vrij veel info voor je neus. Ik zou adviseren om het wat cleaner te houden in het begin, dus korte introductie en overige informatie aan de achterkant van je tool zetten.
- Heldere uiteenzetting. Suggestie: Input als aparte rij /onderdeel. Niet onder Introductie plaatsen.
- In tabblad 2: 'how to use the tool' verder naar boven halen. Dat direct duidelijk is welke tabbladen je moet invullen en op welke tabbladen resultaten staan. Dan wordt het ook duidelijk dat de cost en benefit tabbladen ook niet hoeven worden ingevuld.
- Indeling is goed, maar wordt daarna te uitgebreid. De kosten waren goed te begrijpen, de baten te verspreid.



Average grade: 7.5
Toelichting:

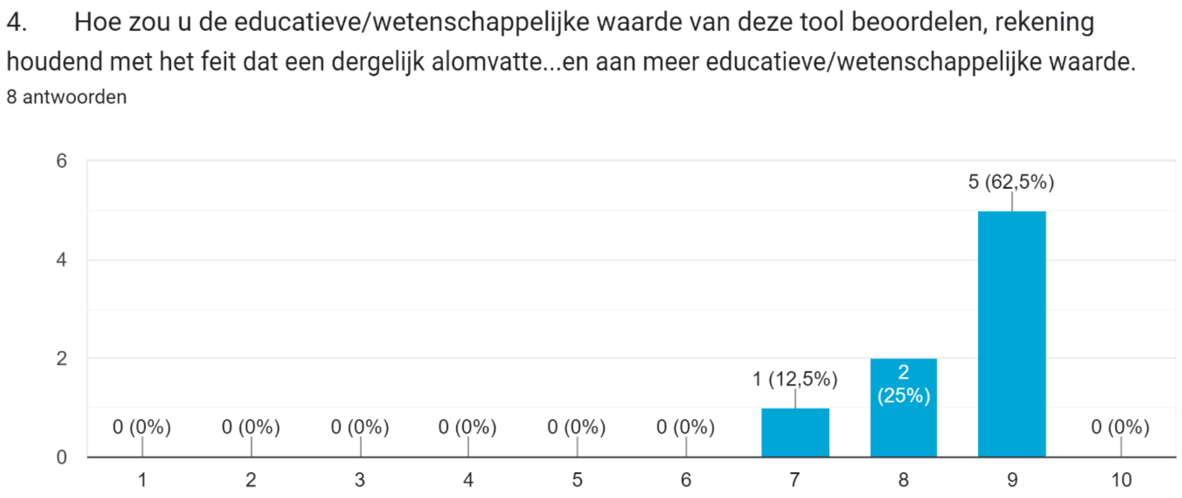
- De toelichtingsvelden vallen soms over de drop-down heen, waardoor dit even zoeken is. Verder gemakkelijk in te vullen.
- Het is heel handig dat je aangeeft waar je de informatie voor de specifieke locatie kunt vinden. Wellicht kan er zelfs een tooltje gemaakt worden die (wanneer je de locatie hebt aangegeven). veel van de basisonderdelen zou inladen.
- Ja het gebruik is heel soepel. De sheets werken heel eenvoudig en het laten overspringen van de tabs (van oranje naar oranje) is top. Het is ook heel helder dat we de andere sheets moeten overslaan.
- Indrukwekkend hoe de tool alles doorrekent op basis van de kerngetallen die je invoert, af en toe is het wel even zoeken naar de juiste plekken om in te voeren en was het mij bijvoorbeeld niet helemaal duidelijk waarom sommige kerncijfers van wijken en buurten wel automatisch werden ingevuld (zoals leeftijdsopbouw) maar andere (zoals bevolkingsdichtheid) niet.
- Hoge gebruiksvriendelijkheid. Goed te gebruiken voor experts; voor beginners kan het overweldigend veel info zijn. En hoeveelheid input data verzamelen mogelijk automateriseren o.b.v. geodata i.p.v. zelf data verzamelen (future outlook). Suggestie 2: versimpelde versie in de toekomst.
- Kortere uitleg. Bondiger introduceren welke tabs je moet invullen, waar de resultaten staan. Staat nu in introductie veel tekst die een gebruiker niet direct gaat lezen. Zelfde geldt voor user guide. Ik zou dit een stuk inkorten en meer to-the-point opschrijven.
- Ik vind het fijn werken, erg overzichtelijk. Wel viel mij op dat je in de intro lang stuk hebt over Green Facade Systems, hier gaat de tool verder niet op door. Het is voor mij niet helemaal duidelijk of dit daarom weg kan of dat je er voor hebt gekozen het erin te houden voor als de tool verder wordt uitgewerkt en je hier ook op door gaat.
- Dit is wel voor de geoefende adviseur. wetenschappelijke opgebouwd en als raamwerk, dus daarom wat mij betreft niet echt gebruiksvriendelijke. Dit was ook niet te verwachten. Door vele locks op de cellen is gebruiksgemak geoptimaliseerd en kan je in ieder geval niks verkeerds doen, dus dat is erg prettig.

3. Hoe zou u de intuïtiviteit (overzichtelijkheid, duidelijkheid, logisch invullen) tijdens het gebruik van deze tool beoordelen? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.
8 antwoorden



Average grade: 7.9
Toelichting:

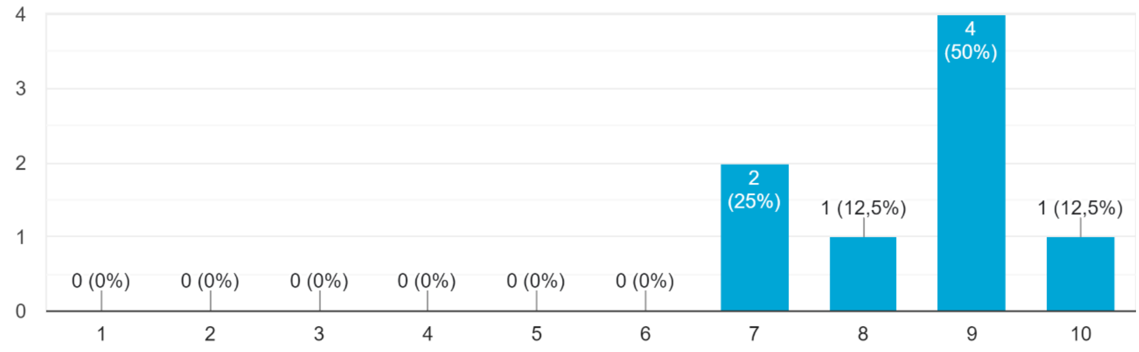
- Zie boven.
- Ik zou een woordenlijst toevoegen voor vaktermen en afkortingen. Ik twijfelde bij ''Real discount rate for discounted cash flow (DCF) analysis in LCCA (financial business case) (%)'' of ik daar 6% moest invullen. Puur omdat afkorting LCCA niet bekend is bij mij, of heb ik de woordenlijst over het hoofd gezien? Bij het volgende tabblad twijfelde ik ook over de term SCBA.
- De rest was allemaal heel helder en begrijpelijk vanuit mijn Engels niveau. Ik zou alleen dus naar die afkortingen kijken.
- De afbakening tussen cellen die je moet invullen en die automatisch worden ingevuld wat duidelijker maken. Dus niet alleen d.m.v. kleurgebruik maar ook overzichtelijk gegroepeerd.
- Goed gebruik gemaakt van tabbladen, kleuren tabs, invulcellen oranje.
- Duidelijk en logisch met kleurtjes. Zou alleen helpen als je in de introductie/user manual tab al heel snel zag in bondige tekst wat welk kleurtje is en hoe je dit moet invullen.
- Achtergrond wit of licht grijs maken (geen vakjes) zodat er wat meer rust ontstaat.
- Door kleurgebruik en menuutjes prima. Maar het is veel dus wel even zoeken.



Average grade 8.5
Toelichting:

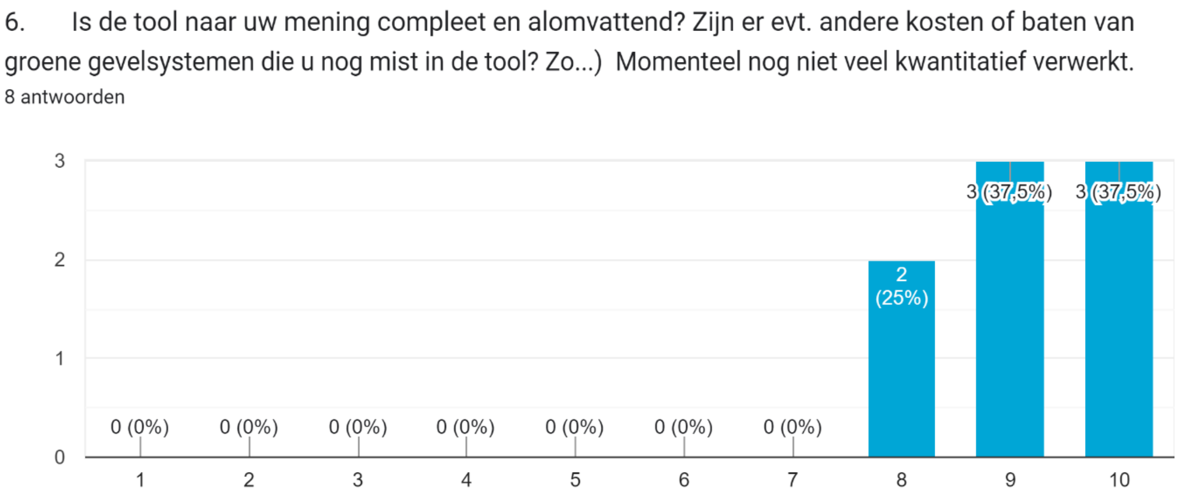
- Vind ik op dit niveau lastig te beoordelen. het oogt wel goed onderbouwd. Ik denk dat het doel overigens niet persé hoeft te zijn dat je break-even uitkomt, maar dat je wat van de kosten terug kan verdienen zou natuurlijk mooi zijn.
- Nu is er natuurlijk nog weinig concreet te resulteren, maar dat gaat vast komen. Ik denk dat je dan een fantastische tool hebt. Het laten visualiseren van de uitkomsten zou het educatieve gedeelte een tandje opschroeven. Maar de basis ligt er heel strak.
- Wanneer de baten ook volledig werkend zijn denk ik dat dit een hele inzichtelijke tool is voor VGS stakeholders.
- Goed onderbouwd, veel bronnen en verwijzingen. Duidelijk over aannames en limitations.
- Als je de tool bekijkt krijg je echt de indruk dat de tool goed onderbouwd is met de vele informatie in alle tabbladen. Wetenschappelijke waarde zou ik meer in een achtergrond document willen, evt. in de introductietab. Ik zou hier niet té veel van invoegen.
- De tool is veelbelovend. Maar wel wetenschappelijk ingestoken en erg uitgebreid. Dat heeft logischerwijs zijn trade-off met gebruiksvriendelijkheid.

5. Hoe zou u de (toekomstige) praktische waarde van deze tool voor het vakgebied van VGS en potentiële klanten beoordelen? Geef evt. een kort...ragen aan meer praktische waarde in de toekomst.
8 antwoorden



Average grade 8.5
Toelichting:

- Heel handig. kan een goede onderbouwing zijn voor het investeringsbesluit!
- De toekomst van de tool is groot in mijn ogen. Groene gevels is een onderwerp die nieuw in onze markt is. Dat biedt perspectief. Je hebt een tool ontwikkeld die heel veelzijdig gaat worden en dat moet je doorpakken. Met weinig input kan een consultant al een hele grote stap naar een uitkomst zetten. Ook zie ik veel mogelijkheden in de automatisering van je tool. Waarin de opdrachtgever enkel de locatie en de aan te leggen m2 hoeft aan te duiden.
- Voor adviseurs is deze tool zeer bruikbaar. Als een 3e partij of klant deze tool wil gebruiken zou de praktische waarde wat hoger liggen als je bijvoorbeeld een losse vragenlijst invult en daar een Excel/pdf uit komt rollen.
- Hoog; zeer welkom om op dit hoge detailniveau dit soort berekeningen te kunnen maken. Tegelijkertijd vraagt het ook om hoogwaardig niveau van input.
- Mooi advies voor de klant. Wel nog lastig voor mij om dit advies ook echt uit te leggen naar een klant: hoe betrouwbaar zijn resultaten? Totaalplaatje van achterliggende zaken achter advies. Bijdrage aan praktische waarde: korte heldere uitleg over wat resultaten betekenen. Mogelijk komt dit nog in dashboard tab?
- Op cijfers gebaseerde baten zijn erg belangrijk om toegevoegde waarde aan te tonen. Praktische waarde tool vooral als meer zaken zijn uitgezocht en uitgewerkt in toekomstige versies.

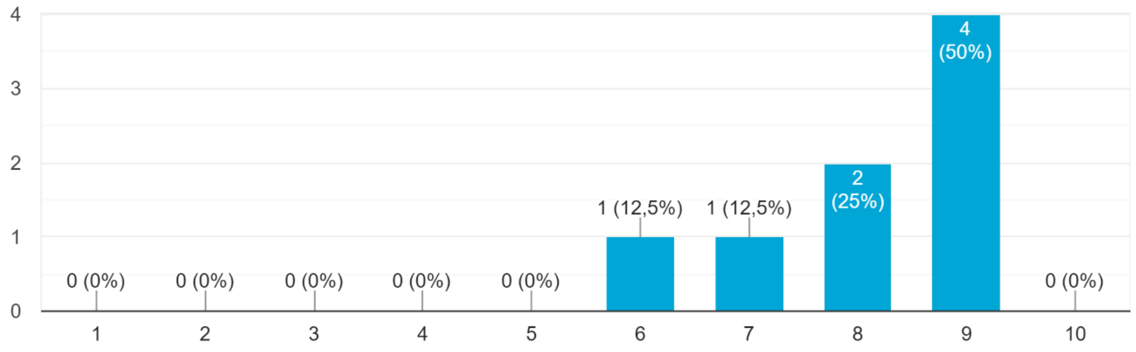


Average grade 9.1
Toelichting:

- Ik zit iets te weinig in de inhoud om hier een goed antwoord op te geven.
- De meest belangrijke aspecten worden benoemd. Ik zou de kerstboom als ze beperkt van toegevoegde waarde zijn, niet verder optuigen.
- De onderwerpen die ik heb gezien zijn echt heel veelomvattend. Dus geen opmerkingen, hij is echt al veel completer dan mijn eigen MKBA-tool.
- Zit heel veel informatie in en zou zeker niet uitbreiden.
- Indirecte en directe schadevermindering klimaatrisico's (zit er al deels in!).
- Ik denk dat je zeker de belangrijkste heb en ik zou aanbevelen om het hierbij te laten.
- Lijkt mij zeer compleet! Indrukwekkend raamwerk.

7. Hebben de toekomstige resultaten van de tool de potentie om nieuwe inzichten te verschaffen omtrent verschillende (gemonetariseer...e? Zo niet, hoe zou dit verbeterd kunnen worden?

8 antwoorden



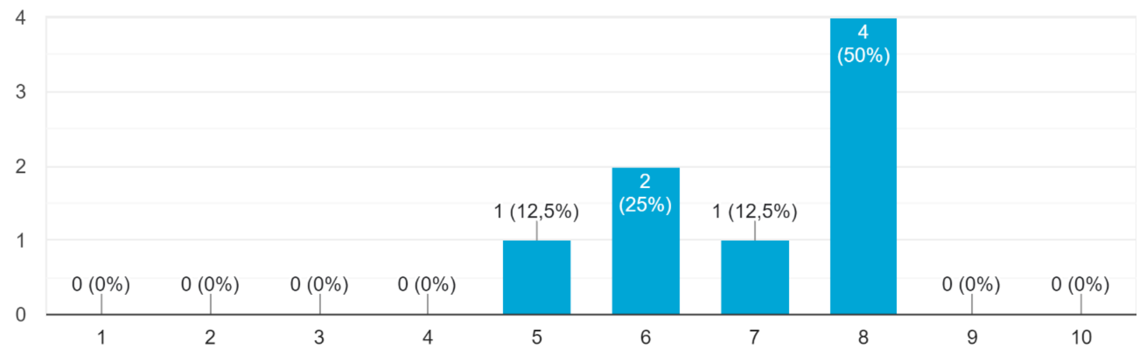
Average grade: 8.1

Toelichting:

- Ik zit iets te weinig in de inhoud om hier een goed antwoord op te geven.
- Ja want het weet het geheel te combineren.
- Hoe de uitslagen gaan uitpakken weet ik niet, dat het een zeer uitgebreid beeld geeft aan te verwachten baten zie ik als grote potentie. Zeker het toevoegen van de NPV kan ervoor zorgen dat je een super stevig product ontwikkelt.
- Uitgebreide en sterk onderbouwde inzichten over kosten en baten van VGS.
- Inzichten in sociale kosten en baten worden door vastgoedpartijen nu vaak niet meegenomen.
- Zeker, ook dat de locatie zo goed meegenomen wordt is top.

8. Worden de resultaten van de tool op een heldere en logische manier gepresenteerd? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

8 antwoorden



Average grade: 7

Toelichting:

- Het is een groot overzicht met resultaten, waar misschien nog een iets meer piramidale opbouw in gemaakt kan worden.
- Moeilijk omdat nog niet alles zichtbaar is.
- Hierin zou ik dus nog investeren. Al weet ik niet of de Excel de uiteindelijke visual wordt. Misschien worden de uitkomsten anders gepresenteerd. Ik zie namelijk in je lijst fantastische dingen staan, maar geen idee hoe een ambtenaar dat ziet. Een geïnteresseerde zal er net zo diep induiken als ik, maar iemand met haast wil misschien wat meer overzicht. Als je dat toepast heb je een tool met inhoud en heel veel uitstraling.
- Resultaten zijn helder te overzien. Ik merkte wel dat ik veel naar boven en beneden moest scrollen om te kijken welke kosten waar op gebaseerd waren. Eventueel dus bovenste rijen bevriezen zodat die vast blijven staan.
- Moet nog uitgewerkt worden (Dashboard). Tabellen zijn helder en logisch.
- Tabbladen 5.1 en 5.2 nog niet af dus lastiger te beantwoorden. Tabellen in opvolgende tabbladen geven wat mij betreft interessante informatie.
- Was nog niet zichtbaar, maar zeker als er grafiekjes en figuren uit komen zal dit top zijn

9. Waren er bepaalde fouten/bugs/glitches waar u tegenaan liep tijdens het invullen van de tool? Zo ja, op welk tabblad en welke cel? Wat was het ervaren probleem?

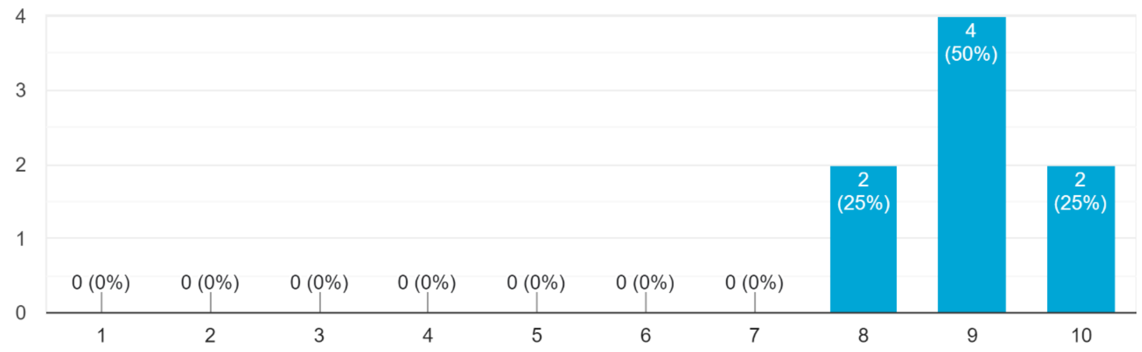
8 antwoorden

Toelichting:

- Nee.
- Niet tegengekomen.
- Geen bugs gehad op dit moment, laat het complete Excel nog eens door mij testen. Dan check ik alles.
- Niet helemaal duidelijk waarom sommige buurtdata wel automatisch werd ingevuld (zoals leeftijdsopbouw) en waarom andere niet (zoals bevolkingsdichtheid). Ook stond er mainenance ipv maintenance ;)
- Geen bugs. Wel is tekst op tab 1.1 onder plaatje gevallen (onderaan).
- Nee.
- Nee, zag alleen in de inleiding een punt verkeerd staan bij bronvermelding (Soliveres et al., 2016).

- Ik moest elke keer uitzoomen om het geheel in beeld te krijgen, maar dat zal met mijn scherminstellingen te maken hebben waarschijnlijk. Verder geen bugs gespot.

10. Indien u een klant zou moeten adviseren omtrent de eventuele implementatie van groene gevels: zou u deze (of een soortgelijke) tool dan...anders aanraden deze tool te gebruiken en waarom?
8 antwoorden



Avarage grade: 9
Toelichting:

- Bruikbare tool om een onderbouwd advies te kunnen geven.
- Omdat het inzicht geeft in de omvang van de baten.
- Financiën zijn altijd de onderliggende factor om het niet te doen. Deze tool kan ondersteunen om mensen juist meer over de streep te trekken. Het simpele gebruik van de tool zorgt ervoor dat ik de implementatie ten zeerste zou aanraden.
- Ja de kerngetallen zijn enorm bruikbaar.
- Zeker, helemaal als er meer maatregelen inkomen zodat je afwegingen o.b.v. kosteneffectiviteit kan maken.
- Zeker meerwaarde om de klant te laten zien wat de meerwaarde is van de groene gevels en zo te stimuleren over te gaan tot installatie daarvan.
- Zeker, op cijfers gebaseerde argumenten zijn schaars op dit vlak, gaat zeker helpen twijfelaars te overtuigen en zelf om meerwaarde te optimaliseren.

Average grade: 7.0
Toelichting:

- Met de basis-skills in Excel zou je dit gemakkelijk moeten kunnen invullen.
- Zeker niet iedereen, maar je hoeft ook geen professor te zijn om onderdelen in te vullen.
- De uitvoer is zeer eenvoudig (voor mij dan). Voor een ambtenaar kan dit misschien lastiger zijn. Het digitaliseren van de tool zou fantastisch zijn (een URL). Waarin de simpele data kan worden omgezet in een snelle uitslag.
- Ik denk dat kennis over Excel wel een vereiste is om deze tool goed in te vullen.
- Vraagt wel enige Excel kennis / navigatie vaardigheden. Suggestie zou een Survey kunnen zijn die je vraag per vraag in vult en enkel resultaten ziet in het dashboard.
- Ja! handig dat er geen programma gedownload hoeft te worden.
- Nee, zeker niet voor iedereen, maar dat hoeft ook niet. Als je voor iedereen toegankelijk wil maken dan zal je een web tool en lightversie moeten maken.

12. Zou u deze tool in de toekomst liever in een ander jasje zien? Zo ja, hoe en waarom?

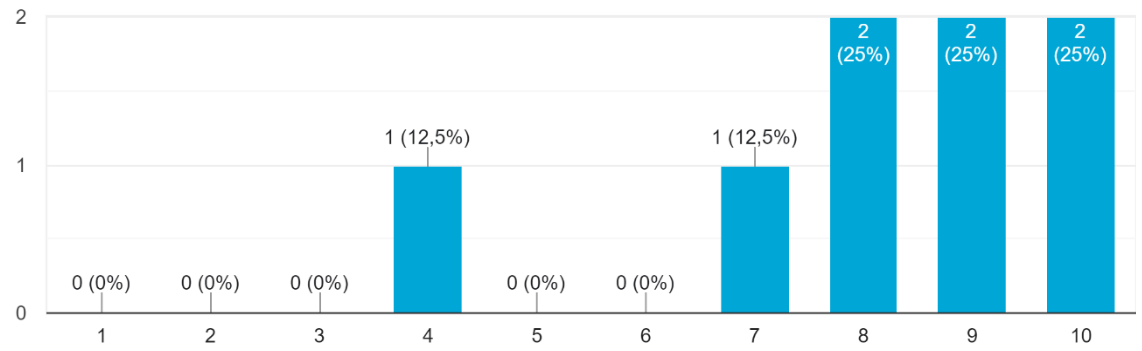
8 antwoorden

Toelichting:

- Een ander middel dan Excel zou misschien professioneler ogen als je dit extern openbaar wil laten zijn. Voor intern gebruik werkt dit goed.
- Een mooi samenvattend rapport waardoor je in één uur een rapport kan uitdraaien voor de klant. Interessant voor ingenieursbureaus, maar mogelijk ook door hoveniers/bouwkundige die groene façades ontwerpen.
- Zie mijn antwoorden hierboven^. Excel is top, voor mensen die het kunnen gebruiken. Het omzetten in een dashboard online zou het afmaken.
- Ja, liever dat je je locatie invoert in een web-viewer met de benodigde kerngetallen en dat daar een rapport in Excel-vorm of pdf uit rolt.
- Mogelijk web-based en meer visualisaties / iconen. Dashboard is ook welkome toevoeging.
- Mogelijk nog extra 'light versie' van maken, wel in Excel.
- Misschien een uitgebreide versie en een minder uitgebreide versie zodat die direct naar klanten kan worden doorgestuurd.
- Uiteindelijk een web tool en simpelere versie. Gebruiksvriendelijker, meer visueel.

13. Hoe heeft u de tijdslimiet van 30 minuten ervaren voor het doorlopen van alle stappen in de handleiding? Was er voldoende tijd? Zo nee, waar lag dit aan?

8 antwoorden



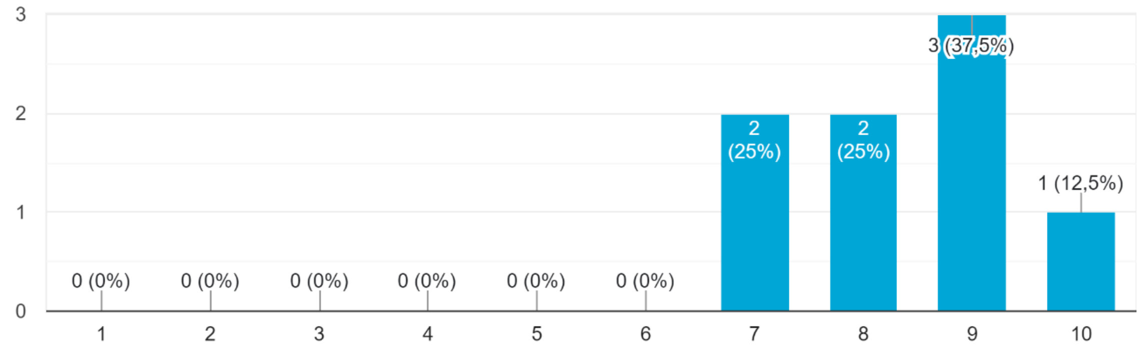
Average grade: 8.1

Toelichting:

- Voor invullen voldoende, echter niet voldoende als je ook even wilt weten hoe de tool in elkaar steekt.
- Meer dan voldoende tijd!
- Was goed te doen.
- Hoeveelheid informatie en teksten te lezen vraagt meer tijd. Handleiding was goed uitgedacht en nam de deelnemer bij de hand. Dit maakte het invullen van de casus erg efficiënt.

14. Hoe heeft u dit test experiment ervaren? Zou naar uw mening iets anders of beter kunnen? Zo ja, licht toe.

8 antwoorden



Average grade: 8.4

Toelichting:

- Leuk om hieraan mee te werken.
- Goed voorbereid.
- Zeer toegankelijk om te gebruiken.
- Meer ruimte voor discussie na afloop was handig geweest.
- Meer tijd reserveren (1,5 uur); uitgebreidere casus geeft meer validatie. Voordelen inzichtelijker krijgen.
- Was leuk om de tool uit te proberen, maar had wel verwacht de baten inzichtelijk te krijgen. Wellicht beter verwachtingsmanagement vooraf, wat kunnen we verwachten van de output?

15. Welke voor- en nadelen ziet u in de opzet/aanpak van dit test experiment? D.w.z. het plenair inplannen van een moment via MS Teams en vervolgens individueel de casus input invullen in de tool?

8 antwoorden

Toelichting:

- Je kunt gelijk dingen vragen en bespreken (voordeel), je bent afhankelijk van de beschikbaarheid van mensen (nadeel - als zij op dat moment niet kunnen, loop je deelnemers mis).
- Handig. Maar je hebt wellicht meer tijd nodig.
- Ik zou de handleiding ook in het Engels uitvoeren. Dan kan de herleiding eenvoudiger worden gemaakt.
- Ideaal zou een fysiek experiment zijn waar je allemaal in 1 ruimte bent. Ook misschien mooi om een stakeholder spel te doen waar je een ontwikkelaar of adviseur bent en je vanuit die bril de tool gaat invullen. Of mooi om een specifieke real-life casus te krijgen van een groene gevel plan en op basis daarvan de tool in te vullen.
- Voordelen: efficiency, plenaire discussie. nadeel: gezamenlijk moment vinden, kan meer tijd kosten om alles in te vullen.
- Voordeel dat je situatie creëert waarin je er echt zelf mee aan de slag moet. Op die manier is het echt alsof je zelf de tool moet gaan gebruiken voor een advies.

16. Hoe zou deze opzet/aanpak naar uw mening invloed kunnen hebben op de uitkomsten van het user experiment?

8 antwoorden

Toelichting:

- Minder resultaten.
- Dat het menselijk functioneert, is een hele mooie conclusie van je experiment. Ik zou het wel nog een paar keer testen als uiteindelijk alle baten erin zitten.
- De discussie is wat minder open via teams.
- Plenaire discussie achteraf kan mogelijk nog beantwoording vragenlijst beïnvloeden.
- Doordat je alle gegevens krijgt, hoef je weinig na te denken bij het invullen van de tool. In real life is het invullen misschien iets moeilijker omdat je dan meer zelf moet achterhalen/bedenken. Uiteindelijk denk ik niet dat dit de uitkomsten van het experiment erg beïnvloed.
- Denk niet in grote mate, omdat je alleen de presentatie plenair hebt gedaan en we daarna individueel aan de slag gingen.
- Minder tijd om te laten bezinken en mening te vormen.

17. Heeft u nog additionele opmerkingen of zaken die u kwijt wilt en die nog niet aan de orde zijn gekomen?

7 antwoorden

Toelichting:

- Succes met de laatste loodjes!
- Dat ik hoop dat je blijft ;). We hebben plannen met je tool namelijk
- Pro versie (uitgebreid, expert kennis, zoals jouw tool) en light versie (enkel adres invullen)
- Indrukwekkende tool!
- Enorm veel werk verzet en veel potentie. Zet ‘m op bij de afronding!

H

LWS impressions from the Netherlands

In this appendix, pictures are displayed illustrating some of the (most recent) LWS implementations in the Netherlands. As can be observed, these façades contain numerous plant species. Also, habitat and nesting features for birds and insects are incorporated in these LWS, in order to facilitate decent living environments for them as well. As was stressed in appendix C, in the right composition and combination, these plant species and habitat facilities ensure the implementation of biodiverse VGS. Furthermore, properly designed and maintained irrigation and nutrition systems should safeguard the vitality of the LWS, guaranteeing the delivery of benefits through Ecosystem Services from a green LWS all year long.

In recent years, leading VGS suppliers and manufacturers have continuously invested in further development of the systems, in order for them to become more sustainable, biodiverse, healthy and vital all year round. Ultimately, these efforts might result in a future in which VGS contribute to enhanced living conditions for humans and all other species present in the urban environment.

H.1 Aeres Hogeschool - Floriade Almere (2021)

Figure H.1: Aeres Hogeschool Almere, retrieved from 'www.twitter.com' (1)

Figure H.2: Aeres Hogeschool Almere, retrieved from 'www.foodagribusiness.nl'

Figure H.3: Aeres Hogeschool Almere, retrieved from 'www.kawneer.com'

Figure H.4: Aeres Hogeschool Almere, retrieved from 'www.twitter.com' (2)

Figure H.5: Aeres Hogeschool Almere, retrieved from 'www.hevo.nl'

Figure H.6: Aeres Hogeschool Almere, retrieved from 'www.floriade.com'

Figure H.7: Aeres Hogeschool Almere, retrieved from 'www.hva.nl'

H.2 Sportplaza Mercator – Amsterdam (2006)

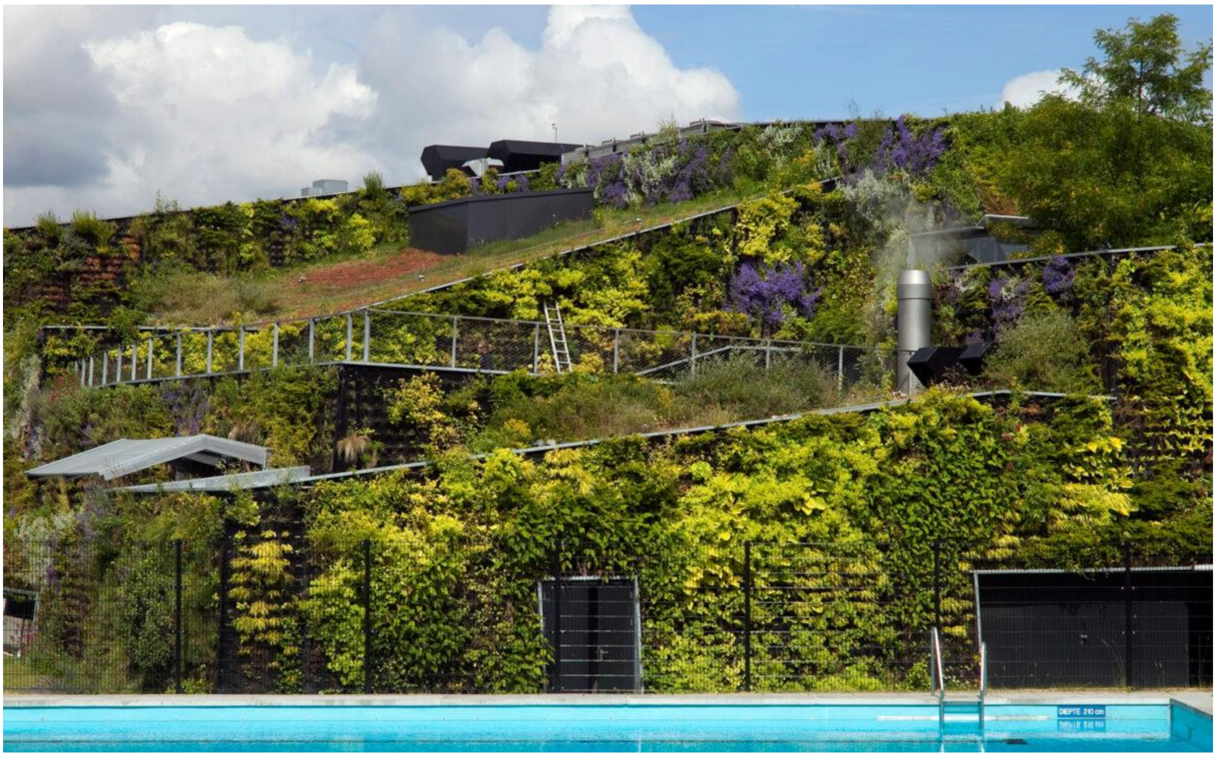


Figure H.8: Sportplaza Mercator - Amsterdam, retrieved from 'www.venhoevencs.nl' (1)

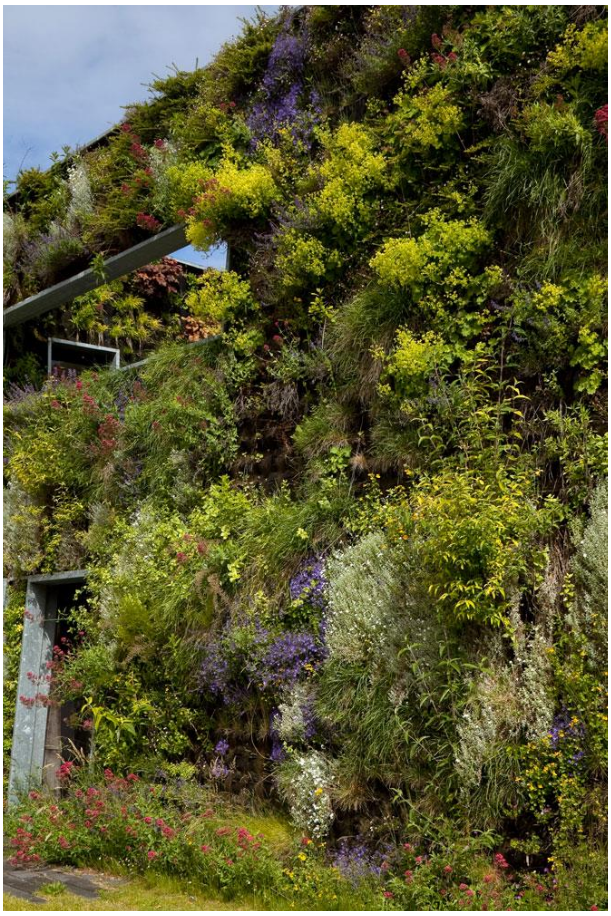


Figure H.9: Sportplaza Mercator - Amsterdam, retrieved from 'www.venhoevencs.nl' (2)

Figure H.10: Sportplaza Mercator - Amsterdam, retrieved from 'www.copijn.nl'

Figure H.11: Sportplaza Mercator - Amsterdam, retrieved from 'www.architonic.com'

I

Extensive future research agenda

As indicated in chapter 9.3, there is still plenty of future research to be done in the field of VGS in general and also into economic valuation of these systems. In order to ultimately arrive at the desired and anticipated level of development for the VGS Valuation Tool, this appendix offers more extensive and elaborated recommendations for a future research agenda and tool development. Herewith, this constitutes an important contribution and outcome of the current study. Recommendations are worked out in relation to scientific purposes, tool extensions and practical & organisational purposes.

The listed recommendations are based on findings and insights gained by the author throughout the research, especially inspired by literature. Furthermore, feedback from the user experiment and constructive conversations (semi-structured interviews) with thesis committee members, TU Delft staff and Sweco employees helped to devise these recommendations. Where this is relevant, a literature reference is included in the recommendation from which research can be developed further.

I.1 Recommendations for academia

Recommendations for scientific purposes are in general aimed towards specific research into valuation mechanisms/methodologies per value indicator, or quantitative values that are currently lacking in literature. This can be both at the cost side, as well as the side of the benefits. Also, recommendations with regards to stakeholders and biodiversity in VGS are included. The same goes for more general encouragement/incentives that are related to the topic of this research. E.g. the results that eventually follow from economic valuation of different types of VGS in the tool, might provide insights as to where research should focus on with further development of VGS.

It goes without saying that scientific breakthroughs or advancements could be systematically integrated within the VGS Valuation Tool in order to make it more comprehensive, accurate and justified. Therefore, links can be created in future research between recommendations in this part and the ones that aim more specifically at the extension of the VGS Valuation tool in the following section on recommendation for the tool.

Generic

- A uniform, standardised or consistent classification and documentation of VGS nomenclature, categories and types should be universally agreed upon within the field. This would allow all research to be reported in the same scientific terminology, enabling more straightforward comparison and correct use of results. Also a comprehensive review (identification and documentation) of research results, as well as new experimental/empirical research, regarding the identified cost and benefit categories per distinct VGS type and in different climates and locations is proposed.

- The methodology used in the tool should be further validated and verified according to Dutch standard practice for performing SCBA's in relation to nature and ES. Since this is a specialised field of study, it might be the case that not all components are incorporated correctly, however by and large this study naturally provides guidance for further development (Romijn & Renes, 2013). Also, an analysis could be included which first monetises all indicators in the SCBA (with the same discount rate for all indicators). Only hereafter, the costs and benefits are distributed among stakeholders (e.g. investors, residents, society at large, government, consultants). This provides a methodologically improved execution of SCBA, rather than only accounting for one stakeholder (residents/society) in this analysis from the start.

Value indicators, valuation methods and input parameters/data

During the research a lot of variation was found in methodological choices made in previous studies regarding both cost and benefit valuation. While different boundary conditions are to be expected for individual case studies, the large variety in methodological choices is striking. Much of the variety between studies and papers is most likely to be attributed to a lack of available and validated scientific, experimental and empirical data, regarding all value indicators as proposed in the VGS Valuation Tool. For example for LCA, this is especially true for data needed regarding water use, lifespan, replacement needs etc. Also more data should become available in a standardized way regarding the benefits that are delivered by VGS (Rowe et al., 2022). Improvements in air quality, reduction of noise, positive effects on hydrology, and visual benefits need much further empirical testing. The current supporting data is mostly qualitative and descriptive, based on the similarities with green roofs.

Hence, future progress also depends on the adoption of a clear VGS nomenclature system and further qualitative and quantitative experimental testing of VGS benefits, which should be clearly linked to a specific VGS construction types so that cross-comparison of studies is enabled (Brković Dodig et al., 2019). This would also enable the differentiation of input data for the tool per VGS type.

Input parameters/data

- More differentiation of input data corresponding to the general principles & assumptions. This entails a strict division in data for e.g. different VGS categories and types, more scientifically substantiated cost data, benefit data, data corresponding to climatic regions or locational properties (i.e. urban context or adjacent street type). All these topics can have influence towards the actual (true) costs and benefits.

- Uncertainty simulations for different input parameters in the tool. Herewith, it can be determined how likely certain outcomes are if some inputs for the tool are not exactly known (Huang et al., 2019). As a sensitivity analysis, the following changes can be made to the input sheets:
    - Alternative discount rates (either in LCCA or SCBA);
    - Alternative value for inflation (cost side, or inflation for perceived beneficial values) (financial business case);
    - Alternative replacement term of the façade (duration of analyses);
    - Alternative population density;
    - Alternative costs of façade.

General principles & assumptions

- More detailed research into the integration of different yearly inflation rates, both for cost side as well as perceived beneficial values. Currently, the analyses are performed based on the assumption that inflation for consumption goods is constant, as well as the relative inflation of ecosystem services in comparison to the consumption goods. Correction for inflation is integrated by using the real discount rate. However, it might occur that society tends to value health benefits or carbon sequestration more in the future, as awareness for climate change and air pollution grows among the general public. These different inflation rates for costs or benefits could have significant impacts on results of the analyses.

- Introduction of a standard price reference year and adjustment of all prices towards this reference year.

Case specific input

Indicator specific input

Financial costs

- More detailed study on the exact accumulation of the financial costs per VGS category or type is recommended. Implementation of these in the VGS Valuation Tool can provide better insight in the potential saving opportunities for each system.

Environmental costs

- Further research into the sustainability of VGS should prioritize on supplementing available (monitoring) data and models to ensure standardized representation of VGS in the LCA methodology.

Potential disservices

- How can cities avoid 'green gentrification' and other unintended outcomes (disservices) of implementing VGS or NBS in general?

Health & Well-being

- Health inequalities due to growing gap between rich and poor (also disparities between neighbourhoods) become more apparent. For the valuation of VGS, it would therefore be interesting to investigate the impact of greening on multiple groups with different socio-economic status and their living environments. From this, potentially certain scaling factors can be deducted that can be integrated in the model. Furthermore, it could provide insights into where the implementation of VGS specifically should be promoted.

Climate Adaptation & Mitigation

Real Estate

- Research regarding property value increase: benefit for investor, disservice for tenants? Does society as a whole (the general public) benefit from increased real estate value in the current economic system that is driven by financial benefit and growth? Increased real estate value will probably mean higher rents for tenants. In Doughnut Economics (Raworth, 2017), for example real estate value could be intrinsically linked to tenant satisfaction levels. Hence, when real estate value is determined by perceived level of resident well-being (instead of financial factors like rent), this could be linked to benefit for society as a whole.

Social & Recreational & Commercial

- Benefit categories pursue to quantify things that have no financial terms as their origin and are deducted from other types of value. It could be the case that due to a diverse spectrum of value indicators that are to be monetized, certain values of indicators will counter one another. Through execution of multiple case studies, these contradictions might be manifested in small details of certain cases. Evaluation of these anomalies can generate new insights with regards to intrinsic relations between different value indicators.

Biodiversity

- Investigation of bequest value: value resulting from the satisfaction of preserving a natural environment and ensuring the availability of biodiversity for future generations.

- Investigation of existence value: value resulting from the satisfaction that something exists (existence of biodiversity/species in the living environment). It's value that goes beyond any physical services that ecosystems provide. Intangible, but yet it does fuel real money transactions, for example people given money to charities. That could be a benefit indicator used to monetize this specific value.

Stakeholders

- More extensive distribution of costs and benefits over the different stakeholder groups involved. For this thesis work, a scientifically substantiated distribution of the costs and benefits over different stakeholders turned out not to be feasible within the given amount of time. Yet, it should be noted that the stakeholder scope demarcation (appendix E) was useful for the initial development of the valuation framework and tool for VGS. In subsequent research or tool versions, a more inclusive number of different stakeholders may be studied in order to gain insights into a more diverse palette of the distribution of costs and benefits of VGS. Guidance for further investigation and implementation of this aspect is integrated in the framework, the tool and in Appendix E.
  A study into quantifying the benefits of green infrastructure, conducted by the Victoria University and University of Melbourne (2018), suggests that different groupings could be established like e.g. public and private, or individuals, communities and institutions. Another option is that the stakeholder groups are to be studied and implemented in the valuation tool on an individual basis. These groups were previously identified by van den Biesen (2018) and are reported in Figure E.1. This would require a more detailed analysis of stakeholder attitudes, preferences and their perceived value perspectives.
  Important research questions/opportunities in this area are:
    - Where are the costs and benefits of VGS felt/noticed/perceived?
    - What are the scales of the benefits?
        - Where scales are divided into *host building location and within the immediate microclimate*, *city-wide* or *global*.
    - What is the nature of the benefits?
        - Does the benefit reduce future costs that would otherwise be experienced through risk reduction, offer net benefits that otherwise would not have been experienced, or both?

  Research into these different types and perspectives of costs and benefits could generate valuable insights for VGS strategies for implementation, help understand stakeholder attitudes and potentially initiate constructive conversations in order to find mutual beneficial business cases or financing strategies.

- Aside from the Life Cycle Cost Analysis (LCCA) for the Real Estate Investor, which only contains direct earnings and monetary transactions, they could be included in Social Cost-Benefit Analysis as well. Here, potentially other benefits might be attributed to the real estate investor as well, like for example improved tenant satisfaction levels and reduced climate risks.

Biodiversity

- For further development of standards, starting points, requirements and boundary conditions regarding biodiversity integration through VGS in the urban fabric, additional research is proposed. This can potentially be based on existing literature, otherwise field investigation is propagated.
  This research could result in establishment of benchmarks regarding biodiversity and sustainability for VGS, in order to stimulate choices for systems that are optimal in specific situations or locations. Eventually, the outcomes of the investigation could be integrated in the tool as well.

- It would be interesting to conduct a study into the different native plant species applicable in LWS which thrive (at different locations or regions) in the Netherlands and contribute to higher biodiversity (and other benefits) (Bustami et al., 2018). Nowadays mostly exotic species are used for LWS in the Netherlands, however there are no indications that native species could not be integrated in these systems. This could be combined with research for native climbers, to make the study applicable for VGS in general.
  The goal of this study would be to produce a more transparent list of properly functioning and native plant species for VGS, which is accessible to anyone who wants to use this knowledge for the good. Local species at multiple trophic are namely mostly attracted by native species. Therefore, it is crucial that future integration of native species is propagated, to further enhance contribution to local biodiversity. (Sweco expert knowledge, 2022)
  It is advised to initiate a study in this field in cooperation with leading VGS suppliers and producers, since it is assumed they already possess a great deal of knowledge through monitoring and evaluating data regarding this topic. Also e.g. cooperation with Wageningen University & Research could be fruitful in this regard.

- Research into the added value for biodiversity is proposed, for both LWS and green façade systems in different configurations, locations and orientations. Also different (sub-)types of VGS and their influence on biodiversity in the surroundings, or the influence of the surroundings on enhanced biodiversity and vitality of the VGS warrant ongoing investigation.
  - A method for this kind of research could consist out of 3 major phases: inventory, quantification and evaluation. Initially, species groups should be selected since the study has to be practically feasible.
    Then, the biodiversity, quantities, behaviour and functions of plant species, pollinators and non-pollinators, birds and bats should be monitored. This should happen 5 times a year in different seasons, for a number of subsequent years. Preferable this would also include a baseline measurement and description of the current situation and location.
    By quantifying/scoring the foregoing with a predefined technique or methodology, for example via 'Natuurpuntencalculator' or similar, the value of the specific VGS (sub-) type for biodiversity can be derived. Evaluation of this quantitative value could finally result in some kind of benchmark or biodiversity value scaling factor for different VGS in the valuation tool.

- Building upon the previous recommendation, research into the integration of a biodiversity-scan at the front end of processes, projects and economic valuation is recommended in order to make an elaborate choice for a specific type or composition of VGS.
  - Relating to Sweco specifically, the 'Natuurpuntencalculator' could for example be used and expanded to generate results for biodiversity values of vertical greening and nature at eye-level.
    This entails the integration of several different sources of information that are neglected till date. Vertical surface areas and their properties could e.g. be mapped via Spotr.AI, a tool that analyses up-to-date pictures and data (for example from Cyclomedia or Google Street View). When the 'Natuurpuntencalculator' is extended to façade areas and green at eye-level, the tool could be promising for the scientific quantification of the value for nature and biodiversity delivered by VGS.
  - This recommendation is also made since common sense has to remain at the basis of VGS implementation. In theory, for certain locations it might be the case that certain problems are most effectively mitigated by implementation of a VGS (or NBS in general) with low biodiversity, as a lot of the same nature appears to be necessary.

- The following outlook is interesting when already multiple VGS (with the same plant composition) are integrated in an urban area. In that case, it can be studied whether integration of a distinct kind of VGS (containing other plant species than already present) would contribute to enhancing biodiversity and attracting other animal species in larger amounts, as compared to the addition of more of the same plant species. This could shed light on the number of different VGS types (and plant species) needed, in order to obtain the desired level of biodiversity.

Further improvement and development of cost & benefit effective VGS

- LWS can help bring nature into urban canyons. However, contemporary LWS are often cost prohibitive and composed of materials with lifespans that are shorter than their host buildings. Nowadays, the high costs therefore often restrict their use to luxury applications, promoting ecological symbolism rather than impactful propagation of urban nature and biodiversity increase. Hence, development of more sustainable, biodiverse and cost effective LWS and VGS in general warrants ongoing investigation.
  An interesting, innovative development in this light is for example bio-receptive or living concrete (Riley et al., 2019). Here, the secondary support systems for living walls are eliminated and the life cycle of the VGS is matched with the construction. An initial cost analysis indicates a 50% cost reduction compared to current LWS. In the Netherlands, the Delft-based company 'Respyre' already developed a bio-receptive concrete solution accommodating moss growth (Respyre, 2022).

- In the future, exploration and interpretation of the costs and benefits per different VGS, location, or stakeholder perspective is proposed. This could be done based on the VGS Valuation Tool. Namely, when multiple extensions are implemented in the tool (section 0), new insights can emerge regarding the contribution of different VGS for the stated cost and benefit themes. This also initiates the opportunity to make substantiated comparisons between VGS at specific locations, which might prove to be valuable for decision-making.

VGS in different economic systems and legislation

- Although not entirely within the scope or touching limits of this research, it might be interesting to investigate how (economic valuation of) VGS, or NBS in general, relate to Doughnut Economy as promoted by Kate Raworth, or Purpose Economy as advocated by Aaron Hurst.
  - How far should economic valuation progress, in order for people gain sufficient insights to look beyond the sole economic values of certain systems, and where they adopt the view of accepting that not all values can or should be expressed in monetary terms? Also environmental values and social values are relevant.
  - From which turnover-point do people take actions or make decisions for the greater good, rather than solely economic gain?

- A deep-dive into how VGS are integrated in legislation, codes and guidelines (and potential values resulting from this) might be interesting. It could be investigated if, and how, these are stimulated by sustainable legislation (e.g. EU-Taxonomy) or certification (e.g. BREEAM, WELL, GRESB) and what the effects are of these efforts. This in order to assess whether further integration in legislation could have positive effects on their implementation.

I.2 Recommendations for VGS Valuation Tool

Since a major part of this thesis consisted of the establishment and development of a uniform valuation framework and tool, only a limited number of quantitative implementations are integrated in the model. Nevertheless, this work should be regarded valuable in the sense that all the basics are covered, paving the way for further research that can focus on the expansion of the tool. The current VGS Valuation Tool is a functioning, full-fledged prototype and guideline for the envisioned comprehensive valuation tool. Yet, due to its extremely broad scope and complexity, there still is much potential to improve its performance and incorporate extended functionality.

In order to encourage the development of subsequent versions of this VGS Valuation Tool, an important aspect of this thesis work is the composition of recommendations for tool extensions. These recommendations could result in a living and expanding file, in which more substantive and quantitative features are integrated over time. Hence, a more comprehensive tool would be developed along the way, containing indicators that were identified for monetization at the start and throughout this thesis work. This ongoing development would enhance both the comprehensiveness and correctness of the framework and the tool itself, as well as the future value these can have following their implementation in business operations and real life projects.

In the VGS Valuation Tool itself, cells containing placeholders for future recommendations and envisioned integration of functionality or data links are marked in purple.

Revision and further implementation of 'cost & benefit indicators' calculations

- The most important and general overarching recommendation for tool extensions is this first one. It encompasses the integration of necessary quantitative input and automated calculations for all value indicators that are displayed in the VGS Valuation Tool and in Appendix F. Most of these contain placeholders in the tool, but are not incorporated in any calculations yet. Scientific research needed for these further implementations is already touched upon in the previous section and throughout the report. This also entails further integration of relevant and corresponding input parameters in the input sheets of the tool:
    - Link input data for the case specific and indicator specific input, to general valuation choices and principles.
        - E.g.: input in cells could be linked to the type of VGS, by setting up a database for these distinct systems in the tool.
    - Include more case specific input and establish interdependencies:
        - E.g.: Building type and specifics (e.g. façade area to be covered)
            - Factor for Economies of Scale, both at cost side as well as benefit side
    - Include more indicator specific input and establish interdependencies:
    - Change assumed data for scientifically validated data (from the correct/governing climatic region).

  Detailed reporting with an elaboration of the methodologies used for each value indicator is recommended. Aside from the presentation of the value calculations in the bottom parts of each Excel sheet in the tool, this can offer transparency and serve as reference work to critical users and other researchers. Thus, further enhancements and integrations in the tool are encouraged.

- Furthermore, effort should be made to gather more detailed, adequate and correct cost data from manufacturers or suppliers of multiple VGS. This allows for substantiated comparisons between different (sub-)types, rather than solely a cost-benefit calculation based on guesstimates. The same goes for VGS material quantities, in order to perform more specific and adequate LCA analysis for shadow cost calculations. Due to competitive and confidentiality considerations, the researcher was unable to extract/collect sensitive data that could be used during this thesis. Therefore, this phase of the development of the tool could only be based on general guesstimates and data from literature in combination with an indication of the total costs for a LWS system by a supplier. These costs were stated as 750-800 €/m^2 for initial costs, topped with a yearly 50 €/m^2 in maintenance costs.

- Currently LCA is worked out for VGS as addition to the existing/conventional built up Dutch bare brick façades. However for future versions of the model, also research regarding the construction of a VGS as outer skin for other existing façade types or of a newly developed building can be performed. This might bring different necessities or require other material quantities. Hence, then the differences in environmental burdens and costs can be exposed and utilised in the tool. This will have consequences on e.g. the total ECI of the building and its (reduced) energy usage (benefit). Also, optimised building envelopes could be realised when VGS are integrated in the building concept from the start.
  Also, LCA methodology should be updated for the new standard: EN15804 + A2. This includes more environmental impact categories and accounting for benefits of end-of-life recycling, among others.

- In the result dashboard, a diagram could be implemented that visualizes the project's (total) yearly expected cost and benefit values over the analysis period. This could provide fast insights into when certain costs or benefits occur, meaning stakeholders can anticipate on this. Furthermore, by including the (accumulated) difference between costs and benefits, the payback period for VGS can be determined.

Make input values dependent on project's starting principles (creation of scenarios)

- The execution of a range of fundamentally different case studies can improve the tool and help develop a more comprehensive and robust model, based on input variables from various sources. For example, it can help initiate more connections between cells in the tool or expose relations that were not incorporated before. Also, it can shed light upon assumptions for input data or calculations that might not be accurate for all cases in general.
  Most importantly, it can help to evolve the tool into a more powerful mechanism, containing economic valuation analyses for a wider range of starting principles. Please note that for each starting principle, various dependent input variables might be applicable. This holds that with further development, the tool should be designed in such a way that more cost and benefit calculations become dependent on input variables which are linked to the initial starting principles or chosen case specifics for the project. This limits user input to very specific input values. Recommendations for extension of general starting principles and case specific principles are provided in the following list:

  - Specification of multiple main VGS categories, other than solely modular living wall systems:
    - Direct green façade systems
      - Range of subtypes
    - Indirect green façade systems
      - Range of subtypes
    - Continuous living wall systems
      - Range of subtypes
    - Cast-in-situ concrete living wall systems
      - Range of subtypes
  - Specification of type of real estate object to which VGS is applied, other than solely residential:
    - Residential (multi-family housing)
    - Residential (single-family housing)
    - Offices

        - Retail facility
        - Healthcare facility
        - Educational facility
        - Recreational facility
        - Logistic facility
    - Specification of type of neighbourhood in which VGS is applied:
        - Dense urban area
        - Suburbs
        - Rural area
    - Specification of adjacent street type at location where VGS is applied:
        - Highway
        - Busy traffic street
        - Traffic street in residential area
        - City centre
        - Pedestrian/Bicycle lane
    - Extension for selection of current existing façade types:
    - Orientation of the VGS
    - Different scenarios in relation to expected lifespan of the VGS or deviant analysis period

- Elaboration of a case study in which a VGS is already implemented. This could help to further establish correct assumptions and relations between certain input parameters or value indicators. Subsequently, this could help to better validate and improve the model/tool with empirical and monitored data. Also the value they possess in relation to direct users or residents could be identified more accurate.

- Looking further down the line, it would be extremely valuable if based on the case specific and indicator specific input, a (sub-) type of VGS could be proposed that optimizes the Net Present Value and Benefit-Cost Ratio of the entire VGS project, or in the themes as prioritized by a client. This would require multiple different (sub-) types of VGS and their dependent input data to be integrated in the tool. In the eyes of the researcher, a functionality like this would definitely approach the end goal of this tool.

Integration of biodiversity in the tool

- Also research is proposed into how the VGS's level of, or its added value for, biodiversity can be integrated in the valuation framework and tool as input or output respectively. Like stressed earlier on in this work, on the one hand the level of internal biodiversity could serve as input for calculations of value indicators. From the other side, the resulting increase of biodiversity in surroundings or the VGS's contribution to preservation of ecosystem functioning could follow as output of a specific value calculation.
  A proposal is made for the integration of the VGS's biodiversity level (and sustainability level) as input in the tool:
    - A benchmark input value for biodiversity of the VGS could be implemented, acting as some kind of scaling factor for benefits or value calculations that follow from the delivery of Ecosystem Services.
    - A value scaling factor for the current biodiversity levels in the surroundings. It should be studied whether already high surrounding biodiversity further enhances the values of an implemented VGS. Or in the contrary, that perceived values of (biodiverse) VGS are potentially higher when only little biodiversity is present in the current situation and neighbourhood.

Values relating to biodiversity that can follow as model outputs are given subsequently. These warrant ongoing investigation (both for scientific purposes as well as for model extension):

- Nutrient cycling: the ability to provide food sources for (other) species
- Bequest value: value resulting from the satisfaction of preserving a natural environment and ensuring the availability of biodiversity for future generations.
- Existence value: value resulting from the satisfaction that something exists (existence of biodiversity/species in the living environment).

Expansion of number of incorporated stakeholders

- Building on proposed research regarding stakeholders and VGS, more stakeholders could be incorporated in the model to whom costs and benefits can be attributed. Along with this, the appropriate economic analysis method (and discount rate) should be determined for valuation (and potentially incorporated in the tool). With SCBA, distribution of costs and benefits is proposed as it can contribute to decision-making (Romijn & Renes, 2013).
  Some stakeholders might only have costs or negative effects of VGS, while others potentially have no costs but only experience benefits or positive effects. It would be valuable to obtain insights into costs and benefits of VGS for the entire spectrum of stakeholders, as touched upon in Appendix E.

Tool actualisation

- Yearly reflection and actualisation of the tool in order to implement the latest scientific insights and to keep track of correct and sound values, hence updating certain costs and benefit parameters.
  - E.g. yearly inflation, product innovation or material scarcity can have significant effects on the results that are ultimately delivered by the tool (Does et al., 2019).
  - Also, updating the data references in the tool might be necessary in order to retain correct data values and sources.

- A deep-dive into how replacement costs should be dealt with exactly is advised. Are these costs that should be incorporated in the current analysis? Or, whilst keeping in mind the transition towards circular economy, are these perhaps revenues at the end-of-life stage that can be sold/reused as resource for something new? Furthermore it could be investigated whether there are any contractual or legally binding options to ensure a minimum level for future reuse.
  - For example, perhaps when the end of the design lifetime is reached in the future, only (minor) parts of the VGS have to be replaced or the system can be reused. Potentially, only new vegetation has to be installed and the lifetime of other architectural/structural components can be extended. Replacement costs in this case could match production and installation costs for a new project, hence a new business case/cost-benefit analysis. Per project, the scope of the analysis and the future outlook after design lifetime should be well documented, in order to correctly assess (economic) feasibility.

User experience and intuitiveness

- In terms of user experience and intuitiveness, improvements can be made by:
  - Simplifying/Reducing/Linking inputs
  - Reducing total number of inputs by creating dependency on project's starting principles
  - Protect sheets and cells were no input from the user is requested

Potential valuation of other NBS with the developed framework

With some modifications, the developed tool could potentially serve as comprehensive mechanism fit to value other NBS as well. Hence it could be used (by practice) to value costs and benefits of other NBS too, complementary to solely VGS. However, for most other NBS already more extensive, elaborate and tested professional tools are available.

Another option would be to investigate the possibilities of implementing the reasoning applied in the developed tool into already more established tools for valuation of urban NBS, like Groene Batenplanner.

I.3 Recommendations for practical & organisational purposes

The following recommendations elaborate on what Sweco or other organisations can do in order to further develop or implement the framework and tool in their business operations.

Establishment of benchmark for VGS

- Government bodies and public authorities are advised to investigate opportunities for establishment of biodiversity benchmark values in project tenders, e.g. like is the case in the municipality of Amsterdam (Appendix C.2.2). Setting minimum limits and assessment criteria as to which the VGS should comply, could benefit living species and the urban environment greatly. It will create awareness for ambitions to develop healthier, nature-inclusive, climate resilient and biodiverse living areas. In combination with legally binding steering mechanisms, this will potentially increase the demand for highly biodiverse and sustainable VGS.

Tool extensions & adequate data implementation

- It goes without saying, that the recommendations as elaborated in previous sections would all enhance the usefulness of the tool. Hence, making efforts or initiating cooperation to achieve these improvements would benefit the company. This by adding a service to its consultancy portfolio and contributing to achieving its main goal of 'Transforming Society Together'.

- Establishment of partnerships with VGS manufacturers and suppliers, in order to enable the collection of detailed and adequate cost and material data, to be used as input for the VGS Valuation Tool. Furthermore, when the exact composition of plant species is known for certain standard VGS systems or location specific design solutions, Sweco ecologists could perform an objective biodiversity analysis for each system. This could lead to the implementation of VGS systems that contribute to enhanced biodiversity only, or initiate the integration of a biodiversity scaling factor in the VGS Valuation Tool.

Tool automation & web application

- Investigate whether it's feasible to perform automated measurements and collection of necessary data input with other existing tools that are already applied within the organisation. One example could be the automated inspection of building specific properties, like façade areas of the project property or percentage of vertical green vegetation in neighbourhood, with SpotrAI (website: https://www.spotr.ai/). This is a tool that enables the analysis of up-to-date real estate pictures and data in the living environment, for example retrieved from Cyclomedia or Google Street View.
  Also the automated integration of data resulting from e.g. 'Klimaateffectatlas' or 'Kadaster data' could prove to be convenient.

- Further enhance the level of data input automation for the tool, e.g. by establishment of a Feature Manipulation Engine (FME) script for the tool. This is software which facilitates ETL-processes between a diverse range of data sources and files. ETL in turn is the abbreviation for extract, transform and load. Put simply, FME enables the import, editing and export of data. This in order to simplify data coupling and to automate processes. Input extraction from data sources and files could for example be initiated by, or based on, the choice for VGS category or type, or the exact project location for case specific data.

- Explore the opportunities to integrate the VGS Valuation Tool with other, more advanced software packages, which already focus on the modelling and quantification of effects of green measures in the built environment. For example, the integration with 'Digital Twin' software Tygron could be investigated.

Organisational implementation & application

- For successful implementation of the tool within the organisation, it is recommended to organise an information session for consultants and other employees that will work with the tool. This will allow them to become familiar with the (potential of) the tool for their (consultancy) work relating VGS in urban environments. First time experience with the tool might overwhelm the users, however a decent information session can mitigate this feeling and highlight the exact steps to be taken. This way the framework and tool could become an equipment of standard practise for consultancy with regards to VGS.

- Further development of the tool in relation to Sweco's KIM-tool (Klimaatrisico Identificatie & Management tool). For example, investigate how results from the VGS Valuation Tool can serve as input for the KIM-tool, or whether the economic valuation of cost and benefits solely constitutes a deep-dive for VGS when these are a proposed solution to clients. Generating insights with regards to the business case could simplify and substantiate the choice for real estate investors whether or not to invest in a green measure. With this, also make sure the results of the VGS Valuation Tool are aligned with (reporting) requirements as set in the EU-Taxonomy.

- In later stages, when the tool and its results are more robust and comprehensive with regards to quantitative outputs and value indicator calculations, the application of the tool in multiple real estate consultancy projects could provide valuable information and insights. For example, it would enable comparisons among different project cases based on the B/C ratio. This could facilitate the company with more instinctive knowledge and experience, as to what projects benefit from certain specific VGS (properties). Hence, identification of the focus areas and benefits could happen more swiftly, enabling objective judgement of potential solutions and speeding up the consultancy process.
  In order to enhance this effect and make sure not every new project has to be inserted from scratch, a database could be established (e.g. on the company's network drive or between several companies) containing multiple projects and their corresponding weighted variants. This would create a 'collective intelligence' where peers can benefit from each other's efforts and knowledge.