Metropolitan Analysis, Design & Engineering: Thesis

USING GREEN FACADES TO INCREASE URBAN SUSTAINABILITY AND RESILIENCE

AN ASSESSMENT OF POTENTIAL VERTICAL GREEN LOCATIONS TO ENHANCE URBAN GREEN SPACE IN AMSTERDAM

Thijs Rang

WUR student number: 1047887

Main supervisor: Sitong Luo;
sitong.luo@ams-institute.org
Wageningen University & Research
Landscape architecture & spatial planning

Additional supervisor: Corné Vreugdenhil;
corne.vreugdenhil@wur.nl
Wageningen University & Research
Geo-Information Science & Remote Sensing

20 – 10 – 2022, Amsterdam

Urban living has many advantages but also has its fair share of issues. This thesis tries to indicate the urban issues that can be solved by implementing vertical green systems (VGS). A literature review is undertaken, and expert interviews are held to examine socio-ecological criteria. The criteria heat stress, air pollution, water stress, noise pollution and percentage of green are determined to be the themes that can designate which locations in the city are suitable for vertical green. Since VGS are implemented on streets, it is necessary to figure out the need for vertical greening on street level. This is done by performing a spatial analysis using QGIS. The spatial analysis uses the criteria to create five thematic maps, showing the Urban Heat Island effect, levels of particulate matter in the air, water depth after extreme rainfall, noise pollution, and the percentage of urban green in an area of ten-by-ten meters. These thematic maps are combined to create the combination map and ultimately a street map that shows the need for vertical green on street level. The underlaying data of this map presents a ranking of streets. This ranking shows that most of the streets that are in very high need for vertical green are located in Amsterdam Centrum and Amsterdam West. To assess peoples' perception of VGS to assess their willingness to pay for implementation a questionnaire is held. The result from the questionnaire shows that half of the respondents are knowledgeable about the benefits of VGS. When people learn about the benefits, they are more likely choose for a green façade or living wall would they get the change. The questionnaire shows that money is the most determining factor in the decision-making process of the respondents, meaning that for implementation of VGS on a large scale to be successful, subsidies would have to be implemented.

TABLE OF CONTENTS

1.INTRODUCTION

This chapter introduces the context and problem definition of the research, the social and scientific relevance and lastly the research objective and its main and sub research questions.

1.1 CONTEXT AND PROBLEM DEFINITION

Urban living comes with many advantages, partly due to the agglomeration effect (Fujita & Thisse, 1996) and broad selection of amenities such as restaurants, cafes, clubs, and museums. The popularity of cities does not seem to come to a halt as the global population living in cities will increase from 55% in 2018 to 68% in 2050 according to the United Nations (2019). According to De Vries et al. (2017) the amount of people living in urbanised areas will continue to grow in the years to come in The Netherlands as well. For those people to have a space to live there is a need for extension or densification of the already dense urban area. Because climate change will bring forth more extreme weather events such as heatwaves and heavy precipitation (IPCC, 2021) and because urban areas are more vulnerable to these negative effects (Rosenzweig et al., 2011) there is a need for sustainable urban development.

Besides all the agglomeration benefits that urban living comes with there are some disadvantages as well. To name a few: air pollution, declining biodiversity, heat stress and flood risk; all leading to a decrease in urban living quality. A way to combat these issues is to implement more urban green (Ghazalli et al., 2019) – as this is an integral part of making the city adaptable to the changing climate (A. Driessen, personal communication, May 25th, 2022). The problem however is that because different urban functions battle over available land there is a lack of space to do so. When designing new-built areas from scratch, policy makers can have a certain percentage of the land designated for green – adding trees for example, with existing buildings and neighbourhoods this is much harder to do (G. Timmermans, personal communication, May 2nd, 2022. A solution to this is to implement vertical green by way of vertical green systems (VGS). These might offer much of the same benefits as traditional horizontal green does and take up much less space.

1.3 RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

This research aims to investigate potential vertical green locations using social and ecological criteria in order to enhance the existing urban green infrastructure network in Amsterdam. The compact city and the fragmentation of urban green spaces lead to multiple complications in the city. Using vertical green is a solution to these issues by using vertical structures for greening, thus leaving the ground level free for other functions. There is currently knowledge missing on all-compassing information of urban issues that can be solved by VGS in Amsterdam, where these mostly take place, and how they can be tackled using VGS, taking into account public cooperation.

The research objective will be assessed by answering the following research question:

What are potential locations for vertical green systems in Amsterdam and how can the urban green space be enhanced using public cooperation?

This research question will be answered by addressing the following sub-questions:

1. Which socio-ecological criteria should be used to find locations for potential vertical green?
2. Which locations for potential vertical green should be prioritised based on GIS-analysis?
3. What is the public perception of vertical green in the potential locations, based on a case study analysis?

2 LITERATURE REVIEW

This section is made up of the results of the undertaken literature review (as discussed in the methodology) and the expert interviews.

According to researchers (Pacini et al., 2022) most of the studies on green facades have been done by engineers and architects. Because of this, most of the information is focussed on engineering aspects such as construction techniques and the influence green facades have on buildings. However, to perform the spatial analysis, information regarding climate and the environment, health and well-being is being sought out as well. Research on construction types and useful plant species however, is useful in designing the questionnaire for testing the public perception regarding VGS. Therefore, these findings are summarised as well.

The results are summarised and divided into the following categories and their subcategories: Summary of scientific research on VGS (different types of green facades, suitable plant species, and public perception of green facades) and effects of vertical green (effects on buildings, effects on climate and environment, and effects on physical and mental health), and lastly; the costs. These findings are used in determining the socio-ecological criteria for the spatial planning and for designing the public perception questionnaire. On top of this, a research gap is identified as well, which will be answered by use of the questionnaire.

2.1 SUMMARY OF SCIENTIFIC RESEARCH ON VGS

This sub-chapter summarises all the information on VGS gathered via the literature review and expert interviews that is used to design the questionnaire to test the public perception.

2.1.1 DIFFERENT TYPES OF VERTICAL GREEN SYSTEMS (VGS)

Radić et al. (2019) identify thirteen vertical green construction types, they divide them into green facades and living walls – four types of green facades and nine types of living walls. Figure 1 shows a schematic display of a green façade and three types of living walls, going from simple to more advanced. The authors do acknowledge that even though they have identified the thirteen different subclasses, there are enough similarities between them to justify classifying them in the two categories of green facade and living wall. Living walls are fundamentally different from green facades according to the authors (Radić et al., 2019) because in living walls "(…) the plants root in a structural support which is fastened to the wall itself. The plants receive water and nutrients from within the vertical support instead of from the ground.".

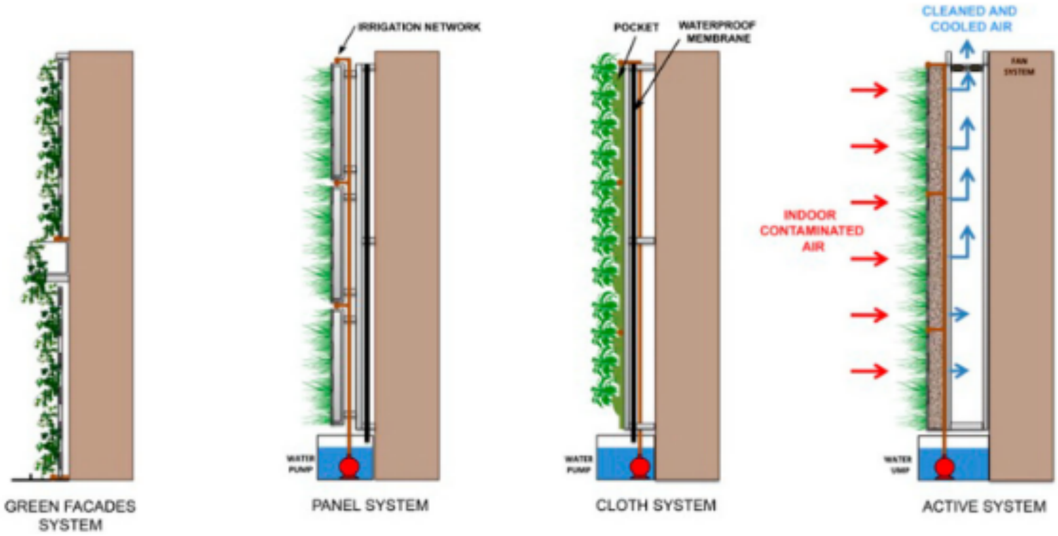


Figure 1: Schematic display of a green façade and three types of living wall, Source: Perez-Urrestarazu et al. (2015)

Other researchers come to a similar conclusion in the sense that they roughly classify VGS in two categories as well: green facades and living walls (Medl et al., 2017; Pérez-Urrestarazu et al., 2015). They state that VGS are either green-wall technologies, vertical gardens or bio walls which can be but do not have to be attached to a building façade. They base their classification on the type of vegetation and support structures that are used. According to authors (Ottelé et al., 2010), a green façade system is characterised by a vegetation cover that is formed by climbing plants which can be (but do not have to be) supported by specifically designed structures. Living walls on the are generally more complicated, so state the authors, requiring more maintenance and protection compared to green facades. Living walls also require an irrigation system, increasing the cost of implementation. The authors state that the costs of implementation and maintenance are important factors to take into consideration as there is a meaningful difference between the two. G. Timmermans (personal communication, May 2nd, 2022) confirms this by saying that VGS with integrated water systems are not only very expensive compared to green facades, but because of this, also very sensitive.

The costs as reported in different studies vary from source to source, this partly has to do with the complexity of the systems (living walls are more expensive to implement, but in this category, there are different complexity levels as well – and as a result these costs are variable as well) (Pérez-Urrestarazu et al., 2015). Other aspects that influence the costs are the installation equipment, the height of buildings, locations and so forth (Radić et al., 2019). Taking these factors into consideration, the implementation costs for a green façade can be less then 75 €/m^2 - measured on the vertical plane - for the simplest implementation (Pacini et al., 2022) but can go up to 300 €/m^2 when the system gets more complex (Pérez-Urrestarazu et al., 2015). Living walls are much more expensive in their implementation due to their advanced complexity, they can go for 300 up to 1200 €/m^2 (Pacini et al., 2022; Pérez-Urrestarazu et al., 2015), the rule here being that generally the more advanced the system is the more benefits it brings. The costs of maintenance are lower with green facades as well: 2- 5 €/m^2 per year as opposed to 40 – 100 €/m^2 per year for living walls.

2.1.2 SUITABLE PLANT SPECIES

The type of VGS affects the type of plants that can be used (Pacini et al., 2022) A green façade allows for a relatively small number of plants, but introducing a structure slightly increases this. A living wall however allows for the largest variety of plant species to grow. Given that Amsterdam is located in a Cfb climate according to the Köppen-Geiger Classification (Kottek et al., 2006) meaning it has warm temperatures, is fully humid and has a warm summer, there are number of suitable plant species (Pacini et al., 2022). For a green façade these are: Ivy, Boston Ivy and Lambs' ear, an added structure will also allow for Virginia Creeper and Common Bean. A living wall will also allow for (besides all aforementioned plant types): shrubs, grasses, perennials, and herbaceous plants to grow.

2.1.3 PUBLIC PERCEPTION OF VERTICAL GREEN SYSTEMS

There have been several studies that delve into the public acceptance of VGS (Pacini et al., 2022). These either focus on the difference in perception of VGS between target groups and settings (Kozamernik et al., 2020), difference in perception between inhabitants of the buildings and passers-by (Magliocco & Perini, 2015) and the socio-economic feasibility of public buildings (Almeida et al., 2021). A case study in Southampton tested the publics willingness to pay for VGS that provide increased biodiversity (Collins et al., 2017). The study shows that the living wall is associated with a higher level of utility compared to the green façade. What is missing in this research, thus identifying the research gap, is an all-compassing testing of VGS acceptance in areas that are deemed as in need for greening based on selected criteria. This research gap is addressed in the public perception questionnaire.

2.2 EFFECTS OF VERTICAL GREEN SYSTEMS

Vertical green systems (VGS) are a part of the urban green infrastructure (UGI) of a city. The urban green infrastructure improves the urban environment and the lives or urban dwellers by affecting the urban heat island (UHI) effect, noise pollution and air quality in a positive way, and by creating an environment that promotes human health (Ghazalli et al., 2019). To assess what these effects are to use them as criteria for the spatial analysis, the literature review is used (see 3.1.1). The effects are divided in three categories: effects on buildings, effects on climate and environment, and the effects on health and well-being.

2.2.1 EFFECTS ON BUILDINGS

Vertical green systems can play a role in reducing energy consumption in buildings because they can mitigate urban heat through evapotranspiration and shading (Bakhshoodeh et al., 2022; Convertino et al., 2021). The combination of these two qualities makes for a stronger solution as opposed to non nature-based solution such as shade sails. The temperatures behind the VGS can be up to 11 °C cooler compared to the ambient air during hot summer days (Blanco et al., 2019, 2021). Susca et al.

(2022) provide similar statistics, stating that VGS can reduce cooling energy demand up to 51% and on top of this also reduce heating energy demand up to 16,5%. It must be stated that to achieve optimal temperature reduction during hot days, the south facing wall is the best wall to green when one must be picked (Sendra-Arranz et al., 2020). Other researchers talk about temperature increase of up to 3 °C during colder days (Hunter et al., 2014).

2.2.2 EFFECTS ON CLIMATE AND ENVIRONMENT

The notable effects that VGS have on climate and environment according to the literature review are urban heat island effect mitigation, air pollution mitigation, regulation of water flow, muffling of noise pollution, and the safeguarding of biodiversity. These different effects are discussed in the paragraphs below.

URBAN HEAT ISLAND EFFECT

The urban heat island effect is an increasing issue in urban environments (Ghazalli et al., 2019). The increased temperatures that they cause affects human health, worsens air pollution, and increases the demand for air conditioning. Susca et al. (2022) state that when enough buildings implement VGS they can reduce the Urban Heat Island effect by up to 5 °C, no matter the climate zone. Other researchers state similar ideas, saying that besides the colling effect on buildings, VGS – just as other urban green infrastructure – poses a beneficial mitigation and adaptation strategy for cooling on the street level (Koch et al., 2020), reducing the ambient air temperature between 0,5 and 4,1 °C (Solera Jimenez, 2018).

AIR POLLUTION

There are different types of air pollutants found in cities such as fine particulate matter (PM), ozone, nitrogen oxide, and sulphur dioxide. Researchers have found that PM has the biggest relative impact on human health (Ghazalli et al., 2019). Exposure to PM, from sources such as road dust, smoke, and vehicle exhaust, negatively affects human health because the small size of these particles makes it possible to easily enter the lungs and bronchioles and cause damage. Even though prevention would be an excellent solution, limiting emissions of these harmful substances, this is not always possible or adequate. Vegetation is then a good solution for PM mitigation because just as regular urban green infrastructure, research has shown that VGS have the potential of reducing particulate matter (PM) in the air (Jeong et al., 2021). Besides being a sink for PM and improving air quality, VGS have the added benefit of adding in the protection of historic walls because their air cleaning qualities (Ghazalli et al., 2019).

REGULATION OF WATER FLOW

Urban areas cope with water stress due to the high levels of stone and concrete, especially during peak precipitation, sewer systems struggle with handling the water flow-through. Vertical green systems potentially play an important role in managing water stress in urban areas. Fully foliated VGS have are able to intercept precipitation between 54 and 94% (Tiwary et al., 2018). This interception causes the VGS to delay the through-flow with at least 30 minutes and thus reducing peak flows, taking stress off the sewer systems in the city.

MUFFLING NOISE

When noise is classified as unwanted or above a certain level deemed as permissible, it becomes noise or noise pollution (Ghazalli et al., 2019). Urban environments are likely to have more noise pollution because there are more noise producing sources such as cars. On top of that, the different vertical structures that are present in the urban environment negatively affect sound dissemination (i.e., sound is being reflected by flat surfaces from buildings). Too much noise exposure by humans can consequently lead to health problems such as hearing loss, cardiac problems, and fatigue (Ghazalli et al., 2019). The authors conclude that the combination of planting media, plants, and moisture that VGS offer, help in screening unwanted noise. VGS absorb, diffract, and reflect sound, thus functioning as sound insulation and mitigating noise on the streets (Medl et al., 2017). As a result, people’s subjective well-being is improved.

SAFEGUARDING BIODIVERSITY

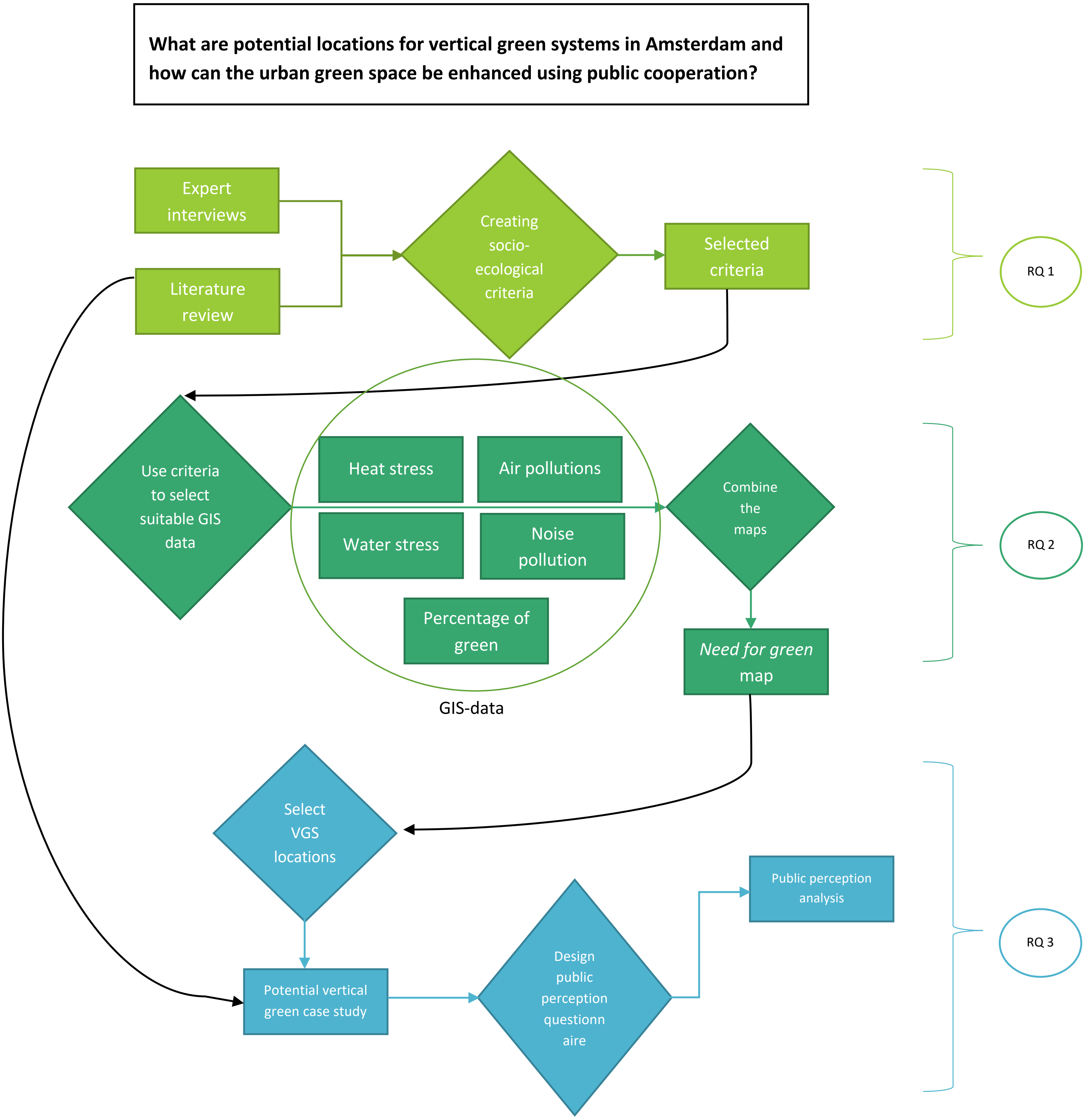
An additional benefit of urban green systems – as they are a part of UGI - is the increase of heterogeneity and urban habitat biodiversity for plants and arthropods (Medl et al., 2017). VGS potentially play a role against habitat fragmentation as they can connect habitats and thus help developing urban ecosystems. Other studies show that VGS can attract birds, butterflies, and bees (Radić et al., 2019).

EFFECTS ON HEALTH AND WELL-BEING

Besides the fact that VGS lead to mitigated UHI, better air quality, and less noise pollution – which all directly impact humans’ quality of life - studies have shown that VGS can positively contribute to humans’ physiological state in another way (Elsadek et al., 2019). Just by looking at a green wall increases mental well-being as opposed to looking at a blank wall which means that VGS improves city dwellers’ quality of life just by being visually present. The mitigative effect that VGS have on UHI in combination with isolation they offer, have a positive effect on the people inside the building as well, as they contribute to a more comfortable living temperature.

3. METHODOLOGY

The methodology diagram (Figure 2) shows the different phases of the research and how the sub research questions will be answered. Three successive steps corresponding with the three research questions can be distinguished. The first research questions will be answered through literature review and expert interviews, the second through GIS analysis and the third through public perception analysis in the locations allocated in the GIS analysis.



3.1 IDENTIFYING SOCIO-ECOLOGICAL CRITERIA

The first research question is *which social-ecological criteria should be used to find locations for potential vertical green?* The socio-ecological criteria are identified based on expert interviews and literature review, the results of these are then used for the GIS case study analysis.

3.1.1 LITERATURE REVIEW

A literature review is carried out in order to assess the socio-ecological criteria which will be used in the GIS-analysis, to help in design the questionnaire for the public perception, and to identify the research gap. A literature review is helpful to get an up-to-date and well-structured overview of the literature in a specific area (Wee & Banister, 2016), such as vertical green systems.

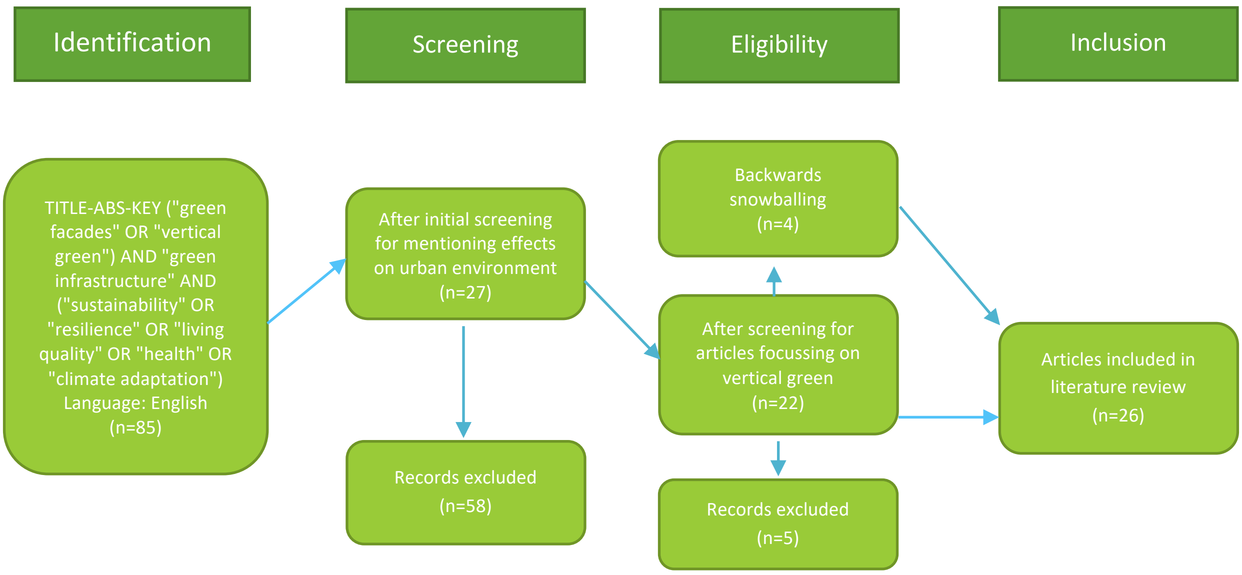


Figure 3: Conceptual literature search and selection process, adapted from Hiestermann (2021)

The literature search and selection to identify the socio-ecological criteria was conducted in four steps, as shown in (Figure 3): identification, screening, eligibility, and inclusion. The aim of the literature review is to list all the known benefits and characteristics of vertical green and based upon that to capture the main criteria to use for the GIS-analysis. Keywords were chosen based on results from the expert interviews; “vertical green”, “green facades”, “green infrastructure”, “sustainability”, “resilience”, “living quality”, “health” and “climate adaptation”. The keywords were combined using the following Boolean operator: TITLE-ABS-KEY ("green facades" OR "vertical green") AND "green infrastructure" AND ("sustainability" OR "resilience" OR "living quality" OR "health" OR "climate adaptation"). As a result, 85 papers were identified using the SCOPUS database. As seen in figure 4, the graph shows an increase in popularity of the research subject over the years, with a spike in the number of papers published in the year 2021 - meaning that more attention is being generated given that more papers will be published in the rest of the year 2022.

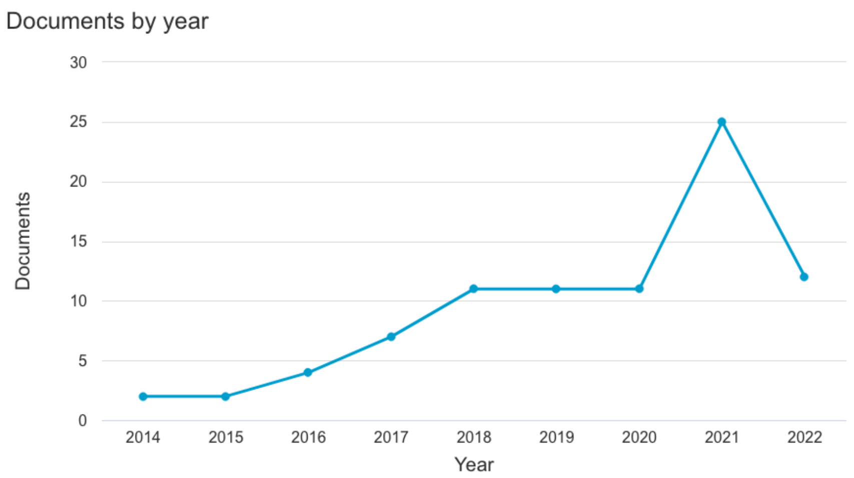


Figure 4: Selected papers per year

The screening and eligibility steps added additional selection criteria, setting boundary conditions to decrease the amount of hits. The title, keywords and abstract of the identified papers are read in order to determine the suitability of the article. In the screening step, papers that do not specifically talk about the effects of vertical green on the urban environment similar to that of Amsterdam (no tropical conditions for example) are filtered out, resulting in a remaining 27 papers. The eligibility step reduces this amount to 22 by excluding papers that tackle green infrastructure as a whole instead of focussing on vertical green. Lastly, unstructured backward snowballing was also applied during this step to include certain articles determined as valuable that were not identified using the selected keywords (Wohlin, 2014). As a result, a total of 26 papers were selected as input for the literature review.

3.1.2 EXPERT INTERVIEWS

Expert interviews are conducted in tandem with the literature review. Four interviews (45 – 60 minutes long) are held with planners and policymakers within the municipality of Amsterdam and other experts in their field in order to gain an understanding of which criteria are viewed as important when designing vertical green. The interview questions that are used as leading questions during the interview can be seen in appendix IV. Besides this, the interviews also served as introductory and explorative phase to get a sense of the structure this research would take. Semi-structured interviews are chosen as interview techniques because they give the interviewer the chance to ask specific questions and leave space to ask follow-up questions based on the answers given by the interviewee (Qu & Dumay, 2011).

Table 1: Interviews taken

Interviewee	Function	Date of interview
Alice Driesen	Policy advisor Rainproof Amsterdam	25-04-2022
Ton Denters	Strategic advisor, urban ecologist	28-04-2022
Geert Timmermans	Urban ecologist, landscape architect	02-05-2022
Nina Sidorov	Project manager sustainable real estate	19-05-2022

Questions were formulated beforehand in order to assess the socio-ecological criteria and to figure out which issues vertical green should address according to the experts. Even though these questions were designed to lead the interview, the idea of the interview was also to investigate the personal views of the interviewees regarding vertical green. This was done by leaving space for the respondents to give their take on the benefits of vertical green. If something interesting was said, follow-up questions were asked in order to get a deeper understanding of these views.

3.2 STUDY AREA

The municipality of Amsterdam is chosen as the study area for further data analysis as it is the capital of the Netherlands and can therefore lead as an example, and because this research is executed in tandem with a graduation internship at the municipality of Amsterdam. Amsterdam is situated in the province of North-Holland and is the largest municipality of the country with a population of more than 900 thousand (CBS, 2022) and has a relatively high population density of 5470 people/km^2 which makes it in need for vertical greening because of the limited amount of space for greening on ground level. The literature review together with the interviews are used for further data analysis.

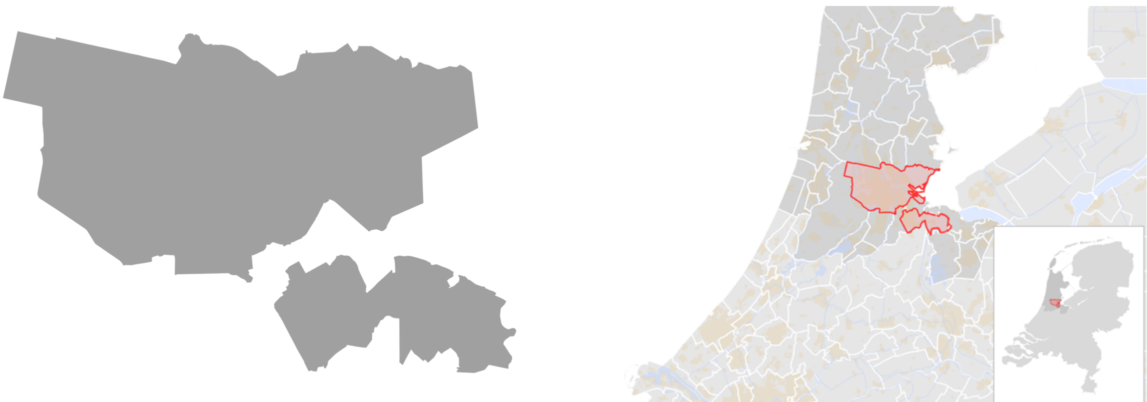


Figure 5: The municipality of Amsterdam and its location in the Netherlands (Weesp included)

3.3 GIS ANALYSIS

The GIS analysis will answer the second research question: *Which locations for potential vertical green should be prioritised based on GIS-analysis?* The analysis will use the socio-ecological criteria of the first research question as input. The software used for this analysis is QGIS as this is a open-source GIS application that works with the M1 MacBook which is used throughout this thesis.

3.3.1 INPUT DATA

The data that is eventually used for the GIS analysis based on the socio-ecological criteria is collected from multiple sources. The different type of data and their sources are shown in (table 2). The criteria are chosen, because the literature review and expert interviews have pointed out that VGS positively affect these and are therefore good indicators for where greening is necessary.

Table 2: Input data used for GIS analysis that represents the necessary spatial units and socio-ecological criteria

Object of interest	**Data**	**Spatial unit**	**Resolution**	**Year**	**Source**
Municipal boundary	Boundary	Polyline	-	2022	Atlas Leefomgeving
Streets	Primary, secondary, tertiary, residential & unclassified streets	Polygon	-	2022	Open Street Map
Water stress	Water depth after extreme rainfall	Raster	2 meters	2018	Klimaateffectatlas
Heat stress	Urban Heat Island	Raster	10 meters	2017	Atlas Leefomgeving
Air pollution	Fine Particulate matter	Raster	25 meters	2019	Atlas Leefomgeving
Noise pollution	Noise	Raster	10 meters	2017	Atlas Leefomgeving
Green	Percentage of green	Raster	10 meters	2018	RIVM

The data that is chosen to represent the multiple input criteria are all based on the literature review and expert interviews. The criteria are discussed in *chapter 4.1 Socio-ecological criteria,* and the input data that represent these criteria follow from the literature review as discussed in *chapter 2.2 Effects of vertical green systems.* The reasoning behind why certain input data is chosen – based on the literature review - to represent water stress, heat stress, air pollution, noise pollution and green are explained below.

For *Water stress*, *water depth after extreme rainfall* is the chosen data, because research has shown that VGS potentially can intercept precipitation and delay the through-flow of water (Tiwary et al., 2018). The reason that cities have difficulty handling water is because of the amount of tiles and concrete that are present and the finite capacity of sewers to drain the water. Urban areas especially struggle when there is a sudden increase of precipitation in a relatively small window of time, because it takes a while for the water to sink into the ground or flow through the sewer system. Therefore, water depth after extreme rainfall is a good indicator for vulnerable areas that can benefit from greening.

In the case of *Heat stress*, it is chosen to use *Urban Heat Island* as input data because this effect shows where urban areas experience heat stress relative to areas that experience less heat stress. Because vertical green systems can help mitigating the heat stress the areas that have a high UHI-effect present, are in need for greening.

For *Air pollution*, *fine particulate matter* (PM) is chosen as data because of all the pollutants commonly found in the air, these have the biggest relative effect on human health (Ghazalli et al., 2019). Since VGS can function as a sink for PM, areas that have high levels of PM, are in need for greening.

The input data chosen for *Noise pollution* is pretty straightforward: all the sources of noise added together. The average level of noise pollution from road traffic, trains, airplanes, industry, and wind turbines are used to create the data. The areas that score high on this criterion are in need for greening as explained in the theoretical framework.

Lastly, for the criterion *Green,* the *Percentage of green* is choses as input data. This data represents the percentage of green in an area of ten meters. When the inverse of the results are calculated – areas with little green should score high instead of low – it shows where there is need of greening.

3.3.2 'NEED FOR VERTICAL GREEN' ANALYSIS

In the pre-processing phase the data described in (table 2) will be processed in order to be suitable for analysis in QGIS. The raster datasets have different resolutions, for them to work together one resolution needs to be chosen. Transforming raster data to a higher resolution gives a false sense of accuracy since no new data is created in the process, transforming to a lower resolution on the other hand will lead to detail getting lost. Because three of the datasets are in a resolution of 10 meters it is chosen to transform the other datasets to this resolution as well. Since no direct conclusions are drawn from the air pollution data on its own, this is permissible. This resolution is detailed enough to visualise the *need for vertical green* as the goal is to distinguish between areas the size of building blocks, not single buildings.

After that the results will be classified in five categories based on their *need for vertical green* ranking. Lastly, the expert interviews and the literature review are used to assess if there is a necessity to distinguish between the weights of the different criteria or not. A spatial overlay is then used to create the final *need for vertical green* map.

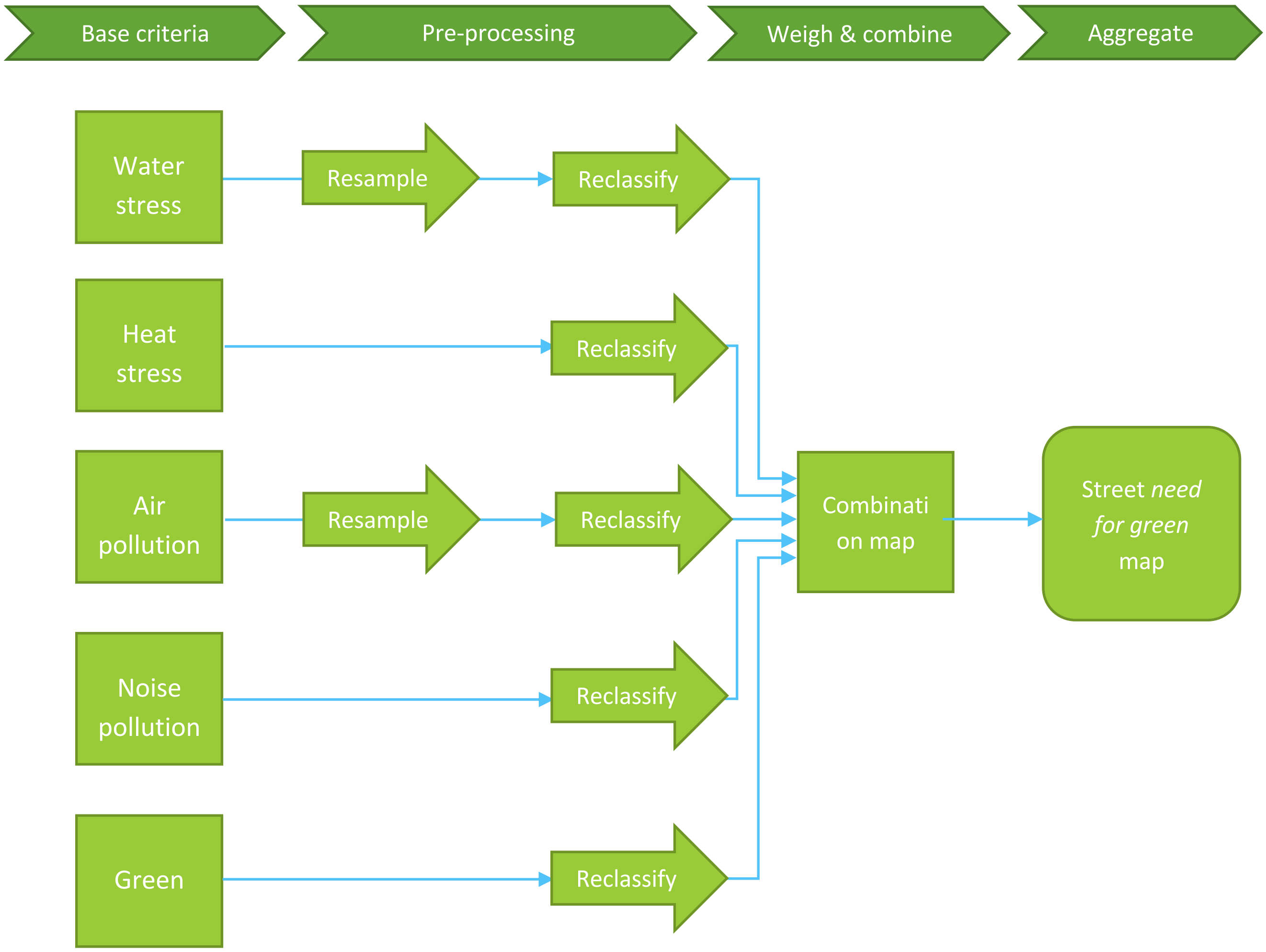


Figure 6: Diagram of the steps taken to analyse suitable locations for vertical green

3.3.3 PREPROCESSING

To clip the data inside the borders of the municipality of Amsterdam polyline data is retrieved from Atlas Leefomgeving. The lines that make up the boundary of the municipality are selected and joined using the *dissolve* function. All the data is then clipped using the *clip raster by mask layer* function.

The data from the streets is taken from Open Street Map (2022). Primary, secondary, tertiary, and residential streets are chosen as locations to study the need for vertical greening (image 1).

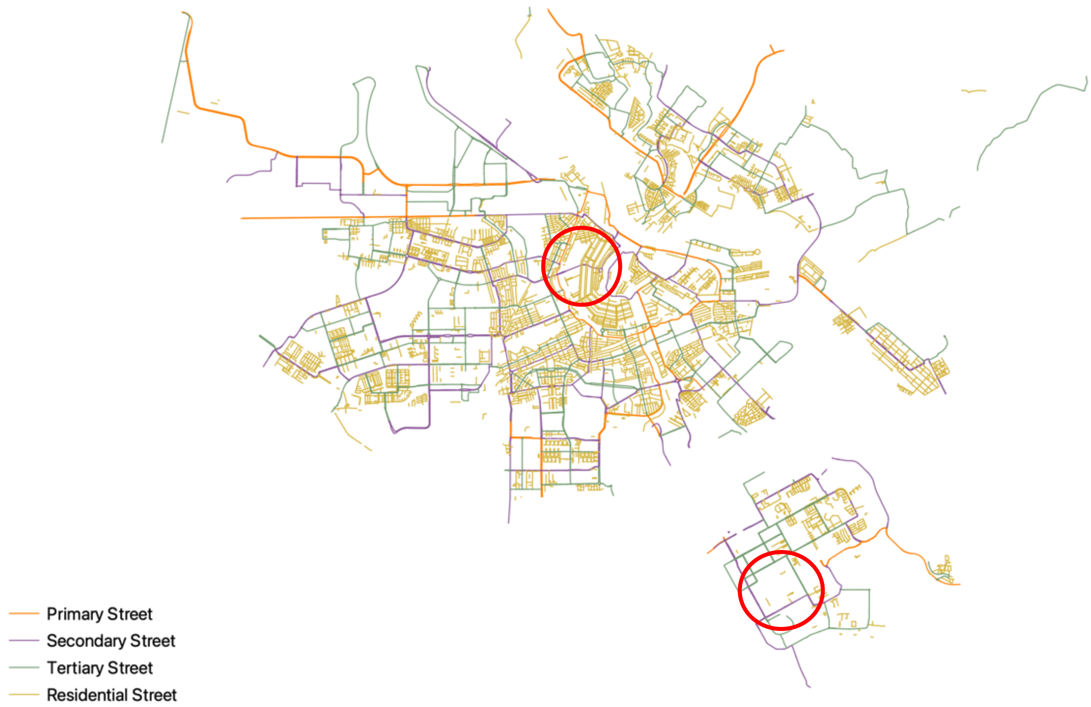


Image 1: Streets, source: Open Street Map (2022)

Looking at certain areas on the map it becomes clear that some streets are missing, for example in Zuidoost and West. This is because there are streets in the database that are not classified. This is fixed by carrying out a new search query in Open Street Map (2022), namely *unclassified*. The downside is that there are some streets added that are of less importance (such as small side roads), but it makes for a much more complete map, which is why the choice is made to include these street segments. These final five street types are then merged to form one layer and are dissolved based on their street name since they consist of smaller parts in the original data.

Since Weesp is included in the municipality of Amsterdam, but these streets are not yet classified as such in OSM, there is one last search query to be done: primary, secondary, tertiary, residential and unclassified streets. Just as the other streets, these are then dissolved based on their street name. The two vector layers are merged to form one data file.

The last pre-processing step for the street data is by removing streets that are outside of the city boundaries by using the *Clip* function in QGIS. The final street map is shown in image 2.

Image 2: Final street map, Source: Open Street Map (2022)

To be able to insert data from the *need for green* map into the street segments during the aggregation phase (see table 2), a buffer zone is created around the street segments using the *buffer* function in QGIS. A buffer is needed because the streets are made up of polylines in the GIS-data, meaning that they have a length and a direction. The actual streets that they represent are of a certain width and therefore the buffer is needed to approximate the area of the streets. A buffer of five meters is chosen.

The next step is to pre-process the data chosen as input to represent the socio-ecological criteria as described before. Some data must be resampled so all of them will be in the same resolution and after that they all need to be reclassified into the five categorical values.

RESAMPLING

Since all the data is in the same grid alignment, no further adjustments have to be made in this area. Because the choice is made to have a resolution of 10 meters, *heat stress*, *noise pollution*, and *green* do not have to be resampled as they already are in this resolution. *Nearest neighbor* is chosen as the resampling method, this function chooses the value of the output raster based on the value of the input raster which is closest to the centre of the output raster cell.

The water stress data has a pixel size of two meters, so it needs to be resampled to 10 meters to be consistent with the rest of the data. The data for air pollution is resampled from 25 meters to a resolution of 10 meters.

RECLASSIFICATION

After the resampling is done, the five datasets are reclassified using *natural breaks* into five value categories that represent the need for vertical greening. Manual reclassification is used if the classes made using natural breaks do not make sense. The categories are: *very low, low*, *moderate*, *high*, and *very high*. The higher the score, the higher the need for vertical greening is according to the spatial analysis. The choice is made for five categories because less would lead to less detail, making it seem as if there is a huge difference between two categories while in reality this would not be the case. On the other hand, if the choice would be made to have 6 or more categories, this would lead to seemingly more detail which would be hard to adequately explain since the difference between categories would be too small. Five categorical values are therefore a good middle ground.

3.3.4 WEIGH AND COMBINE

The expert interviews and the literature review are used to weigh the criteria. The literature review shows that most research concerning VGS has been done in the realm of UHI and thermal effects of VGS. There is however no proof that this quality of VGS has a bigger impact compared to the other effects. The expert interviews show the same result. Therefore, it is chosen to give the criteria equal weight.

The thematic maps are combined using a spatial overlay to create the final map. To do this, the SAGA raster calculator is used as opposed to the standard raster calculator. This plugin enables to use NoData cells, without doing so the final map would have a lot of empty space.

3.3.5 AGGREGATION TO STREET LEVEL

For the final step, the data from the combination map needs to be shown on street level. To do this the buffers created before are used. To do this the QGIS function *zonal statistics* is used to extract the mean of the raster data from the combination map that falls within the buffer zone into the polygon. This will lead to a final map that shows the need for green using the five categorical values per street segment and thus every street segment has a value that tells how high the need for vertical greening is according to the spatial analysis.

3.4 PUBLIC PERCEPTION

The design and verification part of the research will answer the third research question: *What is the public perception of vertical green in the potential locations, based on a case study analysis?* From a political point of view there is a willingness to green the city (G. Timmermans, personal communication, May 2nd, 2022) but the question remains how this will be implemented. Researching the willingness of urban dwellers to participate in this greening is an important step in figuring out how to go forward. The *need for vertical green* analysis from the second research question points out several suitable locations for vertical greening. In these locations the public perception will be tested by designing a questionnaire. This questionnaire (see appendix I) will be distributed among the residents.

For sake of simplicity the questionnaire offers two hypothetical implementations (next to the option of doing nothing), because offering all thirteen VGS solutions identified by Pérez-Urrestarazu et al. (2015) would make it too complicated. The costs of implementation and maintenance are interesting figures to use in the questionnaire to test whether the public is willing to pay more for a living wall – or willing to pay for any VGS at all. These are interesting questions because this way it can be figured out whether there is a need for a subsidy for example, when the public is not willing to pay full price themselves. The difference in plant species that can be used, influences the appearance of the solution and on the benefits it brings, both are presented in the questionnaire.

The different aspects of the green façade and living wall are shown in table 3. The information that is given to the respondents is all sourced via the literature review as explained in sub-chapter *2.1.1 Different types of vertical green systems (VGS).*

The questionnaire estimates the public's perceived value of VGS via their willingness to pay (WTP) and assesses if certain knowledge about VGS – such as the benefits on the environment – influences their decision.

First the respondent gets asked some basic information: age, employment status, yearly income, if they own or rent the property and if they are familiar with the benefits of VGS. This is to see if there will be some correlation between this and their WTP for VGS. After this the respondents get asked what effects of VGS they are familiar with, and after getting information on the benefits they get to rank them in order of what they would like to see improved in their street.

After this, the respondents get new information on the green façade and the living wall after which they get to choose an answer, and then they get new information again, so on and so forth. The information they receive is the following: photos of how the VGS might look, information on the qualities of the green façade versus the living wall, and the implementation costs of the green façade versus the living wall. This sequence of provision of information to the respondents is chosen to see if certain knowledge has an influence on their choice.

After this they get asked if a municipal subsidy would impact their decision and why, if they would like to perform maintenance themselves or leave it in the hands of the municipality or a third party. The final question is what their final choice is, and which aspect weighs the most in the reasoning behind their decision.

Table 3: Overview of the pros and cons of a green façade versus a living wall Pérez-Urrestarazu et al. (2015), Radić et al. (2019)

Green façade		**Living wall**	
Pros	Cons	Pros	Cons
Easy to implement	Takes time to reach full coverage	Reaches full coverage earlier on	More expensive to implement
Requires less maintenance	Performs slightly worse on sustainability aspects	Performs better on sustainability aspects	Requires more maintenance
Costs less to install and maintain		Higher diversity possible in plant types	Costs more to install and maintain
	Lower temperature reduction	Higher temperature reduction	

The information in table 4 is presented to the respondent in the end of the questionnaire to give them a detailed description of the differences between the green façade and the living wall before they get to make their final decision. This way, it can be determined if this increase in detail and information influences their decision.

Table 4: The properties of a green façade (assuming it has reached full coverage) and a living wall. Pérez-Urrestarazu et al. (2015), Radić et al. (2019)

	Green façade	**Living wall**
Implementation cost	40 – 300 €/m^2	300 – 1200 €/m^2
Inside temperature reduction during summer	Up to 2,5 °C	Up to 3,5 °C
Energy reduction during winter	Up to 20%	Up to 25%
Sound insulation (dB)	5 - 8	5 - 12
Water retention	Takes up water from the ground, may prevent flooding	May use water collected from roof, to relieve the sewer capacity
Air Quality (pm10 reduction)	10%	23%
Biodiversity	Maintain biodiversity	Increase biodiversity

The results of the questionnaire will be shown and discussed in *chapter 4.3 public perception,* giving answer to the third and final sub-question, and ultimately answering the main research question.

4. RESULTS

In this chapter the results of the literature review and expert interviews, the spatial analysis, and the public perception are shown as answers to the three sub-research questions.

4.1 SOCIO-ECOLOGICAL CRITERIA

This section answers the first sub-research question of what socio-ecological criteria should be used for the spatial analysis to find locations for VGS. The results are collected through interviews with policy makers and planners, and via the literature review as described in the methodology. In the *theoretical framework* the several proven benefits of VGS have on urban areas are explained. These researched benefits, substantiated by findings from the expert interviews, result in the following themes: *temperature, air, water, noise, biodiversity,* and *liveability.* These themes need to be measured via the spatial analysis in one way or another to assess in which streets the need for VGS is the highest. To do this, every theme is represented by a socio-ecological criteria, backed by data gathered from the expert interviews.

The literature review showed that temperature control is the most researched benefit of VGS. As discussed in the theoretical framework, VGS affect the temperature on the street as well as the temperature inside buildings. According to the expert interviews, vertical green decreases the heat stress felt on street level (A. Driesen, personal communication, April 25th, 2022) and has a temperature regulating ability for buildings as well (G. Timmermans, personal communication, May 2nd, 2022). As can be seen in the theoretical framework, the difference in temperature in the city can be seen via the effect of the Urban Heat Island. Since VGS have a regulating effect on UHI (T. Denters, personal communication, April 28th, 2022) this is a great way to measure temperature.

Air pollution is another area of concern in cities, luckily vertical green – just as more traditional forms of urban green - are excellent at absorbing air pollutants. VGS can absorb aerosols as well as carbon dioxide (G. Timmermans, personal communication, May 2nd, 2022). Because aerosols, also known as particulate matter (PM) are most damaging to human health, these will be used to measure air pollution in the city.

According to one expert interview, water stress is already heavily anchored in policy in Amsterdam because it is easily measurable and therefore also easy to implement in policy. Vertical green can potentially be an important puzzle piece in the mission of making the city rainproof (A. Driesen, personal communication, April 25th, 2022). The way to measure water stress in the city is by looking at the water depth after extreme rainfalls, as these can potentially be very disruptive to the city. The rate that urban areas are able to handle the throughflow of water is very telling for the level of water stress, and thus for the need for VGS.

As discussed in the theoretical framework, vertical green systems can muffle noise. Streets with a high level of noise pollution would therefore be in need for vertical greening. The most straightforward way to measure this need, would be by looking at noise pollution data.

A quality of vertical green much appreciated by urban ecologists is its ability to safeguard and improve biodiversity (T. Denters, personal communication, April 28th, 2022). Green attracts birds and insects. It is however difficult to compare one street to another street in terms of biodiversity (G. Timmermans, personal communication, May 2nd, 2022). What is possible, is to look at the percentage of green, as an indicator of biodiversity because most of the time, more green leads to more biodiversity.

All the expert interviews mentioned the aesthetic qualities of vertical green to cities, it improves the looks of buildings and of the streets (N. Sidorov, personal communication, May 19th, 2022). Besides the benefits green brings in terms of climate adaptation it should not be forgotten how beautiful it is according to G. Timmermans (personal communication, May 2nd, 2022). It shows the city dwellers the flow of seasons and gets them in touch with nature. As the theoretical framework shows, the simple presence of vertical green gives a boost to city dwellers' wellbeing and thus improves the liveability of the city. This liveability as a result of the presence of vertical green is hard to measure, especially with the intention to show the difference of liveability between streets. Because of this, the choice is made to have liveability - just as with biodiversity, be represented by the percentage of green.

4.1.1 SELECTED CRITERIA

The criteria that are chosen to represent the themes that followed from the literature review are shown in table 5. The datasets used to measure these criteria are seen and explained in chapter 3.3.1 *Input data.* As discussed before, every theme is represented by a single criterion, except for biodiversity and liveability which are included in the criterion *percentage of green.*

Table 5: Themes and their correspondent criterion

Theme	**Criteria**
Temperature	Urban Heat Island effect
Air	Particulate matter (PM)
Water	Water depth after extreme rainfall
Noise	Noise pollution
Biodiversity	Percentage of green
Liveability	

4.2 SPATIAL ANALYSIS

This chapter gives an answer to the second sub-research question: *Which locations for potential vertical green should be prioritised based on GIS-analysis?* It shows the results of the spatial analysis described in chapter *3.3 GIS-analysis.* The five maps designed in QGIS are shown and discussed (Image 3 through 7). As explained in the methodology, these thematic maps are subsequently combined to form the combination map (Image 8), and for the last step the data from the combination map is aggregated to street level to form the street *need for green* map (image 9).

4.2.1 THEMATIC MAPS

Five thematic maps have been created in QGIS based on the criteria representing the themes *temperature, air, water, noise,* and *biodiversity & liveability* as explained in chapter *4.1 socio-ecological criteria.* The datasets that are used to create these maps are explained in chapter *3.3.1 input data.* It has to be noted that the upper bound is not included in the categorical classes (0,5 – 0,6 is without 0,6). Also, the value judgement that is given to each class (very low, low, etc.) is a relative value based on the data in Amsterdam. Therefore, a certain criterion being low for example, means that it is low compared to other values in Amsterdam, but not that it is a healthy or wanted value necessarily. To explain this, each thematic map is given context and explanation.at

TEMPERATURE

Image 3 shows the Urban Heat Island (UHI) effect in Amsterdam. What is remarkable is that the effect is mostly located in the city centre, Westpoort and Bijlmer-centrum. This can be explained by the fact that these areas are made up of a lot of stone and concrete, lacking in urban green, and have a high building density - which is exactly how the UHI effect flourishes. The yellow lines seen in the centre of the map are the canals, this can be explained by the cooling effect that water has on the temperature of the air. Other areas of interest are Westelijk Havengebied, and the different parks that light up on the map due to the cooling that effect green has.

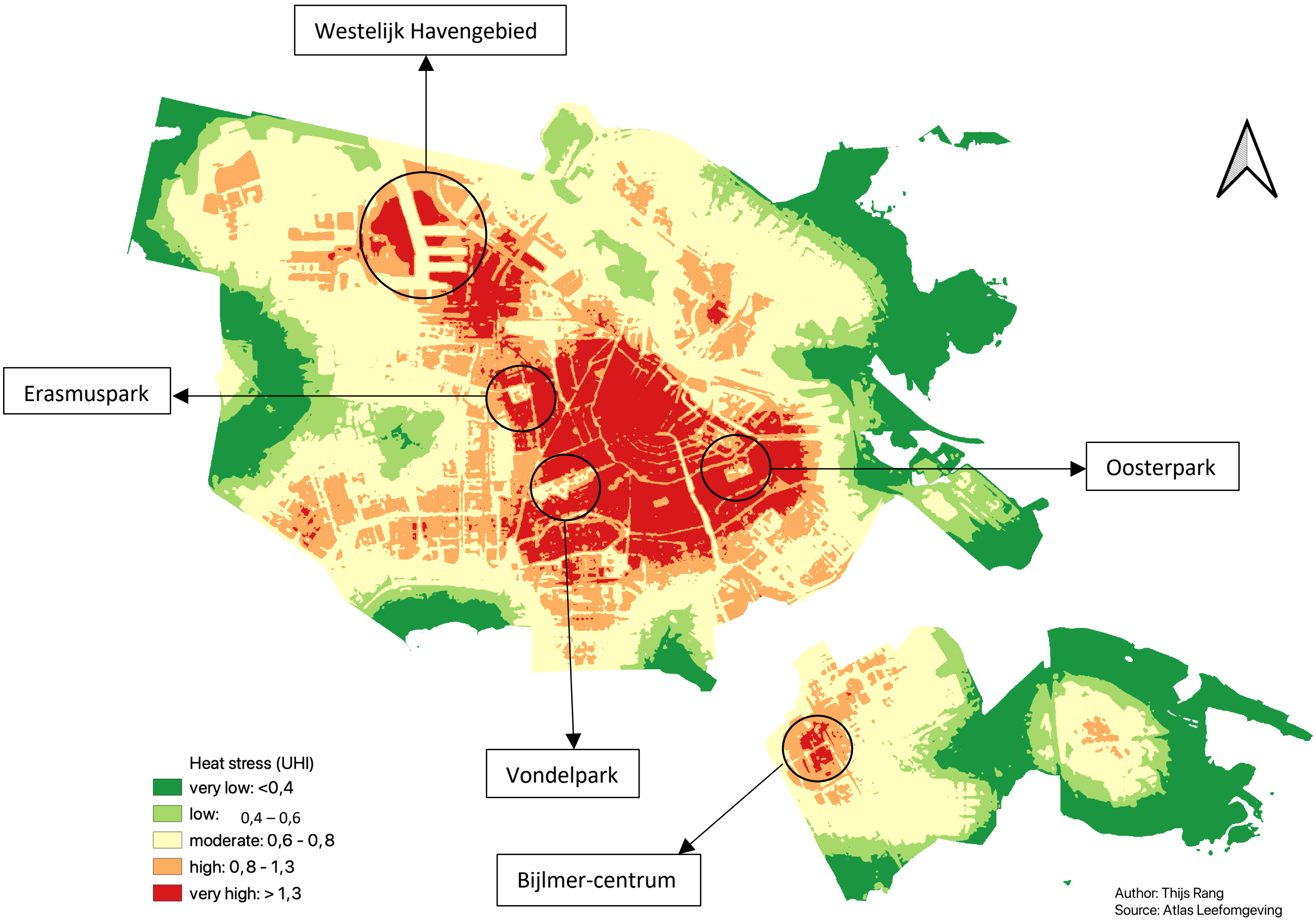


Image 3: Heat stress

The values seen in *image 3* might seem small. A *very high* UHI of more than 1,3 could be seen as negligible. The reason for this is because these are yearly averages, and because during the colder months almost no UHI takes place, the values are quite low. However, on summer days the difference in temperature between the urban areas and rural areas can be quite big, and this explains the different between the classes.

AIR

The air pollution map (Image 4) has less detail compared to the other maps due to the way the pollutants in the air have been measured. Looking at the map there seems to be a fairly rough pattern of squares, but there are some details that are of notice. The first remarkable thing is that most of the air pollution is located in the centre of the city, with an island of noise located in the Westelijk Havengebied. The area that is most problematic however is in and around the Kinkerbuurt (the large red square). There are also some red lines visible, when compared to a street map, it can be seen that these are the Stadhouderskade, Van Woustraat and the Ceintuurbaan, and the Nassaukade, Rozengracht and the Raadhuisstraat - which are all very busy streets with a lot of car traffic. Also noticeable is that the air quality in the rural part of Amsterdam Noord, is relatively good.

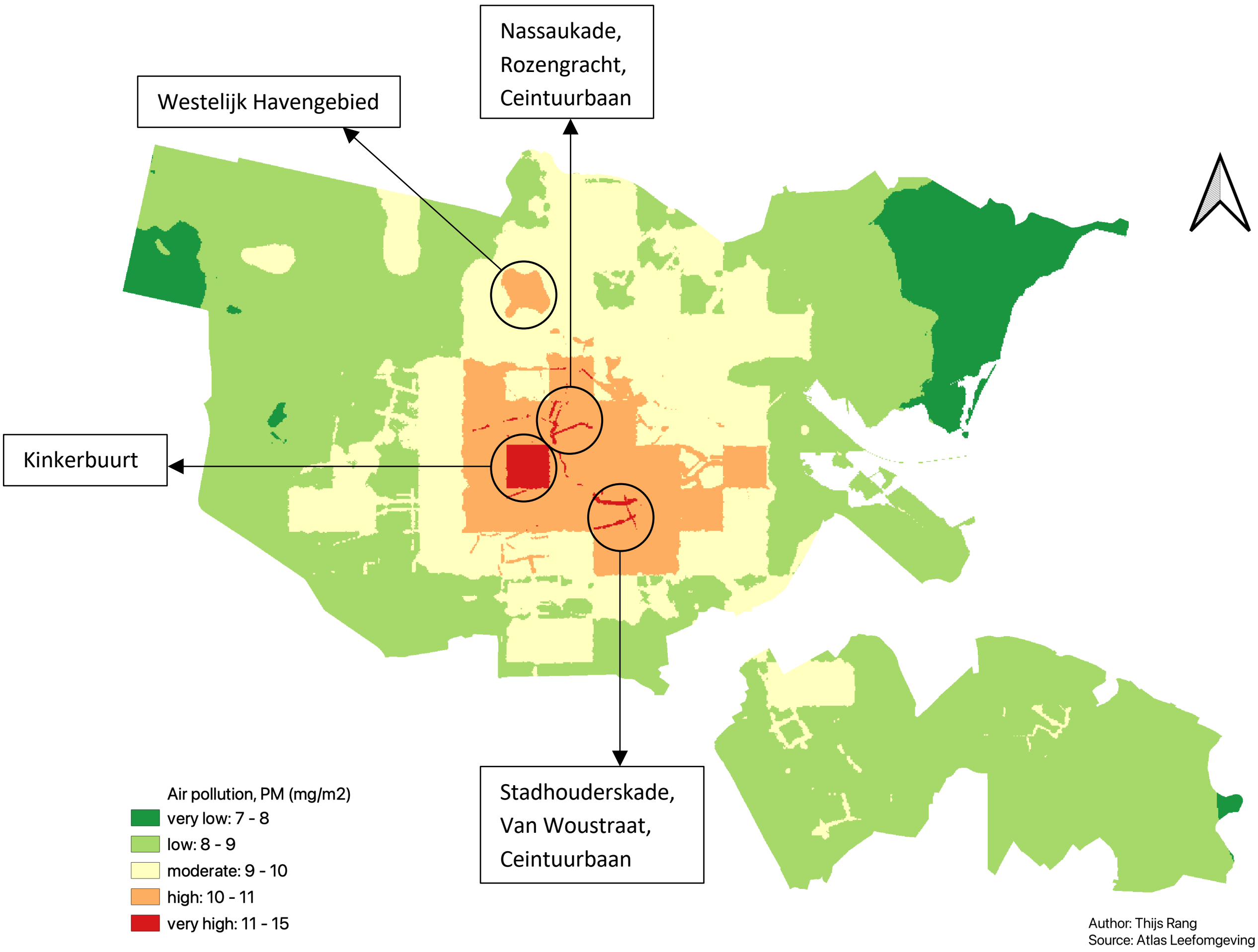


Image 4: Air pollution

The World Health Organization recommended value of PM2,5 / m2 is less than 5, this means that the whole of Amsterdam exceeds this value. Categorical values classified as very low and low for example, are relative to other values in the city but are not at a healthy level.

WATER

The water stress map (image 5) has a pattern of streets. It must be noted that areas with bodies of water such as the canals do not have data and therefore show up as blank on the map. Most of the water stress is located in the city centre, but less so compared to other maps. The water stress is situated on paved streets and since these are all over the city the water stress is more spread out. This can be explained by the fact that paved streets make it harder for the water to descend into the ground. However, there are still some areas of interest. Westelijk Havengebied is a problematic area once again, but Sloterdijk and the Piet Heinkade look to be in trouble as well. Overall, water stress is more of a city-wide problem, especially if you compare it to other urban issues explored in this thesis which are more concentrated in specific areas.

Image 5: Water stress

NOISE

Looking at the noise pollution map (image 6) there is a clear divide visible between problematic and less problematic areas. Rural North is almost completely dark green, meaning that there is relatively little noise pollution. Areas that more noise pollution compared to other areas in Amsterdam are the ring road (A10) – clearly visible as an almost non interrupted circle of red, around the A4, Westelijk Havengebied, Westpoort & Ruigoord, shunting yard west, the train tracks in the Middenmeer, the Nieuwendammerkade and in the centre of Weesp. It can be concluded that most of the noise is coming from the roads – corresponding with what is discussed in the theoretical framework, as cars are a large source of noise pollution. Business parks and train tracks however, produce a lot of noise as well.

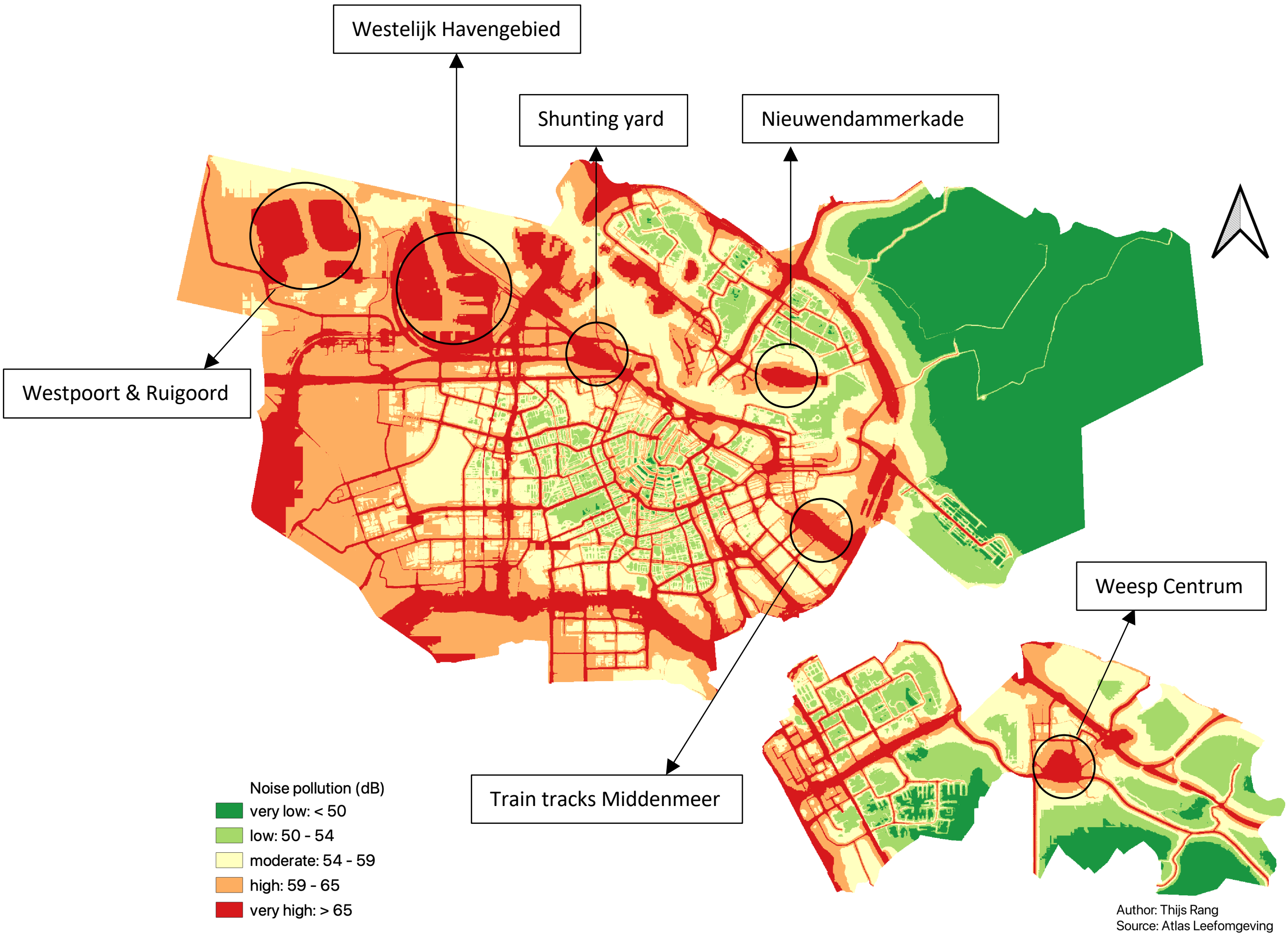


Image 6: Noise pollution

The source of noise pollution map has the data categorised in seven sections, ranging from very bad to very good. These categories are based on a value system from the RIVM (n.d.). As in this research the choice was made for five categorical values, this could not be directly adapted. However, there is overlap in the categories. RIVM states that everything below 50 dB is good or very good (corresponding with *low* and *very low* in *image 6)* and everything above 66 dB is bad (corresponding with *very high)*.

URBAN GREEN

The map with the percentage of green is pretty self-explanatory: per cell the percentage of green in that cell is shown. What can be seen is that usually a cell has either very little green (0 – 20%) or a lot of green (80 – 100%). Because of this, a clear distinction between built and non-built areas are visualised. Because of this, there are not any real surprises to be seen, the areas with little green are roads and buildings, areas with a lot of green are parks, rural areas, and other green areas.

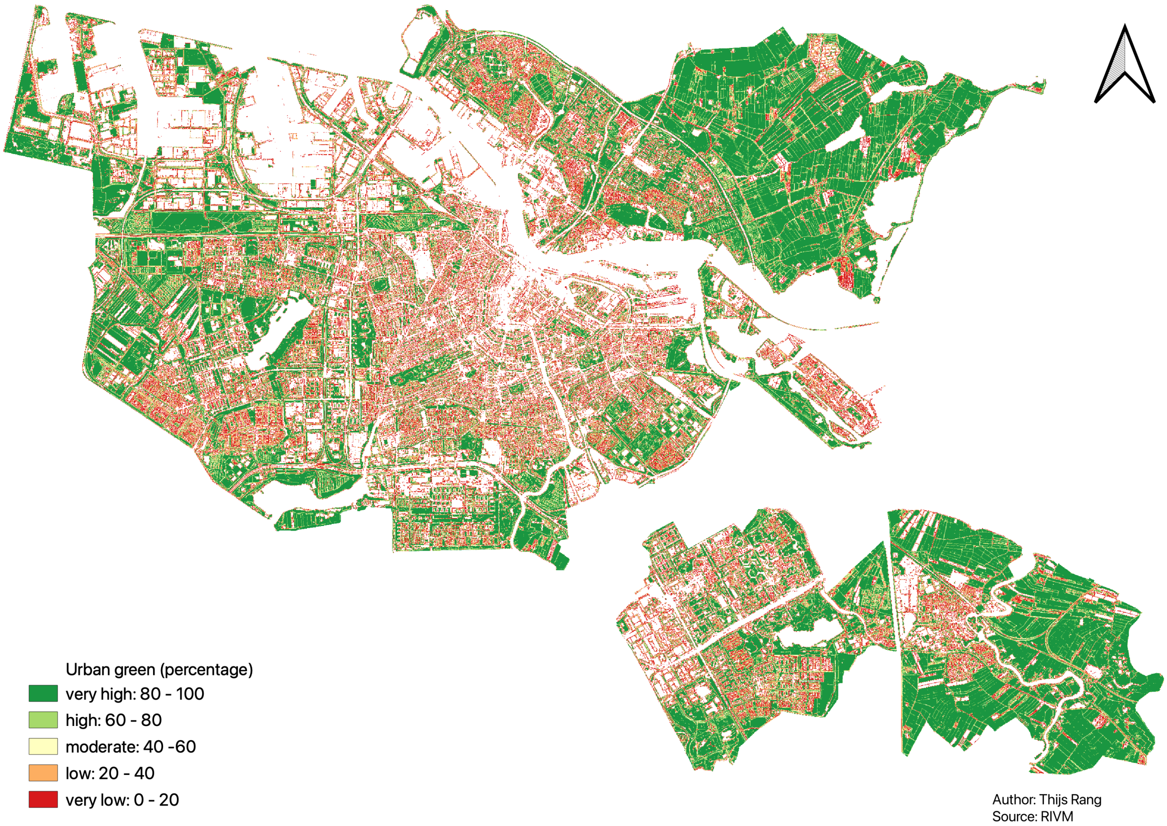


Image 7: Percentage of urban green

4.2.2 NEED FOR VERTICAL GREEN

As explained in the methodology, the map showing the need for vertical green is created by combining the multiple thematic maps. Having examined the thematic maps by themselves, one could already envision what the combination map could like since a lot of the urban issues discussed are focussed around the same areas. The result of the overlay can be seen in image 8.

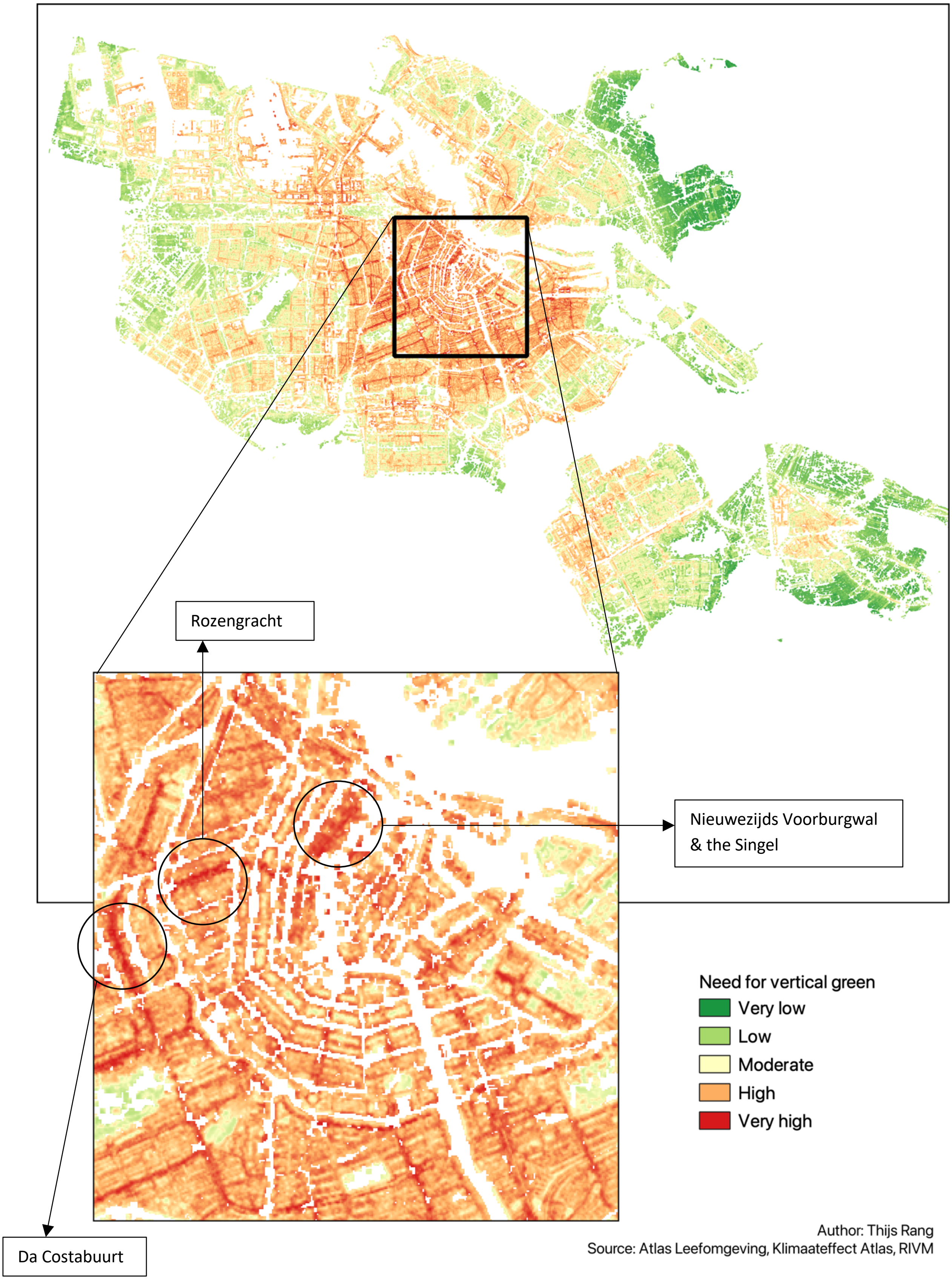


Image 8: The need for vertical green in Amsterdam

As can be seen, the need for vertical greening is mostly located in the centre of Amsterdam. Other areas that are notable are Westelijk Havengebied, Amsterdam Noord (mostly around Van der

Pekbuurt and Floradorp), the western part of Amsterdam Zuidoost, and the centre of Weesp. Zooming in on Amsterdam Centrum, we see notable differences between areas. A lot of problematic areas seem to be located in the western part of Amsterdam Centrum and Oud West. Areas with the darkest red – meaning that the need for vertical greening is even higher compared to their surroundings – are for example, the areas between Nieuwezijds Voorburgwal and the Singel, the Rozengracht, and the Da Costabuurt.

For the last step in the spatial analysis, the data from the combination map is aggregated to street level. In this map it will be seen that the observations done in the combination map are reflected in the ranking of the streets.

4.2.3 NEED FOR VERTICAL GREEN ON STREET LEVEL

As explained in the methodology chapter, the last step of the spatial analysis is the aggregation of the data from the combination map to street level. This is done taking the average of the cells inside the created buffer. The result of this can be seen in image 9. It looks very similar to the combination map except here, the need for vertical green is shown per street. The colourisation is done by using the quantile distribution in QGIS.

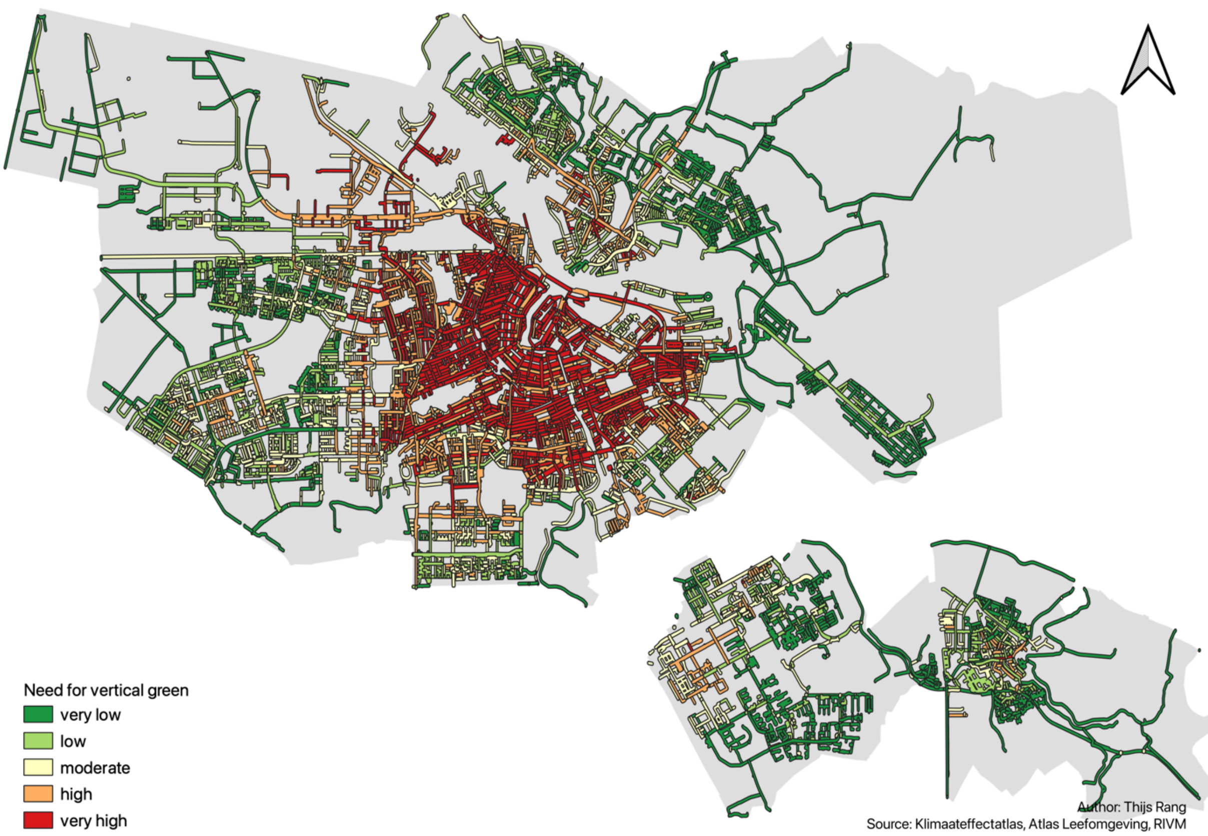


Image 9: Need for vertical green per street

In appendix II the ranking of the streets can be seen from 1 until 180. Out of the 4343 streets, 306 score above 4, meaning they are in very high need for vertical greening. The top 20 can be seen in table 6. The street that scores the highest - the Rozengracht, is a street that was already noticed in the air pollution map (image 4), and the combination map (image 8). The Bilderdijkstraat and the Kwakersplein are located in the Da Costabuurt – which was noted in the combination map (image 8), and the Van Woustraat and the Kinksterstraat – which is located in the Kinkerbuurt, are noted in the air pollution map as well (image 4).

Table 6: Top 20 streets in need for vertical greening

	Street name	**Neighbourhood**	**Score (1 – 5)**
1	Rozengracht	Centrum	4,53
2	Bilderdijkstraat	West	4,52
3	Kwakersplein	West	4,51
4	Beursstraat	Centrum	4,49
5	Witte de Withstraat	West	4,44
6	Kinkerstraat	West	4,40
7	Maritzstraat	Oost	4,39
8	Raadhuisstraat	Centrum	4,37
9	Tweede Rozendwarsstraat	Centrum	4,36
10	Wijdesteeg	Centrum	4,35
11	Frederik Hendrikstraat	West	4,35
12	Vijzelstraat	Centrum	4,35
13	Korte Marnixstraat	Centrum	4,35
14	Turfsteeg	Centrum	4,34
15	Van Woustraat	Zuid	4,34
16	Jan Pieter Heijestraat	West	4,34
17	Overtoom	West	4,33
18	Akoleienstraat	Centrum	4,33
19	Hekelveld	Centrum	4,32
20	Spuistraat	Centrum	4,32

Looking at table 6, the *neighbourhood* column shows that in the top 20, eleven streets are located in Centrum, seven in West, and only one street in Oost and Zuid each. This is in line with the expectations based on the different thematic maps and the combination map. The reason for this can be explained by the fact that much of the urban issues discussed are present in these neighbourhoods, because of a lack of green – as can be seen in the urban green map (image 7).

4.3 PUBLIC PERCEPTION

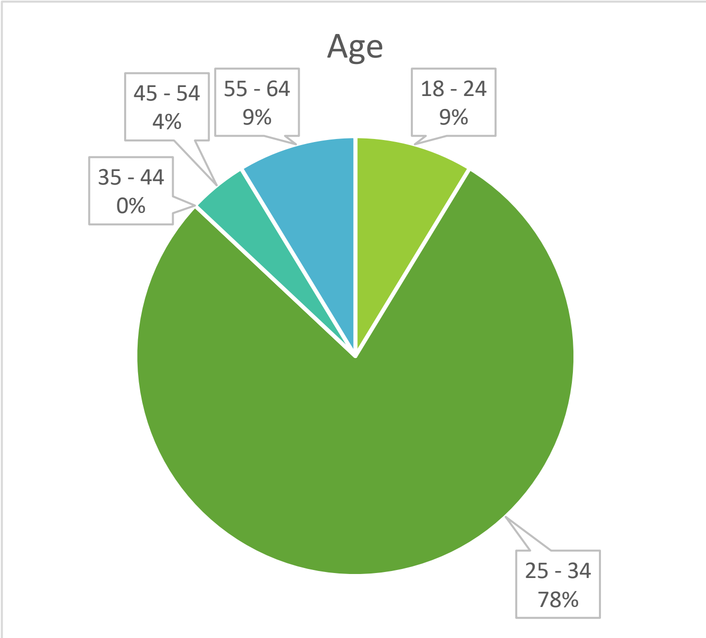
Twenty-three people have been surveyed using the questionnaire as discussed in the methodology chapter *3.4 public perception.* All of these respondents are living in a street designated as *in very high need for vertical greening* in the spatial analysis. This chapter answers the third research sub-question *What is the public perception of vertical green in the potential locations, based on a case study analysis?*

4.3.3 PERSONAL INFORMATION OF THE RESPONDENTS

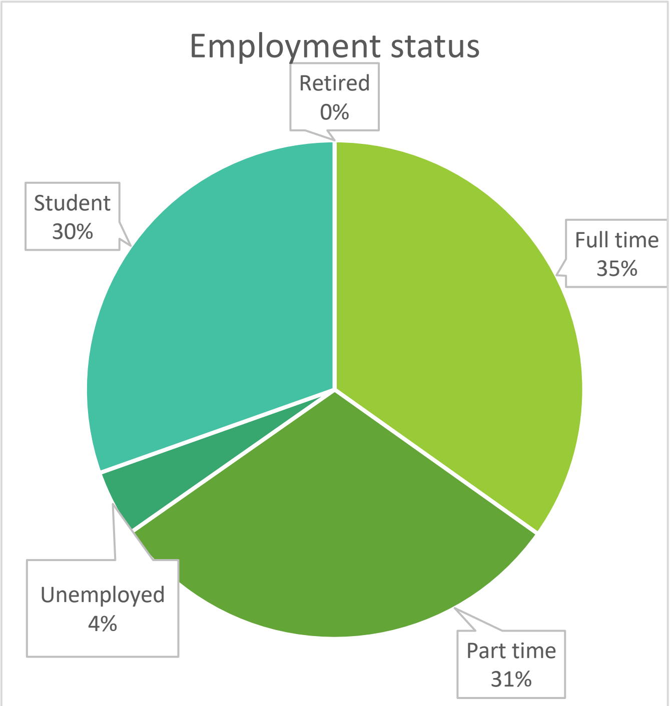
This chapter discusses some personal information about the respondents, whether this is in line with the citywide average or not, and how a possible deviation can be explained.

AGE

The largest age group within the respondents, with almost 80%, is 25 – 34. This is a larger representation than the average, because even though the municipality of Amsterdam (allecijfers, 2022) states the age group of 25 – 45 is the largest with more than 320 thousand, this is less than the share within the respondents. This could be explained by the fact that there are more young people living in Centrum and West (the city districts where most of the problematic streets are located), or because this age group is more likely to respond to questionnaires.



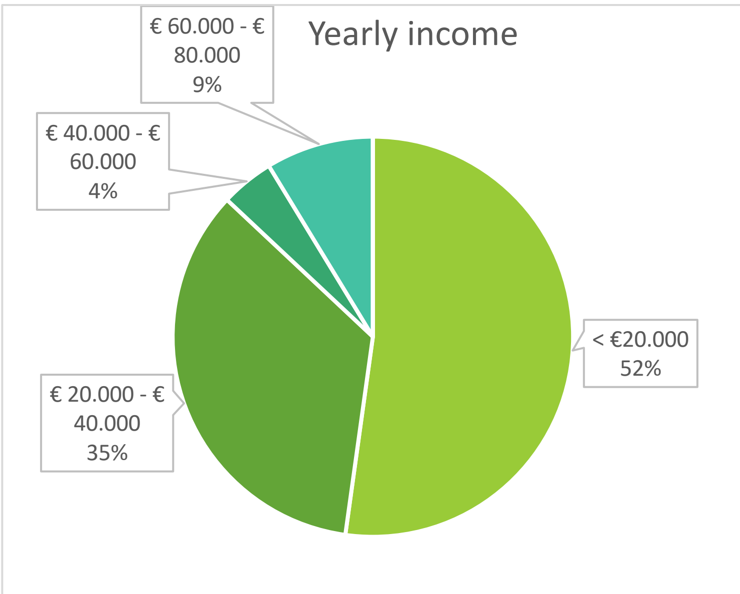
EMPLOYMENT STATUS



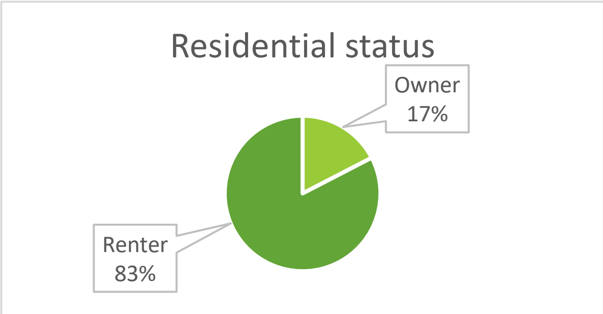
Among the respondents the employment status is mostly divided between *full time, part time,* and *student.* Only one respondent stated that he or she was unemployed, and no one is retired. The percentage of students is higher than the municipal average; 30% versus 7% being the average (Rekenkamer Amsterdam, 2021). The municipal average of unemployment was 5,3% in 2020 (NH Nieuws, 2021), being roughly the same. The higher percentage of students as compared to the municipal average could be explained by the higher number of students living in the problematic streets, or because students are more likely to cooperate with questionnaires.

YEARLY INCOME

Most of the respondents earn less than €20.000. This is to be expected because a large part of the respondents answered they were in the age group 25 – 34, and a large part said they are students. These attributes usually go together with a lower yearly income. Since there is also a relatively large part that answered they earn between €20.000 and €40.000 a year, it would be interesting to see if this difference in income influences their willingness to pay.



RESIDENTIAL STATUS



The municipal average of owners and renters is 29% and 71% respectively (allecijfers, 2022). The average within the respondents skews a little more towards rent. This can be explained the same way as with age, employment status and income; younger people tend to earn less and are more likely to rent.

4.3.4 FAMILIARITY WITH VGS BENEFITS

Before the benefits of VGS were explained to the respondents they were asked about their knowledge of vertical green. This way, it is possible to get a sense of the education of the urban dwellers, and assess if a lack or their level of knowledge might influence their decision making and willingness to pay. Image 10 shows all the answers the respondents gave to the question: *What are the benefits that you know of?*

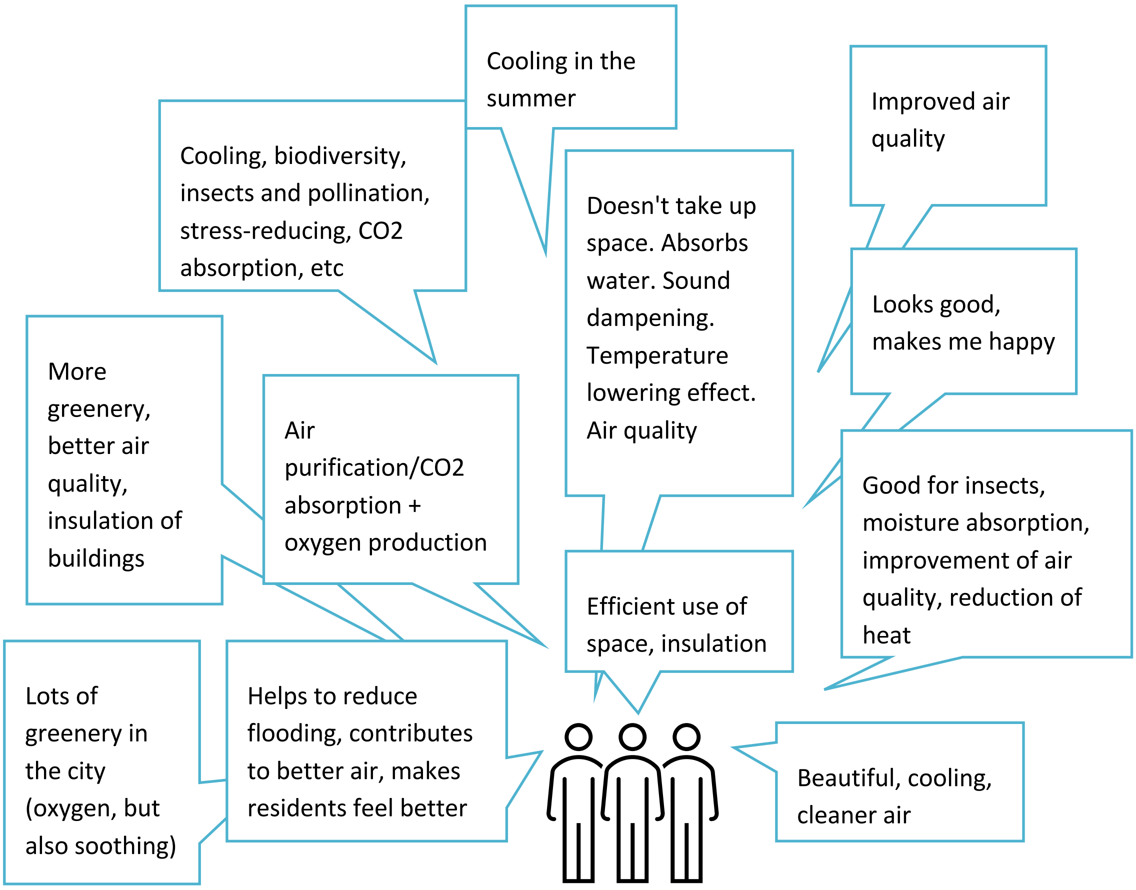


Image 10: The respondents' knowledge on the benefits of VGS

Looking at the answers of the respondents that did give an answer, it seems they are quite knowledgeable already. A lot of their remarks correspond to the findings of the literature review.

However, half of the respondents did not answer this question, meaning they did not have any knowledge about VGS beforehand. It would seem that there lies a big opportunity in educating urban dwellers on the benefits of VGS when the goal is to get them to participate in greening the city.

Table 7: Qualities mentioned by respondents

Quality	Count
Cooling	4
Biodiversity	2
Wellbeing	4
Air quality	8
More greenery	2
Insulation	2
Water retention	3
Space efficient	1
Sound dampening	1
Aesthetics	2

Looking at the number of times certain qualities are mentioned, it is noticeable that *air quality* is mentioned eight times, whereas *cooling* is only mentioned four times – even though most of the research concerning VGS is done in the realm of its effects on the urban heat island effect. Space efficiency, one of the big advantages of VGS versus traditional urban green, is only mentioned once. Also, *insulation* is only mentioned twice, which is interesting because this is one of the effects of VGS that could potentially be very beneficial for personal gain, as it could reduce heating costs.

After the respondents learn more about the benefits of VGS, adding to the knowledge they already had, they get asked which of the urban issues that VGS help with they recognise and would like to see improved in their street. Image 11 shows a selection of the respondents' answers (Appendix III b shows all of them). The urban issue that gets the most votes, being mentioned nine times at the number one spot and twice at the second spot, is heat stress. What is noticeable with this response is that previously only four respondents stated they were familiar with the cooling quality of VGS, meaning educating people on this could prove beneficial. Improving air quality gets relatively many votes as well, receiving four times the number one spot, and six times the number two spot. However, as the previous question seemingly pointed out that people are already quite knowledgeable about the air cleaning qualities of VGS, this is not the area where most can be gained.

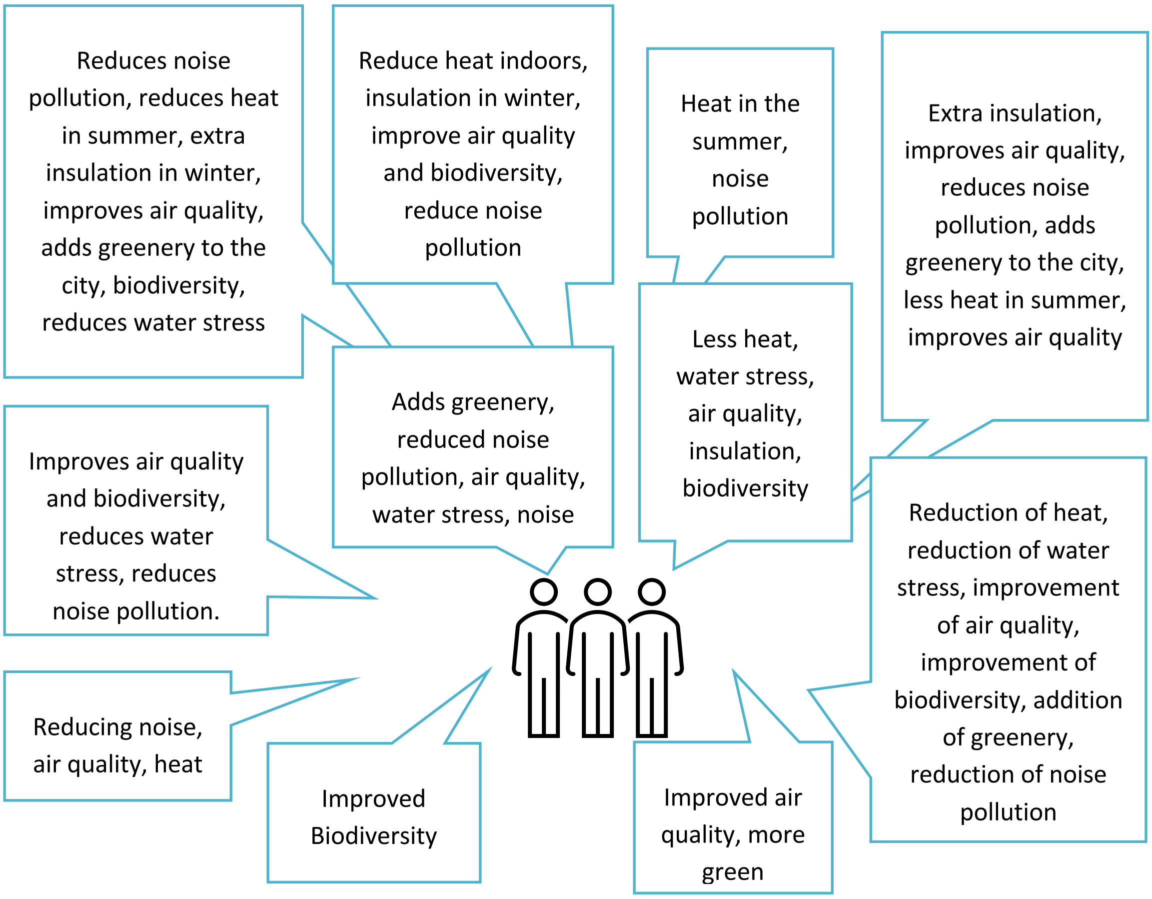


Image 11: Some of the responses on the order people would like to see urban issues get resolved

4.3.5 PREFERENCE IN VGS

As the theoretical framework showed that there are roughly two categories of possible VGS interventions, these have been presented to the respondents to see what their preferences are, which factors determine their choice, and if there are any factors that potentially can shift their choice.

When the respondents get to choose between a green façade, a living wall or no intervention solely based on pictures (see appendix II), there is an almost equal division between the green façade and living wall (48% and 52% respectively). However, after they are shown some basic information about the difference between a green façade and a living wall (see appendix II), a much larger part of the respondents answered they would prefer a living wall (83%). This means that knowing the benefits, is very determinative in their decision making. But, after presenting them the information of the costs – a living wall being much more expensive in its implementation and maintenance, their preference totally shifted. The green façade became the most popular with 83%, while no one wanted the living wall anymore – meaning the high costs proved too much. 17% of the respondents now stated they would choose for the *do nothing* option. This can be explained by the fact that the relatively large part (52% earns less than 20.000) does not have the financial means, or is not willing to invest such a large part of their income to VGS. A subsidy could be beneficial in this situation.

CHANGE IN PREFERENCE

To assess how big of a role money plays in the decision-making process of the respondents they get asked how a municipal subsidy would change their preference. When a subsidy would partly cover the costs, this would incentivise people to opt for the living wall more, 52% now says to opt for a living wall, 44% for a green façade, and 4,3% for no vertical green.

Twenty respondents stated in their written answers (for the full list see appendix III c) that the subsidy does play a role in their decision, for some being it the determining factor in choosing a green façade, or switching from a green façade to a living wall. Again, this can be explained because 52% earns 20.000 or less, thus having limited financial means. Besides the money aspect, multiple respondents commented on the aesthetic value of the green façade versus the living wall, some saying they prefer the former others saying they prefer the latter.

Another interesting finding is that some would prefer the option that requires more maintenance as they like working with plants - while for others, having to work on it themselves would make them choose for the option which requires less handywork. When getting to choose, 56,5% would like to work themselves, and 43,5% would prefer to have the maintenance done by the municipality. Seeing that the majority of the respondents is willing to do the maintenance themselves, and money being an important factor, an option could be to increase the subsidy for those willing to do their own maintenance. This way there is a financial incentive to invest in VGS, and the municipality saves on having to pay labour costs to maintenance workers.

DECISIVE FACTORS

The last question to the respondents was to state the decisive factor that made them choose the way they did. The factor that was mentioned the most, as expected when looking at previous answers, is money – it was mentioned a total of fifteen times. The benefits of the VGS were mentioned six times as a determining factor, aesthetic qualities four times, and time investment twice.

Money being such an important factor could be explained by that a lot of the respondents are in a lower income scale. However, no correlation could be detected between income and VGS choice. A larger pool of respondents would be needed to assess whether or not such a correlation exists.

Image 12 shows some of the answers of the respondents, for the full list see appendix III d.

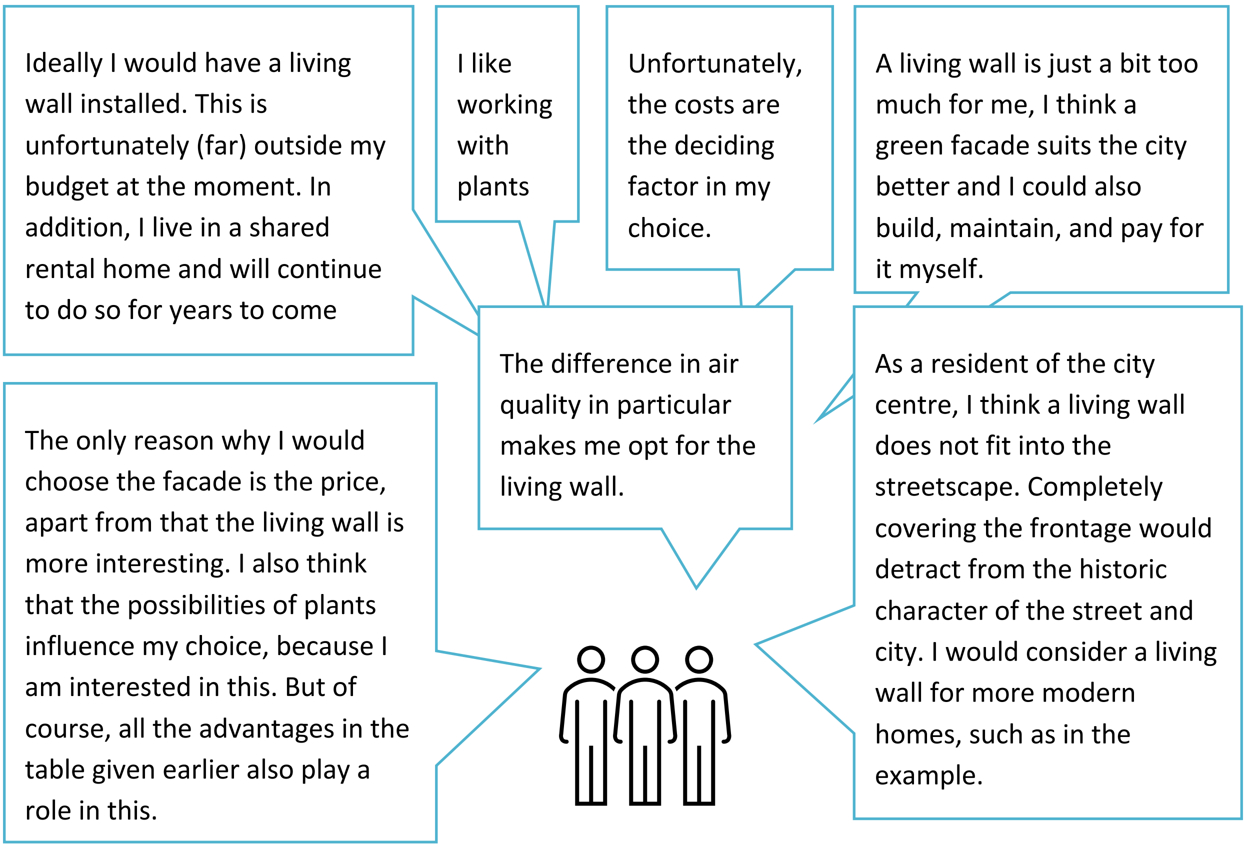


Image 12: A selection of decisive factors for respondents making their choice

5. CONCLUSION

This chapter highlights the findings based on the results in the previous chapter and draws a conclusion to answer the research questions.

Which socio-ecological criteria should be used to find locations for potential vertical green?

The literature review showed, backed up by the expert interviews, that to touch on important urban issues in Amsterdam the following themes should be used: Heat stress, air pollution, water stress, noise pollution, and percentage of green. Biodiversity is found to be an important criterion as well, but as explained in the discussion, this could not directly be used in this research. These criteria are used to answer to next research question.

Which locations for potential vertical green should be prioritised based on GIS-analysis?

The spatial analysis used the criteria from the first research question to create five thematic maps, a combination map and ultimately street map that showed the need for vertical green on street level. The underlaying data of this map presented a ranking of streets. This ranking showed that most of the streets that are in very high need for vertical green are located in Amsterdam Centrum and Amsterdam West. Examples are: Rozengracht, Bilderdijkstraat and Kwakersplein. Therefore, when choosing location for implementing vertical green systems, Centrum and West are the neighbourhoods to look into.

What is the public perception of vertical green in the potential locations, based on a case study analysis?

The result from the questionnaire showed that half of the respondents are knowledgeable about the benefits of VGS. When people learn about the benefits, they are more likely choose for a green façade or living wall as opposed to nothing. However, their financial situation greatly impacts their choice, when they get familiar with the costs, their decision changes towards the financially feasible option, i.e., the green façade, and they mostly defer from the expensive option, i.e., the living wall. Money is the most determining factor in the decision-making process of the respondents. This means that if the municipality would want to implement VGS on a large scale, a subsidy would be very beneficial.

What are potential locations for vertical green systems in Amsterdam and how can the urban green space be enhanced using public cooperation?

Potential locations that are in need for vertical greening are the Rozengracht, the Bilderdijkstraat, Kwakersplein and other streets mentioned in the results chapter, mostly located in Amsterdam Centrum and Amsterdam West. In order to get the public along, they should get properly educated on the personal and societal benefits that VGS can offer to Amsterdam, and a subsidy should be implemented as a financial incentive.

6. DISCUSSION

This chapter discusses the limitations and implications of this research, offers a reflection on the interdisciplinarity, and proposes some possible future research directions.

It was considered to use the liveability index from Leefbaarometer (2020) as input as the literature review shows that vertical green has a positive impact on liveability, therefore areas with low liveability scores would benefit from vertical greening. However, as the index is made up of five segments (the appreciation by residents of the housing stock, physical environment, amenities, social cohesion and nuisance and unsafety) from which physical environment is already reflected in the *green* criteria and because the results are vastly different compared to the other criteria which might distort the results it is chosen to leave this criterion out. However, liveability is an important factor and having it represented by percentage of green could be seen as a bit short sighted.

Biodiversity is another theme or urban issue that is deemed as important according to the literature review and expert interviews. Measuring biodiversity is very hard to do and so the decision was made to have this criterion be represented by green as well. This might however not be a perfect display of biodiversity. When improving biodiversity is an important factor, it should be tried to do more in depth research on flora and fauna in Amsterdam, for example by gathering data about the number of different species present in different locations.

The selection of data source to represent the different themes also impacts the outcome. Here the choice was made to use PM2,5 as a representation of air quality, but PM10 could be used as well for example and would have given different results. In this case PM2,5 was chosen as this is a smaller selection of particles and shows a clearer distinction between areas in Amsterdam, but a case could be made for using PM10 as well, for example that particles between 2,5 and 10 micrometre are detrimental to health as well.

As there was a need to use QGIS which I was unfamiliar with at the start of this research, getting to learn this software was set as a personal learning goal – together with raking up general knowledge of GIS taught during my masters.

Open Street Map uses opensource data for street names and other geographical data. As a result of this many streets are unclassified or even wrongly classified meaning it is quite hard to gather the data needed. A large datafile with over 4000 entries can have potentially some errors crept in. It is therefore advisable to take this into consideration when using this plugin in QGIS.

When implementing VGS the owners of buildings need to extend their cooperation. Because in Amsterdam a lot of people are renting, this means the owner is usually a housing association or a private landlord. Even though it is necessary to assess perception of the renters on the matter of VGS, nothing can be done when the housing associations and landlords do not go along. For future research it could be looked into what is needed for these stakeholders to get to be a part of the vertical greening mission.

Because all aforementioned issues, choices data selection etc. influence the outcome. Caution should be taken into how the results are interpreted. Different choices of data and methodology, interviewed stakeholder groups, will lead to a different result. Also repeating the process in a different city would not necessarily lead to a similar outcome. Therefore, follow-up research, using different techniques and in different situations, could be interesting to see if results are similar or differ completely.

Because the pool of respondents was too small to assess if there was any correlation between income, age, education level, and preference for VGS implementation. For future research it could be interesting to see if there is such a correlation by attracting a larger stakeholder group to the research. This way, potential VGS locations can be investigated on basis of demographic attributes.

This thesis is quite interdisciplinary in the sense that different research methods were used to answer the research question. Literature reviews are common practice in social and natural sciences, GIS analysis is used in disciplinaries such as urban planning and social geography, whereas analysing public perception is usually something done in social sciences such as sociology.

Moreover, the task of trying to solve urban issues that arise and worsen as a result of processes such as climate change and urbanisation could be categorised as a wicked problem, as there are so many factors involved that influence the outcome. This thesis is only one possible way of trying to tackle the issue but there are many possible angles making it inherently interdisciplinary.

BIBLIOGRAPHY

Almeida, C., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Socioeconomic feasibility of green roofs and walls in public buildings: The case study of primary schools in Portugal. *The Engineering Economist*, *66*(1), 27–50.

Bakhshoodeh, R., Ocampo, C., & Oldham, C. (2022). *Exploring the evapotranspirative cooling effect of a green façade*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85126324487&doi=10.1016%2fj.scs.2022.103822&partnerID=40&md5=59b59cce82e8d83e54b46599ca4ddea0

Blanco, I., Convertino, F., Schettini, E., & Vox, G. (2021). *Energy analysis of a green façade in summer: an experimental test in Mediterranean climate conditions*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105867467&doi=10.1016%2fj.enbuild.2021.111076&partnerID=40&md5=32b0d3d61979243658615f4458e37d12

Blanco, I., Schettini, E., & Vox, G. (2019). *Predictive model of surface temperature difference between green façades and uncovered wall in Mediterranean climatic area*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85072566988&doi=10.1016%2fj.applthermaleng.2019.114406&partnerID=40&md5=643c5bbc6e1bc7ff510ba4828e943aab

Collins, R., Schaafsma, M., & Hudson, M. D. (2017). *The value of green walls to urban biodiversity*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85014346312&doi=10.1016%2fj.landusepol.2017.02.025&partnerID=40&md5=73fdebfa25cc00e058e6340d46140f2c

Convertino, F., Vox, G., & Schettini, E. (2021). *Evaluation of the cooling effect provided by a green façade as nature-based system for buildings*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85109353676&doi=10.1016%2fj.buildenv.2021.108099&partnerID=40&md5=14051b1b7bd5523a540cb60fe8740df0

de Vries, E. A., Boone, P., de Rooij, L. L., & Keip, L. (2017). *De groene compacte stad: Een verkennende studie naar de kwantitatieve resultaten van het wegnemen van verharding in stedelijke gebieden.* Wageningen Environmental Research.

Elsadek, M., Liu, B., & Lian, Z. (2019). *Green façades: Their contribution to stress recovery and well-being in high-density cities*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85071948855&doi=10.1016%2fj.ufug.2019.126446&partnerID=40&md5=41ded75797ea37dfd8701e6186ad3349

Fujita, M., & Thisse, J.-F. (1996). Economics of agglomeration. *Journal of the Japanese and International Economies*, *10*(4), 339–378.

Ghazalli, A. J., Brack, C., Bai, X., & Said, I. (2019). *Physical and Non-Physical Benefits of Vertical Greenery Systems: A Review*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074307310&doi=10.1080%2f10630732.2019.1637694&partnerID=40&md5=8e96be7eae16afe77e0e6c5778c612fc

Hiestermann, M. (2021). *Circular Economy Strategies for Photovoltaic Solar Panels: A Literature Review*.

Hunter, A. M., Williams, N. S. G., Rayner, J. P., Aye, L., Hes, D., & Livesley, S. J. (2014). *Quantifying the thermal performance of green façades: A critical review*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84892470777&doi=10.1016%2fj.ecoleng.2013.12.021&partnerID=40&md5=e5b2608849c5895de0a60c0ae141efa2

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

Jeong, N. R., Kim, J.-H., Han, S. W., Kim, J.-C., & Kim, W. Y. (2021). *Assessment of the particulate matter reduction potential of climbing plants on green walls for air quality management*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85115988054&doi=10.11628%2fKSPPE.2021.24.4.377&partnerID=40&md5=ac25429c9cd95658a6026d16d80b1f09

Koch, K., Ysebaert, T., Denys, S., & Samson, R. (2020). *Urban heat stress mitigation potential of green walls: A review*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85091640679&doi=10.1016%2fj.ufug.2020.126843&partnerID=40&md5=bc34e7fd49ba59bb538b44ea2627ea25

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). *World map of the Köppen-Geiger climate classification updated*.

Kozamernik, J., Rakuša, M., & Nikšič, M. (2020). How green facades affect the perception of urban ambiences. *Urbani Izziv*, *31*(2), 88–100.

Magliocco, A., & Perini, K. (2015). The perception of green integrated into architecture: installation of a green facade in Genoa, Italy. *AIMS Environ. Sci*, *2*, 899–909.

Medl, A., Stangl, R., & Florineth, F. (2017). *Vertical greening systems – A review on recent technologies and research advancement*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85032898639&doi=10.1016%2fj.buildenv.2017.08.054&partnerID=40&md5=a1004fedd8dfa8a1de21f18a13d397ff

Ottelé, M., van Bohemen, H. D., & Fraaij, A. L. A. (2010). Quantifying the deposition of particulate matter on climber vegetation on living walls. *Ecological Engineering*, *36*(2), 154–162.

Pacini, A., Edelmann, H. G., Großschedl, J., & Schlüter, K. (2022). A Literature Review on Facade Greening: How Research Findings May Be Used to Promote Sustainability and Climate Literacy in School. *Sustainability (Switzerland)*, *14*(8). https://doi.org/10.3390/su14084596

Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). *Vertical Greening Systems and Sustainable Cities*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84958053808&doi=10.1080%2f10630732.2015.1073900&partnerID=40&md5=9bc4a6d4c8e8e14578adecb26517b7e0

Qu, S. Q., & Dumay, J. (2011). The qualitative research interview. *Qualitative Research in Accounting & Management*.

Radić, M., Dodig, M. B., & Auer, T. (2019). *Green facades and living walls-A review establishing the classification of construction types and mapping the benefits*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85071985406&doi=10.3390%2fsu11174579&partnerID=40&md5=44929961e261e4a7ced2d8e20e4aa72f

Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehrotra, S. (2011). *Climate change and cities: First assessment report of the urban climate change research network*. Cambridge University Press.

Sendra-Arranz, R., Oquendo, V., Olivieri, L., Olivieri, F., Bedoya, C., & Gutiérrez, A. (2020). *Monitorization and statistical analysis of south and west green walls in a retrofitted building in Madrid*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85089518208&doi=10.1016%2fj.buildenv.2020.107049&partnerID=40&md5=4f5ebdb354f8f1892de56311ff79d23c

Solera Jimenez, M. (2018). *Green walls: a sustainable approach to climate change, a case study of London*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85035325571&doi=10.1080%2f00038628.2017.1405789&partnerID=40&md5=bcf4018daa91f59482151a99bfbee4c1

Susca, T., Zanghirella, F., Colasuonno, L., & del Fatto, V. (2022). *Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85125267962&doi=10.1016%2fj.rser.2022.112100&partnerID=40&md5=98a1c234b5a83bde6d15c0c06dde42c5

Tiwary, A., Godsmark, K., & Smethurst, J. (2018). *Field evaluation of precipitation interception potential of green façades*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85050613556&doi=10.1016%2fj.ecoleng.2018.07.026&partnerID=40&md5=7203f30f5b6babd4e52fa51f3eafa6d9

United Nations. (2019). *World Urbanization Prospects The 2018 Revision*.

Wee, B. van, & Banister, D. (2016). How to write a literature review paper? *Transport Reviews*, *36*(2), 278–288.

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering*, 1–10.

APPENDIX I

1	Rozengracht	4,5298722736040755
2	Bilderdijkstraat	4,518333838954908
3	Kwakersplein	4,5106764066787
4	Beursstraat	4,487059036890666
5	Witte de Withstraat	4,43532757339726
6	Majoor Bosshardtbrug	4,421152220831977
7	Kinkerstraat	4,399163510892298
8	Maritzstraat	4,392258365948995
9	Pesthuysbrug	4,382630745569865
10	Raadhuisstraat	4,368564160097213
11	Tweede Rozendwarsstraat	4,363793347563062
12	Wijdesteeg	4,350318827629089
13	Wiegbrug	4,349404454231262
14	Frederik Hendrikstraat	4,348791579750572
15	Vijzelstraat	4,347228005989311
16	Korte Marnixstraat	4,345858540799883
17	Turfsteeg	4,343643003580522
18	Van Woustraat	4,342727275506636
19	Jan Pieter Heijestraat	4,339430184634226
20	Overtoom	4,333698619962932
21	Akoleienstraat	4,327580398442794
22	Hekelveld	4,319706374320431
23	Spuistraat	4,318456021310849
24	Tweede Bloemdwarsstraat	4,317633697861119
25	Quellijnbrug	4,312732219696045
26	Concertgebouwplein	4,311017262197174
27	Hans van Mierlo brug	4,310976415872574
28	Oosterspoorplein	4,309390317434552
29	Oranjebrug	4,3084734916687015
30	Van Baerlestraat	4,306042196499955
31	Schiemanstraat	4,301155953407288
32	Beukenplein	4,300090094407399
33	Steenhouwerijbrug	4,2988384791782925
34	Eerste Rozendwarsstraat	4,2970011322586625
35	Scheldestraat	4,2894680697537035
36	Eerste Bloemdwarsstraat	4,286716960725331
37	Vijzelgracht	4,279835573697494
38	Kattengat	4,278890427201986
39	Nicolaas Berchemstraat	4,277584791183472
40	Nieuwezijds Voorburgwal	4,277064892206845
41	Staalkade	4,276005506515503
42	Eerste Ringdijkstraat	4,2753566553195315
43	Tweede Hugo de Grootstraat	4,274461184314747
44	Agatha Dekenstraat	4,273254610243297
45	Spiegelgracht	4,273056265470144
46	Wijttenbachstraat	4,2706827577554956
47	Ouwe Fransenbrug	4,270673534144526
48	Hugo de Grootplein	4,265440787038496
49	Beukenweg	4,261980850072134
50	Simon Carmiggeltstraat	4,252189808421665
51	Eerste Constantijn Huygensstraat	4,248041850856588
52	Leliesluis	4,245748233795166
53	Damrak	4,2415233842024564
54	Spiegelbrug	4,239639737389305
55	Waterlooplein	4,2316524687267485
56	Mercatorplein	4,225962114597553
57	Niek Engelschmanbrug	4,224616133648416
58	Veemarkt	4,2236108117289355
59	Rijnstraat	4,22108072595498
60	Eerste Anjeliersdwarsstraat	4,219286298751831
61	De Lairessestraat	4,214161514158708
62	Lucas Jansz Sinckbrug	4,2131242752075195
63	Soendastraat	4,211461371845669
64	Padangstraat	4,211155492918832
65	President Steynstraat	4,209131209404914
66	Dapperstraat	4,206948470186304
67	Oetgenssluis	4,2066850662231445
68	Armbrug	4,206462556665594
69	Kees Fensbrug	4,205408181462969
70	Palamedesstraat	4,204699898665806
71	Keerwal	4,197368791917476
72	De Clercqstraat	4,197333461083706
73	Billitonstraat	4,196308667199654
74	Grote Brouwerssluis	4,1962686538696286
75	Kneppelhoutstraat	4,194395529257284
76	Jeroenensteeg	4,192517379919688
77	Binnen Oranjestraat	4,190900752038667
78	Ter Haarstraat	4,189408134406721
79	Bellamystraat	4,189244222124561
80	Van Hallbrug	4,185750293731689
81	Eerste Goudsbloemdwarsstraat	4,185225645701091
82	Noorderkerkstraat	4,185182815248316
83	Weesperstraat	4,184429569083427
84	Molukkenstraat	4,1842458715309965
85	Borneostraat	4,1827388872343185
86	Koggestraat	4,182040559328519
87	Martelaarsgracht	4,1799560546875
88	Zeilstraat	4,179659104641573
89	Tweede Anjeliersdwarsstraat	4,176882276729661
90	Schollenbrugpad	4,175079723457237

91	Planciusstraat	4,17484957521612
92	Roelof Hartplein	4,174741110380958
93	Djambistraat	4,172417433707269
94	Korte Niezel	4,168079684178035
95	Lampongstraat	4,1654257053552675
96	Stadionplein	4,162570509270056
97	Nieuwe Willemsstraat	4,1616711020469666
98	Westerstraat	4,160935652546766
99	Van Limburg Stirumplein	4,158164343591464
100	Ceintuurbaan	4,156702154972514
101	Tweede Nassaustraat	4,155806567610764
102	Beursplein	4,154318216235139
103	Gasthuismolensteeg	4,152746415719753
104	Javaplein	4,15027543173896
105	Haarlemmerplein	4,147646147795398
106	Stephensonstraat	4,145694594283204
107	Madurastraat	4,14375367978724
108	Tweede Egelantiersdwarsstraat	4,143734769387678
109	Ernst Cahn en Alfred Kohnbrug	4,142855644226074
110	Valkenburgerstraat	4,142819688474532
111	Rhijnspoorplein	4,140211201425808
112	Lodewijk Boisotstraat	4,139125982109381
113	Tweede Laurierdwarsstraat	4,138774665919217
114	Willemsstraat	4,13876269882471
115	Lootsstraat	4,137766280839609
116	Vinkenstraat	4,137004179165776
117	Blauwbrug	4,13542426150778
118	Schakelstraat	4,135294063956336
119	Violettenstraat	4,134767880806556
120	Stromarkt	4,134740957399694
121	Eerste Boomdwarsstraat	4,134206325288803
122	Nieuwe-Werckslbrug	4,131165981292725
123	Hilletjes Brug	4,131065047704256
124	Armeensebrug	4,130021784986768
125	Fokke Simonszstraat	4,12808060977194
126	Ruyschstraat	4,127783149859984
127	Buiten Vissersstraat	4,123516448338827
128	Van Limburg Stirumstraat	4,1232960981291695
129	Roelof Hartstraat	4,1230478127797445
130	Marnixplein	4,122382730519006
131	Westeinde	4,119332873131618
132	Eerste Leliedwarsstraat	4,119291081720469
133	Nicolaas Beetsstraat	4,11702030724015
134	Kleine Houtstraat	4,11311517379902
135	Wormerveerstraat	4,11228225425798
136	Zeilbrug	4,1117472648620605
137	Hoofdweg	4,108739063353606
138	Lombokstraat	4,107107670534225
139	Korte Korsjespoortsteeg	4,10709707736969
140	Wibautstraat	4,106970973382486
141	Tweede Tuindwarsstraat	4,102732730466266
142	Meester Visserplein	4,102680323780447
143	Nieuwebrugsteeg	4,102615384494557
144	Nieuwe Wagenstraat	4,101425204958234
145	Buiten Wieringerstraat	4,1013203172972705
146	Tilanusstraat	4,100308212459597
147	Paulusbroedersluis	4,100089258617825
148	Pieter Baststraat	4,098347957645144
149	Buiten Dommersstraat	4,095157736226132
150	Bellamyplein	4,092199548668818
151	Pieter Langendijkstraat	4,091812955705743
152	Willemsparkweg	4,091427577393396
153	Elisabeth Wolffstraat	4,090726702513095
154	Ferdinand Bolstraat	4,089531979175529
155	Tichelstraat	4,0890868610805935
156	Schalk Burgerstraat	4,089011902809143
157	Tweede Constantijn Huygensst...	4,087339411283795
158	Swammerdamstraat	4,087281875312328
159	Foeliestraat	4,0866977118310475
160	Haarlemmer Houttuinen	4,085500737677113
161	Westermarkt	4,084212366990217
162	Plantage Middenlaan	4,084016726198924
163	Van Slingelandtstraat	4,083522201986874
164	Tempelhofstraat	4,0833508674009344
165	President Steynplantsoen	4,08285869564022
166	Tweede Atjehstraat	4,082191918790341
167	Eerste Lindendwarsstraat	4,082018975700651
168	Prinsenstraat	4,081351053519327
169	Danie Theronstraat	4,081225742528468
170	Scheldeplein	4,081116838888689
171	Oudezijds Achterburgwal	4,080934503311927
172	Tweede Helmersstraat	4,080748045403803
173	Paulus Potterstraat	4,080164697918579
174	Javastraat	4,078424269446467
175	Slatuinenweg	4,077131570012946
176	Hofmeyrstraat	4,077058530890423
177	Hazenstraat	4,076684969442862
178	Eerste Looiersdwarsstraat	4,075765505171659
179	Paleisstraat	4,075588496526082
180	Moreelsestraat	4,075522930014367

APPENDIX II

Public Perception Questionnaire

Hi, thank you so much for taking a couple of minutes of your time to fill in this questionnaire. It helps me a lot! You will stay completely anonymous, and the data will only be used as input for my thesis.

1) What is your age?
    - 18 - 24
    - 25 – 34
    - 35 – 44
    - 45 – 54
    - 55 – 64
    - 65 +
2) What is your employment status?
    - Full time employed
    - Part time employed
    - Unemployed
    - Student
    - Retired
3) What is your annual household income?
    - < €20.000
    - €20.000 - €40.000
    - €40.000 - €60.000
    - €60.000 - €80.000
    - €80.000 - €100.000
    - > €100.000
4) Are you an owner or a renter?
    - Owner
    - Renter
5) Which street do you live on?
    ………………………………………….
6) Are you familiar with the benefits of (vertical) green in the urban context?
    - Yes
    - No
    a. If so, could you name some benefits that you know of?
    ……………………………………………………………………………………………………

Vertical green helps with the reduction of heat in the summer (inside and outside), adds extra isolation in the winter, noise pollution, water stress, improves air quality and biodiversity and adds green to the city.

7) Which of the aforementioned points do you encounter / would you like to see improved in your street? Name them from most to least important.
    ……

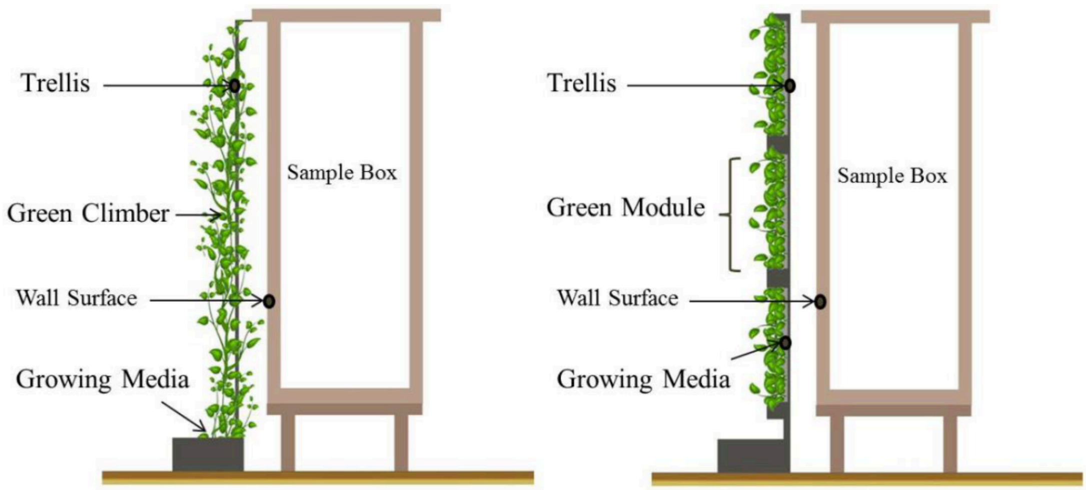
The choice can be made between two implementations: the green façade and the living wall. These options are chosen because they have a contrasting aesthetic difference that may influence preference. The pictures below show what they could look like.

a. Green façade

b. Living wall

Option c. No green wall

The green façade is a more traditional way of vertical greening as it involves herbaceous climbing plants rooted in the ground or in planter boxes on the wall or trellis (see picture below, on the left). Green facades are restricted in the variety of species they can support. Living walls are a more intricate solution. They consist of a modular system of planter boxes, often with an integrated water delivery and drainage. This leads to more uniform and faster coverage.



8) Based on these pictures, which implementation would you prefer?
   - Option a

- Option b
- None

9) The second option allows for higher coverage and allows for multiple plant species. Because of this it has a larger positive impact on the benefits mentioned before. Knowing this, which option would you prefer?
    - Option a
    - Option b
    - None
10) Both interventions cost money to implement and maintain, but option b more than option a. If these costs would be added to your service costs 40 – 75 €/m^2 for option a, 500 – 1000 €/m^2 for option b). If you had to pay for this yourself, which option would you then choose?
    - Option a
    - Option b
    - None
11) If you were given the option to implement and maintain a green façade yourself, with a subsidy from the municipality thus costing you no money, would you then be interested?
    - Yes, because ……………………………………………………………………………………………………
    - No, because ……………………………………………………………………………………………………

If we put all the pros and cons of the green façade and living wall together it will look like this:

Green façade		**Living wall**	
Pros	Cons	Pros	Cons
Easy to implement	Takes time to reach full coverage	Reaches full coverage earlier on	More expensive to implement
Requires less maintenance	Performs slightly worse on sustainability aspects	Performs better on sustainability aspects	Requires more maintenance
Costs less to install and maintain		Higher diversity possible in plant types	Costs more to install and maintain
	Lower temperature	Higher temperature reduction (3.5)	

The table below shows the properties of a green façade (assuming it has reached full coverage) and a living wall.

	Green façade	**Living wall**
Implementation cost	40 – 300 €/m^2	530 – 1200 €/m^2
Inside temperature reduction during summer	Up to 2,5 °C	Up to 3,5 °C
Energy reduction during winter	Up to 20%	Up to 25%
Sound insulation (dB)	5 - 8	5 - 12
Water retention	Takes up water from the ground, may prevent flooding	May use water collected from roof, to relieve the sewer capacity
Air Quality (pm10 reduction)	10%	23%
Biodiversity	Maintain biodiversity	Increase biodiversity

12) Having all this information, which option would be your final choice: green facade, living wall, or none? Self-maintained or by the municipality? Could you elaborate?

………

13) Which one of the properties weighs the most in influencing your decision?

APPENDIX III

a. If so, can you name some of the benefits you are aware of?

improved air quality

Cooling in the summer

More greenery, better air quality, building insulation

Looks good, makes me happy

Doesn't take up space. Absorbs water. Sound dampening. Temperature lowering effect. Air quality

Air purification/CO2 absorption + oxygen production

Helps to reduce flooding, contributes to better air, makes residents feel better

Cooling, biodiversity, insects and spraying, stress-reducing, CO2 absorption, etc

Good for insects, moisture absorption, improvement of air quality, reduction of heat

Efficient use of space, insulation

beautiful, cooling, cleaner air

Lots of greenery in the city (oxygen, but also soothing)

b. Which of the previously mentioned points do you encounter / would you like to see improved in your street? List them from most to least important.

reduce heat indoors, insulation in winter, improve air quality and biodiversity, reduce noise pollution

I didn't come across anything, but in order of importance: Extra insulation, improves air quality, reduces noise pollution, adds greenery to the city, less heat in summer, improves air quality

Summer heat - biodiversity - sound insulation

improves air quality and biodiversity, reduces water stress, reduces noise pollution.

Extra insulation, air quality, biodiversity, water stress, noise pollution

Heat in the summer, noise nuisance

Reducing noise pollution, improving air quality, biodiversity, extra insulation

Improved air quality, more green

Reducing heat in summer, reducing noise pollution, improving air quality

Air quality, biodiversity, adds greenery, noise pollution, water stress, insulation

1: improve air quality and biodiversity, 2: reduce heat in summer, 3: add greenery to the city, 4: add extra insulation in winter, 5: reduce water stress, 6: reduce noise pollution.

Reduces noise pollution, reduces heat in summer, extra insulation in winter, improves air quality, adds greenery to the city, biodiversity, reduces water stress

Reduce summer heat, improve air quality, reduce water stress

Reduced summer heat, air quality, biodiversity,

Reducing noise / air quality / heat

Improved Biodiversity

Adding greenery, water stress, air/bio, insulation

less heat, water stress, air quality, insulation, biodiversity, ,

Reduction of heat, reduction of water stress, improvement of air quality, improvement of biodiversity, addition of greenery, reduction of noise pollution

Adds greenery, reduced noise pollution, air quality, water stress, noise pollution, reduce heat, insulation

reduce heat in summer, but extra insulation in winter, improve air quality and biodiversity, reduce water stress, adding greenery to the city

extra insulation, reduces noise pollution, reduces water stress, improves air quality, adds greenery

1.improvement of air quality/biodiversity,2.reduces water stress,3. Reduces noise pollution.

c. If you were given the opportunity to realize and maintain a green facade yourself, with a subsidy from the municipality that costs you no money, would you be interested? Can you explain why?

Yes, because it looks good, has several positive influences on the quality of life and does not cost any money due to the subsidy.

Yes, I like it and it offers benefits

If the subsidy makes it possible to build a living wall, that is my preference

Yes. I think it is important to add greenery in the city. If I can do this myself, I'd be happy to. I could say a lot about it on a creative level and I think it inspires others to get started themselves.

Yes, definitely, I'm a big supporter of the idea with a subsidy

Yes, because you receive a subsidy.

Yes, because it looks nice

Yes, it costs no money, but you do have all the advantages!

Yes. The advantages mentioned speak for themselves. In addition, I think it is beautiful and fits well into the streetscape.

Yes, of course. Besides that I like it, there are other advantages that might save me more money. Think isolation.

Certainly, it looks good and it has many advantages (compared to no green facade/living wall). Preference would of course be for living wall, but the costs are high here. A green facade is a good middle ground.

I would certainly be interested. The advantages are convincing and green facades brighten up the cityscape. It should be noted that many people rent their house through a housing association and therefore have no control over their facade. It therefore seems important to me that corporations/private landlords are actively approached should such a subsidy ever come about.

Yes, partly social interest. Only the investment is such that I don't know if I can and want to pay for it myself

However, in the green facade because of the aforementioned advantages. I personally find the living wall quite ugly, so I would skip this one.

Together with others (time and money issue)

Yes, in the end it has more benefits for the resident and for the municipality. Improved insulation and improved biodiversity

Certainly, a garden would be too much work for me, but maintaining a green facade seems to do me good and gives the house something extra in addition to all the benefits of air quality, water stress, etc.

300-1200 euros is a large investment with which you can realize floor insulation, for example.

Yes absolutely, besides looking nice, I think the mentioned benefits are very important.

Yes, already interested in paying yourself, so if it is reimbursed it only makes it more interesting think so, but it depends on how much work it takes to maintain the wall

yes, because I think it is very important but now I have no money

Yes! Because I receive a subsidy and still have the advantages of a green facade.

d. Can you explain your final choice? Which characteristics determine your final choice?

Assuming that the (entire) €300-1200/m² for the living wall is not covered by the municipality, I would choose the green facade. For me, the benefits outweigh the time investment of maintaining.

Living wall is more beautiful and offers more advantages. If this is heavily subsidized it is better in all respects

Price

I think 500-100 Euro per m2 is a lot. It promotes the aspects mentioned in a positive way, but I think a green facade is also a good alternative. So my choice ultimately goes out to the green facade, which is cheaper and yet makes a difference in the green area. Maintaining your green facade yourself is easy to do and a reason to work with your hands.

Living wall is better in everything but more expensive

Price and not super big differences regarding my objections

Living wall looks nicer

Better benefits

As a resident of the city centre, I think a living wall does not fit into the streetscape. Completely covering the frontage would detract from the historic character of the street and city. I would consider a living wall for more modern homes, such as in the example.

Living wall is a lot more expensive but also more useful and cheaper in the long run. I also like it better.

Unfortunately, the costs are the deciding factor in my choice.

Ideally I would have a living wall installed. This is unfortunately (far) outside my budget at the moment. In addition, I live in a shared rental home and will continue to do so for years to come;

Investing in a rental property is unfortunately (largely) wasted money, so this is not a realistic option. However, if it is possible to install (and maintain) a green facade free of charge, I would certainly make use of this.

Financial property

I think the green facade is the optimal choice. It brings with it the aforementioned advantages of an increased amount of greenery, is relatively cheap and is also an aesthetic addition. In my opinion, the Living Wall reduces the appearance of the city and is also significantly more expensive, while the extra benefits compared to the green facade seem not too bad.

Money and time (time: only if you can do it together with others)

The difference in air quality in particular makes me opt for the living wall.

A living wall is just a bit too much for me, I think a green facade suits the city better and I could also build, maintain and pay for it myself.

Good insulation value, energy saving and water management capacity for a reasonable price.

In the end, I wouldn't choose green, because I'm a poor student. Suppose I did have a fixed income, I would opt for the living wall, because in that case the benefits outweigh the price

The only reason why I would choose the facade is the price, apart from that the living wall is more interesting. I also think that the possibilities of plants influence my choice, because I am interested in this. But of course all the advantages in the table given earlier also play a role in this.

I am for it in every way. enough benefits in my opinion

I like working with plants

I opt for the living wall, the table convinces me of its advantages and above all of its own contribution to actively improving the environment.

APPENDIX IV

Interview questions

Introduction

Can you tell something about yourself?

Current situation

What is the role of green in current municipal plans?

To what extent is *insert interviewees discipline* considered in these plans?

Criteria

Do you think vertical green can play a role in improving *insert interviewees discipline*?

Is it possible to measure *interviewees discipline* on a locale scale, let's say street level?

Which criteria do you think should have priority in indicating hot spot areas?

Does *insert interviewees discipline* weigh enough in this decision process?

What in your opinion is the largest contribution of vertical green to the city?

(Social) acceptance

What are the obstacles that prevent large-scale greening in building plans and existing buildings?

Do you think vertical greening should be implemented top down or that we should leave this partly in the hands of the residents?

How do we make residents aware of the benefits of greening?