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Nature in Neighborhoods:
Assessing the Influence of Nature Based Solutions on Gentrification in Leeuwarden

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Abstract

Cities are at the forefront of adaptation and mitigation related to climate change. With over half of the world's population living in cities, it is important that these spaces remain livable, safe and equitable. One increasingly applied method of mitigating the effects of climate change is the use of Nature Based Solution (NBS). The city of Leeuwarden is one of the many cities that is using NBS as part of their adaptation strategy and in helping them reach their climate goals. One of these solutions is urban greening. The implementation of more vegetation in the urban environment can help reduce heat stress and flood risk, as well as enhance air quality and promote biodiversity. However, the subsequent increase in attractiveness and desirability of these newly greened spaces means urban greening could potentially be a driver of gentrification, raising questions surrounding environmental justice. This study looks into the key indicators of gentrification in Leeuwarden on two spatial levels and subsequently attempts to link this gentrification to urban greening. Gentrification mechanics can be identified in 2 of Leeuwarden's districts and in 2 of its neighborhoods. These areas are found to not have experienced an increase in vegetation or urban greening, and therefore greening can not be linked to gentrification in the city of Leeuwarden.

Key Words: Nature based Solutions; Urban Greening: Green Gentrification; Urban Adaptation Governance; Social Justice

Note from the author: In this study the Dutch area classification *wijk* is referred to as district and the area classification *buurt* is referred to as neighborhood.

TABLE OF CONTENTS

1. Introduction

Urban areas are at the forefront of the fight against climate change, one of the biggest problems in today's society. The impact of climate change is widespread and affects many aspects of life, including ecosystems, human health, and the global economy (Lwasa, et al., 2022). Addressing climate change in urban areas is not only important for achieving global climate targets, but also for improving urban livability and increasing urban resilience. Increasing attention is given to the potential of Nature Based Solutions (NBS) in mitigation and adaptation when it comes to climate change (Cucca, et al., 2023; Lwasa, et al., 2022).

Around the world, cities are tapping into the positive externalities provided by green-blue infrastructure projects by using Nature Based Solutions (NBS) to improve livability, increase resilience and negate the negative effects of climate change (Cucca, et al., 2023). This includes, for example, the creation of parks, the installment of green roofs and walls, or the construction of blue infrastructure and other urban greening projects. These measures can be a cost-effective way to reduce greenhouse gas emissions, enhance carbon sequestration, and improve the resilience of ecosystems and communities to climate impacts (Toxopeus, et al., 2020). The positive effects of these NBS, such as decreased pluvial flood risk due to the absorbing capacity of green and blue infrastructure, are widely studied (Kabisch, et al., 2016). However, they can also yield negative side-effects (Cucca, et al., 2023).

One potential negative side effect of using NBS in the urban environment is gentrification, defined as a change in the local demographic composition led on by modification of a district's built, retail or social environment (Maia, et al., 2020). Districts are at risk of gentrification when the social or physical environment are improved and these areas subsequently become more attractive because of these improvements (Cole, et al., 2021). This, in turn, can lead to the displacement of vulnerable groups such as socioeconomically disadvantaged residents due to increasing property values and eventual diminishing sense of community (Gould & Lewis, 2017). The establishment of parks and other green infrastructure not only makes the local environment physically more attractive, it also increase the livability of the area by, for example, mitigating the urban heat island effect and decreasing flood risk. When this leads to an increase in property values and real-estate prices, the phenomenon is described as green gentrification (Cole, et al., 2021). This raises questions of social justice and spatial inequality.

The city of Leeuwarden has been selected as a case study for this study, since it is located in one of the least wealthy provinces in the Netherlands. Having 48% of its residents classified as *low income* (Huisink, 2023), makes almost half of its households vulnerable to the threat of (green) gentrification. The study focuses on the 14 districts in Leeuwarden that were established before the beginning of the

study period, 2016-2021. These 14 districts can be subdivided into 73 neighborhoods, used to examine gentrification on different spatial levels. Districts and neighborhoods are subsequently assessed based on average household income (AHI), and those ranking below the citywide AHI at the beginning of the study period are deemed eligible to gentrify and are included in this study. Leeuwarden has been actively working with NBS for a number of years to improve livability and reach its climate goals (Gemeente Leeuwarden, 2020). If the overall hypothesis that Leeuwarden is subject to green gentrification can be supported based on empirical evidence, policy makers may take this into account and steps could be taken to ensure that vulnerable groups are protected. Accordingly, this study expands the existing body of literature on green gentrification and could serve as a starting point for other Dutch cities in revisiting their Municipal environmental and housing policies.

2. Study objectives and research questions

Cities that increase their percentage, size and quality of green amenities are at risk of green gentrification due to the increased attractiveness that is brought about by these interventions (Anguelovski, et al., 2018). Should this hypothesis hold true for the city of Leeuwarden, social justice questions may arise (Cucca, et al., 2023). This may also affect adaptation governance in Leeuwarden. If necessary, policy recommendations will be proposed based on the research findings to promote social justice.

Objective of the study: The objective of the study is to identify possible drivers of green gentrification in the city of Leeuwarden and to test the hypothesis that the city is experiencing green gentrification.

Main research question: **What are the effects of Nature based Solutions in the form of urban greening on the housing market in the city of Leeuwarden?**

Sub-question 1: What are the key indicators used to measure gentrification?

To be able to uncover whether or not the city of Leeuwarden is experiencing green gentrification as a result of the implementation of NBS, it is important to understand what drives green gentrification and how this can be researched. The first sub question will help form the basis of our understanding of gentrification and what can trigger it, and will enable us to identify the elements driving gentrification in Leeuwarden.

Sub-question 2: What evidence of gentrification can be identified in the city of Leeuwarden?

This question explores whether sound evidence of gentrification can be found in the city of Leeuwarden. Selected districts and neighborhoods of Leeuwarden will be analyzed based on the indicators of gentrification which are the result of sub-question 1. The districts where evidence of

gentrification is found will be cross referenced with the data on district greening (see sub-question 3). If green gentrification can indeed be identified, it is important that actions are taken to support vulnerable groups that may suffer from the negative consequences of implementing NBS in the city.

Sub-question 3: What projects relating to urban greening have been implemented in the gentrified regions of Leeuwarden?

To find out whether the city of Leeuwarden is at risk of green gentrification it is necessary to identify where greening has happened in the city. This can then be cross referenced with data on districts experiencing gentrification. If districts that show signs of gentrification have undergone significant urban greening, it may be possible to find a causal connection between the two processes.

3. Theoretical framework

3.1 The role of governance

Globally, urban areas are particularly vulnerable to the negative effects of climate change (Dabrowski, 2017; Kabisch, et al., 2016). Cities, responsible for about 70% of global greenhouse gas emissions (OECD, 2020), are at the forefront of climate adaptation efforts (Dabrowski, 2017). With 56% of people currently living in cities, and a projected rise to 70% by 2050 (World Bank, 2022), it is important that cities take decisive action to adapt to climate impacts, build resilience, and work on mitigation. High population density in cities can make urban environments high-risk areas for experiencing the negative impacts of climate change, often affecting large parts of the population. Therefore, due to the severe impact of climate change on cities and their residents, urban areas are important places to adapt to, and mitigate, the effects of climate change.

Climate change adaptation, broadly speaking, involves preparing for and adjusting to both the negative impacts and potential opportunities presented by climate change (The World Bank Group, 2011). Governance plays a crucial role in how this process unfolds, as government policies and programs shape a region's response to climate change and determine, for example, urban adaptation strategies. Urban governance can be defined as "the process of steering and coordinating urban policies between the public, private, and voluntary sectors to achieve collectively-agreed goals (Kokx & Spit, 2012). Cooperation between different sectors and levels of government and governance, including the private sector and civil society, is deemed necessary for effective urban adaptation as climate change influences a broad variety of policy fields or sectors, and does not have a *one size fits all* solution (Kokx & Spit, 2012).

3.2 Dutch adaptation governance

Adaptation has become an integral part of Dutch urban governance. Traditionally, adaptation efforts were spread out across various sectors, causing policy fragmentation and issues surrounding efficiency, which is why contemporary governance has embedded adaptation in spatial policy (Kokx

& Spit, 2012). The national government has drawn up two programs, the national Delta Programme and the National Climate Adaptation Strategy (NAS) regarding climate adaptation. National policy programs are adopted by provincial and municipal governments and implemented in their respective regions, tailored to the specific locale. The Delta programme's measures are rooted in the idea that local and regional governments, together with private sector actors and citizens, must be informed, inspired, and incentivized through communicative governance (Ministerie van Economische Zaken en Klimaat, 2020). This approach seeks to enhance "climate awareness" and facilitate the implementation of adaptation measures (Molenveld, et al., 2020). The City Deal for climate adaptation, for example, was introduced in 2016 (Kennisportaal Klimaatadaptatie, sd). This collaboration between multiple levels of government, citizens and private parties was meant to catalyze adaptation within Dutch cities, sparked innovative ideas and resulted in a report that serves as a guide for making cities more climate adaptive (City Deal Klimaatadaptatie, 2021; Klarus, 2021). One of the key adaptation objectives outlined in this report is the creation of climate-proof and nature-inclusive development (Kennisportaal Klimaatadaptatie, sd).

3.3 Nature-Based Solutions

The implementation of NBS is a popular adaptation strategy due to its many positive effects on the local environment (Cucca, et al., 2023; Kabisch, et al., 2016). For example, NBS and other urban greening projects provide crucial ecosystems services (ES). According to Almenar, et al. (2021) these ecosystems services can be subdivided into three categories: regulation, cultural and provision. Regulation is the key ES which is most often linked to adaptation and mitigation. This involves the regulation of functions such as temperature, humidity, water flow, the hydrological cycle, filtration or storage, and biodiversity. In the cultural category, NBS can lead to an enhanced perception of safety, greater perceived recreational and aesthetic values, and increased human health (Almenar, et al., 2021). These functions and services have the potential to improve livability and increase the attractiveness of a space.

3.4 Green gentrification

The process of gentrification entails a change in the local demographic composition led on by modification of a neighborhoods' built, retail or social environment (Maia, et al., 2020). These modifications are often put forth by tenants and home or small-business owners and serve the purpose of improving their own neighborhood. As a result, the improved neighborhood can attract the interest of real estate investors who wish to capitalize on the situation (Gould & Lewis, 2017). Property values rise and this can lead to the re- or displacement of vulnerable groups, especially socioeconomically disadvantaged residents (Maia, et al., 2020). The most commonly used indicators of gentrification include median income, race, ethnicity, age, level of educational attainment, poverty rate, professional status, home ownership rate, housing values, and rent (Anguelovski, et al., 2018). A change across multiple indicators has to be observed in order to determine the presence of gentrification.

When this phenomenon is the result of the installation of new urban green amenities, it is called green, climate or environmental gentrification (Anguelovski, et al., 2018). This is a subset of gentrification. It may be a result of intervention by governments or of residents themselves.

This research will focus on municipal government-led greening efforts and collaborations with the municipal government, and aims to demonstrate how government actions can impact residents, potentially prompting policy changes. Determining the causal relationship between gentrification and greening can be challenging, as the effects can influence each other bidirectionally. Greening can cause gentrification but gentrification can also cause greening (Gould & Lewis, 2017). However, previous case studies have indicated that, as the number, size, and quality of green spaces in urban areas increases, the more attractive and desirable it becomes, possibly driving the process of green gentrification (Anguelovski, et al., 2018).

4. Study Area & Methodology

4.1 Study Area

Gentrification primarily has a negative effect on vulnerable groups in society, for example ethnic minorities and socioeconomically disadvantaged populations (Garcia-Lamarca, et al., 2020; Cucca, et al., 2023; Gould & Lewis, 2017). Friesland is the province with the Netherland's second lowest average and disposable income (CBS, 2023). These lower income groups have a higher risk of being displaced as a result of rising real estate prices (Gould & Lewis, 2017). The city of Leeuwarden has been selected for this research project as it is home to a relatively high number of households (48%) classified as low income (Huisink, 2023). Green gentrification can pose a threat by increasing real-estate prices and possibly displacing vulnerable groups that reside within the city.

The city of Leeuwarden is subdivided into 16 districts/83 neighborhoods. For the sake of this study, 2 districts have been excluded based on their establishment after the beginning of the study period 2016. Without these locations, 14 of Leeuwarden's districts/ 73 neighborhoods are defined as the study area.

4.2 Methodology

The empirical research conducted for this study will be based on a case study performed within the city of Leeuwarden. Conducting such a case study allows for an in-depth exploration of specific NBS implemented in the city together with their impacts on the local housing market. The indicators of (green) gentrification will first be identified through a structured literature review. This is followed by finding emperical proof of gentrification in Leeuwarden. The final sub-question will focus on the mapping of urban greening in the city of Leeuwarden's gentrified areas. Based on the results of these sub-questions, conclusions can be drawn about the presence of green gentrification in the city.

MRQ: **What are the effects of NBS on the housing market in the city of Leeuwarden?**

To answer the main research question, a number of sub-questions have been developed. The respective sub-questions and their relevance are briefly explained in the following section.

RQ 1: What are the key indicators used to measure gentrification?

This research question will be answered using the existing body of literature on (green) gentrification through a structured literature review. Relevant articles will be analyzed resulting in an overview of indicators or drivers of gentrification. Search terms used to find these articles are: *Gentrification*; *Gentrification* AND *indicators; Gentrification* AND *Measures; Gentrification* AND *Drivers; Green gentrification* AND *Indicators; Green Gentrification* AND *Measures; Green gentrification* AND *Drivers.* These are entered into searchable academic databases such as Smartcat, Sciencedirect, and Jstor. Research papers resulting from these search terms are selected based on the relevance of the papers. This will make for a deeper knowledge of gentrification and results will thereafter be used to inform the other secondary research questions.

RQ2: What evidence of gentrification can be identified in the city of Leeuwarden?

To research whether there is evidence of green gentrification, an analysis of the various districts and neighborhoods of Leeuwarden is conducted based on socioeconomic indicators. This is done using data collected through neighborhood surveys by the municipality of Leeuwarden and by the central bureau of statistics (CBS) in the categories income and house value. Data that is used in this selection are: WOZ value and average household income (AHI). How the various districts and neighborhoods in Leeuwarden score in each of these categories will be used as an indicator of gentrification within the city.

Relevant data will be gathered and compiled using three primary data sources, the Central Bureau for Statistics (CBS, 2023), Alle Cijfers (2016) and Leeuwarden in Cijfers (Gemeente Leeuwarden, 2023). Data will be analyzed over a period of six years (2016-2021). This demographic and socioeconomic data will be cross-referenced with the mapped data on urban greening initiatives in Leeuwarden (results of RQ3). By comparing the data on gentrification and the data on greening, the aim is to uncover any potential correlations or causal relationships between urban greening initiatives and gentrification patterns.

RQ3: What projects relating to urban greening have been implemented in the gentrified regions of Leeuwarden?

Leeuwarden has been working on urban greening for a number of years. This includes, but is not limited to: green roofs and- walls, green strips, public gardens, and tree planting (Gemeente Leeuwarden, 2020). Using remote sensing techniques, aerial images from the gentrified locations are

analyzed (Walton, et al., 2008). To assess the amount of vegetation or greening in an area, infrared aerial pictures that are provided by PDOK are used. Beeldbank Nederland supplies a database of areal images of the Netherlands in color and infrared on a yearly basis. In these infrared aerial pictures, red hue indicates vegetation. Using ArcGIS pro software, a cutout is made of selected gentrified areas. These are then adjusted using GIMP software. This adjustment entails removing all hues except for red and increasing saturation of red hue in the aerial images. As a result, vegetation (red space) becomes increasingly visible (Map 2).

The resulting images are analyzed using online color summarizer software, which summarizes the images in color-clusters calculated using K-means clustering (kclusters). This software allows you select the number of clusters to summarize in, and the precision of the analysis in pixels. For this study, it was opted to summarize the images into 8 color clusters at the highest level of precision (vhigh – 200px). The output of this analysis encompasses the colors in the image, clustered into 8 groups (k-means). The average color of the colors for each cluster is shown. The second output of the analysis is a range of images compiled of the pixels pertaining to each respective K-cluster, allowing for visual inspection of the color locations and classification into vegetation or non-vegetation categories when necessary.

The aerial imagery from 2016 and 2021 visually differ in quality and trees have variable leaf cover. This is corrected by calculating the distortion value of each image. To calculate this value, 3 control patches from 2016 and from 2021, without new visible greenspace, of each district and neighborhood have been analyzed. These patches cover various typologies within the areas, i.e. residential, recreational, and sports sections. These test areas have been separately processed using the color summarizer software. The percentage of distortion between the two years for each of the 3 control locations was then weighted based on the share of the study area that is covered by the respective typologies. The resulting percentage is the distortion value that is used to correct part of the differences between 2016 and 2021 in the various districts and neighborhoods. The results of these analysis are the percentage of vegetation in the total surface area of the districts and neighborhoods. These are subsequently compared to determine the change in vegetation between 2016 and 2021.

Combined, these questions will allow for me to answer the main research question: *What are the effects of nature based solutions on the housing market in the city of Leeuwarden?*

5. Results

5.1 RQ 1: What are the key indicators of (green) gentrification?

5.1.1 Literature review

A multitude of indicators are introduced in the literature to assess whether a location is experiencing gentrification. There is a general consensus on the use of multiple indicators to justify labelling a place gentrified, including demographic and socio-economic factors.

A structured review of the literature was conducted to determine the most frequently used indicators to assess gentrification. The following search terms were entered in the searchable databases ScienceDirect, JSTOR, and SmartCat: Gentrification; Gentrification AND indicators; Gentrification AND Measures; Gentrification AND Drivers; Green gentrification AND Indicators; Green Gentrification AND Measures; Green gentrification AND Drivers. For each search term, the 15 top results were included, sorted on relevance/best match. This resulted in a dataset of 315 pieces of literature. A screening process was subsequently conducted and 255 articles have been excluded based on the following criteria:

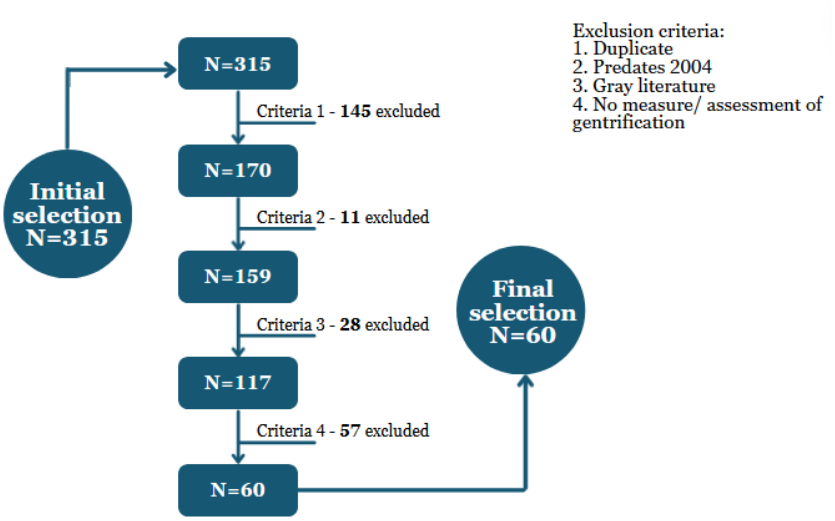


Figure 1: Literature review exclusion process

The resulting 60 articles have been analyzed. The analysis involved examining the resulting articles and tallying the indicators utilized to assess gentrification (Table 1). This study employs the most common indicators, which are subsequently analyzed within the city of Leeuwarden to evaluate CTs susceptible to or experiencing gentrification. From this review it was found that gentrification is typically assessed on the bases of a combination of SES indicators and economic indicators. Most often used are median household income and home value.

There are many examples of income being used as an indicator in studies of neighborhood change, for example caused by gentrification (Anguelovski, et al., 2018; Assaad & Jessini, 2024; Rigolon & Nemeth, 2019). Gentrification is a process where higher-income households relocate to traditionally low-income neighborhoods. This process can alter the social and cultural makeup of the neighborhood (Martin, 2017). Income measures are therefore crucial for fully understanding neighborhood changes and identifying low-income households as they are are most vulnerable to displacement due to rising

housing costs. A gentrifying area may see a faster rise in household or nonfamily income, as new residents may be more likely to cohabitate with unrelated adults (Cohen & Pettit, 2019).

Property value is a second frequently used indicator to measure gentrification. When an area gentrifies, property values can increase affecting both renters and home owners. While homeowners have more stability than renters, they are not immune to the pressures of gentrification. As property values rise in gentrifying areas, so do property taxes. This can be a significant financial burden for homeowners, especially those on fixed incomes. As neighborhoods gentrify, there can be social pressure to improve the appearance of homes (e.g., landscaping, exterior renovations), which can be costly. Rising property values can attract real estate speculators who may offer incentive to homeowners to sell. The combined financial pressures and social changes can displace low- and moderate-income homeowners, lead to a loss of affordable housing options and alter the demographic makeup of the neighborhood (Cohen & Pettit, 2019).

Table 1 Frequency of use of measures of gentrification

Measures of gentrification	Frequency of use	Frequency in %
Income	38	13,2%
Housing value	32	11,1%
Level of education	31	10,8%
Ethnicity/race	24	8,4%
Gross rent	20	7,0%
Age	17	5,9%
Poverty rate	15	5,2%
Professional occupation	11	3,8%
Home ownership	10	3,5%
Population density	9	3,1%
Change in local commerce	8	2,8%
Share of renters	6	2,1%
Residential mobility	5	1,7%
Vacancy rate	5	1,7%
Nr of new residential buildings	5	1,7%
Family composition	5	1,7%
Employment status	4	1,4%
Gender	3	1,0%
Property age	3	1,0%
CBD access	3	1,0%
Governmental aid	3	1,0%
Dwelling type	3	1,0%
Unchanged residence	3	1,0%
Nr of sales	3	1,0%
Marital status	3	1,0%
Local physical improvements	2	0,7%
Architectural value	2	0,7%
Commuting means	2	0,7%

Vehicle ownership	2	0,7%
Proximity to amenities	2	0,7%
Airbnb listings	2	0,7%
Monthly expenditure	1	0,3%
Level of congestion	1	0,3%
Working hours	1	0,3%
Household size	1	0,3%
Nr of pictures of site on social media	1	0,3%
Property tax	1	0,3%

5.2 RQ2: What evidence of gentrification can be identified in the city of Leeuwarden?

5.2.1 Gentrification in Leeuwarden

For this study, 14 districts in Leeuwarden have been considered (*De Zuidlanden and* Middelsee have been excluded based on the development of a large share of the district after the start of the study period.) A subset of districts has been selected based on how these districts score on factors that are considered as key indicators for gentrification. The districts that are most likely to be gentrified are used in this study to test the effects of greening on gentrification in Leeuwarden. Existing studies on gentrification have been consulted to identify the key indicators of gentrification (Assaad & Jessini, 2024; Thackway, et al., 2023; Hawkins, et al., 2022; Gray, et al., 2023). Key indicators that have been identified are: household income and house value.

In this study, a district is classified as gentrified when it has experienced changes in the demographic and economic characteristics specified in table 2. Using the Ding measure, the gentrification status of each district is assessed. Being below the CT average household income at the beginning of a period (qualifies as gentrifiable) and 2) experiencing an above-median increase in either gross rent or home value (Kiani, et al., 2024).

Table 2 Indicators of gentrification

Indicator	Measure	Gentrified if:
Household income	District household income vs. Average city household income	Growth of district household income > growth city household income
Property value	District property value vs. average city property value	Growth of district average property value > Growth of city average property value

5.2.1.1 Household income

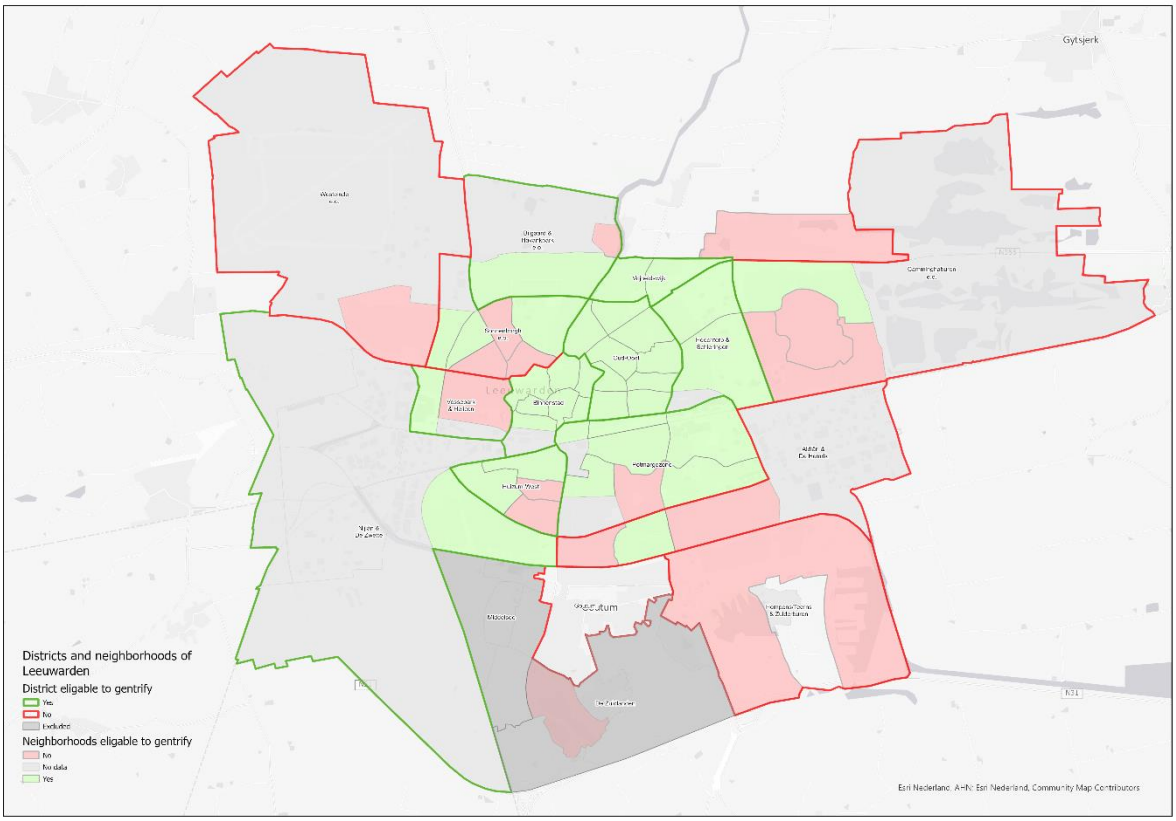
First, all districts in Leeuwarden are classified as either *eligible to gentrify* or *not eligible to gentrify*. For a district to be eligible to gentrify, median household income has to be lower than or equal to the city wide value at the beginning of the period of analysis (Ding, et al., 2016). Data on median household income is unavailable on a district level in Leeuwarden, therefore, average household

income is used instead. Average household income in Leeuwarden at the beginning of the period (2016) was € 26.203,50, 6 districts are deemed not eligible to gentrify based on average income being above the average city wide income (Table 3/ Map 1). This section continues using the 8 districts that are eligible to gentrify.

Table 3 Average district & neighborhood income Leeuwarden 2016. Districts eligible to gentrify are depicted green.

	District	Average household income disctricts 2016	Neighborhoods eligable to gentrify	Average household income neighborhoods 2016
1	Aldlân & De Hemrik	€ 28.026,00	x	
2	Bilgaard & Havankpark e.o.	€ 20.731,00	Bilgaard	€ 19.954
3	Binnenstad	€ 23.119,00	Blokhuisplein Hoek Oldehove Grote Kerkbuurt De Waag Nieuwestad Zaailand	€ 15.397 € 15.704 € 16.400 € 19.672 € 20.361 € 21.704 € 22.167
4	Camminghaburen e.o.	€ 29.411,00	X	
5	Heechterp & Schieringen	€ 18.809,00	Heechterp Schieringen	€ 16.557 € 19.073
6	Hempens/Teerns & Zuiderburen	€ 41.802,00	X	
7	Huizum-West	€ 25.791,00	Jan van Scorelbuurt Hollanderwijk	€ 21.534 € 22.615
8	Nijlân & De Zwette	€ 24.336,00	X	
9	Oud-Oost	€ 22.596,00	Zeeheldenbuurt Cambuur Molenpad Welgelegen Indische buurt Oldegalileën Bloemenbuurt Cambuursterpad	€ 15.456 € 17.111 € 18.079 € 18.871 € 18.960 € 19.745 € 21.278 € 22.071
10	Potmargezone	€ 24.199,00	Wielenpôlle Schepenbuurt Tulpenburg Oranjewijk Achter de Hoven	€ 10.900 € 14.397 € 18.071 € 20.945 € 22.467
11	Sonnenborgh e.o.	€ 29.674,00	Valeriuskwartier Rengerspark	€ 16.528 € 18.674
12	Vossepark & Helicon	€ 31.138,00	Helicon	€ 18.851
13	Vrijheidswijk	€ 20.083,00	Vrijheidswijk-Oost Vrijheidswijk-West	€ 18.139 € 21.040
14	Westeinde e.o.	€ 27.134,00	X	
	Leeuwarden	€ 26.203,50		€ 22.837

Map 1 Eligable to gentrifiy based on average income in 2016. Gentrifiable districts have an average household income below €25.866.



After the exclusion of 6 districts on the basis of not being eligible to gentrify, an analysis on average household income (AHI) was conducted. The change in district AHI (dAHI) was calculated using the following formula:

$$\text{Change in dAHI} = (dAHI_{2021} - dAHI_{2016}) / dAHI_{2016}$$

Heechterp & Schieringen has experienced a rise in AHI of 18,2% which is 2,2% greater than the average rise in Leeuwarden. Huizum-West has experience a rise in AHI of 16,1% which is 0,1% more than the average increase in Leeuwarden. Lastly, Westeinde e.o. saw a rise in income of 22,7% which is an increase that is 6,7% greater that the increase of Leeuwarden. Based on this analysis, three districts, Heechterp & Schieringen, Huizum-West, and Westeinde,e.o. meet the criteria for gentrification related to the indicator household income.

Table 4 Change in average household income on a district level (2016-2021) (green marks values that correlate with gentrification, red marks values that do not correlate with gentrification)

	District	Household income 2016	Household income 2021	Change household income
1	**Bilgaard & Havankpark e.o.**	€ 20.196	€ 23.314	15,4%
2	**Binnenstad**	€ 22.541	€ 25.844	14,7%

3	**Heechterp & Schieringen**	€ 17.833	€ 21.085	18,2%
4	**Huizum-West**	€ 23.938	€ 27.793	16,1%
5	**Nijlân & De Zwette**	€ 22.861	€ 25.539	11,7%
6	**Oud-Oost**	€ 21.970	€ 25.058	14,1%
7	**Potmargezone**	€ 23.570	€ 26.710	13,3%
8	**Vrijheidswijk**	€ 19.732	€ 22.542	14,2%
9	**Westeinde e.o.**	€ 24.863	€ 30.498	22,7%
	Leeuwarden	€ 25.866	€ 30.059	16%

5.2.1.2 Property values

One of the key indicators of gentrification is a rise in property values. This includes housing value and rent prices. An analysis of housing prices in the districts across Leeuwarden's districts was conducted to identify areas undergoing significant increases in average house values. The average WOZ value of each individual district had been compared to the overall average WOZ value in Leeuwarden. The WOZ across all of Leeuwarden's districts has risen from € 132.662 in 2016 to € 201.667 in 2022. This is an increase of 52,0%. Change in district property value (dWOZ) have been analyzed using the following formula:

$$\text{Change in dWOZ} = (dWOZ_{2022} - dWOZ_{2016}) / dWOZ_{2016}$$

Bases on this analysis, 6 districts, Heechterp & Schieringen, Huizum-West, Nijlân & de Zwette, Oud-Oost, Vrijheidswijk, and Westeinde e.o. are found to show signs of gentrification based on the indicator property value. These numbers have been summarized in table 6. Gentrification cannot be measured using a singular indicator, therefore this study looks at a combination of indicators. There are 2 districts in Leeuwarden that have likely experienced gentrification in the period 2016-2022, namely Heechterp & Schieringen, and Huizum-West. These districts were eligible to gentrify, and experienced a greater than average increase in household income and WOZ value.

Table 5 Change in average WOZ value on a district level (2016-2021) (green marks values that correlate with gentrification, red marks values that do not correlate with gentrification)

	District	Average WOZ 2016	Average WOZ 2022	Value increase 2016-2022 (%)
1	**Bilgaard & Havankpark e.o.**	€ 105.110	€ 158.000	50,3%
2	**Binnenstad**	€ 104.000	€ 136.000	30,8%
3	**Heechterp & Schieringen**	€ 74.122	€ 122.000	64,6%
4	**Huizum-West**	€ 110.356	€ 173.000	56,8%
5	**Nijlân & De Zwette**	€ 99.000	€ 156.000	57,6%
6	**Oud-Oost**	€ 96.707	€ 151.000	56,1%
7	**Potmargezone**	€ 116.189	€ 162.000	39,4%
8	**Vrijheidswijk**	€ 104.314	€ 159.000	52,4%

9	**Westeinde e.o.**	€ 132.000	€ 205.000	55,3%
	Leeuwarden	€ 132.662	€ 201.667	52,0%

Table 6 District gentrification in Leeuwarden based on AHI and WOZ (green marks values that correlate with gentrification, red marks values that do not correlate with gentrification)

District	Average household income 2016	Change average household income 2016-2022	Change WOZ value 2016-2022
Aldlân & De Hemrik	€ 26.698	12,2%	41,44%
Bilgaard & Havankpark e.o.	€ 20.196	15,4%	50,32%
Binnenstad	€ 22.541	14,7%	30,77%
Camminghaburen e.o.	€ 27.253	15,5%	47,41%
Heechterp & Schieringen	€ 17.833	18,2%	64,59%
Hempens/Teerns & Zuiderburen	€ 36.006	19,9%	50,63%
Huizum-West	€ 23.938	16,1%	56,77%
Nijlân & De Zwette	€ 22.861	11,7%	57,58%
Oud-Oost	€ 21.970	14,1%	56,14%
Potmargezone	€ 23.570	13,3%	39,43%
Sonnenborgh e.o.	€ 26.787	15,6%	60,15%
Vossepark & Helicon	€ 29.586	17,0%	66,24%
Vrijheidswijk	€ 19.732	14,2%	52,42%
Westeinde e.o.	€ 24.863	22,7%	55,30%
Leeuwarden	€25.866	15,6%	52,0%

5.2.2. Neighborhood differentiation

To test whether and how gentrification is present at various spatial levels, the neighborhood-level is analyzed to examine whether differences can be identified within districts. Gentrification is therefore tested in neighborhoods within Leeuwarden's city limits. Running the analysis on a neighborhood provides results that vary from the district level analysis. AHI data on a neighborhood level is compiled and summarized in Appendix 1. The neighborhoods are classified as either *eligible to gentrify* (AHI of neighborhood < Leeuwarden in 2016) or *not eligible to gentrify* (AHI of neighborhood > Leeuwarden in 2016), or excluded based on lack of data. The AHI of Leeuwarden based on neighborhood data in 2016 was € 22.837. As a result 30 neighborhoods are eligible to gentrify, 22 neighborhoods are not eligible to gentrify and 31 are excluded. An overview of these neighborhoods is provided in Map 1.

5.2.2.1 Household Income

AHI from 2016 and 2021 of the neighborhoods that are eligible to gentrify is used to calculate the change in income in the study period. The change in neighborhood AHI (nAHI) was calculated using the following formula:

$$\text{Change in nAHI} = (nAHI_{2021} - nAHI_{2016}) / nAHI_{2016}$$

From this calculation, 9 neighborhoods experienced a rise in AHI that is greater than the citywide rise in AHI meaning these neighborhoods show signs of gentrification (Table 7).

5.2.2.1 WOZ value

The indicator house value is measured by average WOZ value. Data from 2016 and 2021 are compiled in Appendix 3. Changes in neighborhood property value (nWOZ) have been analyzed using the following formula:

$$\text{Change in nWOZ} = (nWOZ_{2022} - nWOZ_{2016}) / nWOZ_{2016}$$

Based on this analysis, 4 neighborhoods show sings of gentrification based on the indicator house value (Table 7).

The results of these calculations have been summarized in Table 7. Gentrification is measured using a combination of indicators, in this case AHI and WOZ. Neighborhoods need to have undergone a rise in both AHI and WOZ that is greater that the rise in AHI and WOZ in the city of Leeuwarden in order to be considered gentrified. Based on the analysis of data, 2 neighborhoods, Blokhuisplein and Wielenpôlle can be allocated the status of gentrified. Neither of these neighborhoods are part of the district-level gentrified areas.

Table 7 Neighborhood gentrification based on AHI and WOZ (green marks values that correlate with gentrification, red marks values that do not correlate with gentrification)

Neighborhood	District	Change AHI	Change WOZ
Achter de Hoven	Potmargezone	10,7%	39,8%
Bilgaard	Bilgaard	15,7%	36,0%
Bloemenbuurt	Oud-Oost	8,7%	35,1%
Blokhuisplein	Binnenstad	35,1%	83,0%
Cambuur	Oud-Oost	1,3%	33,9%
Cambuursterpad	Oud-Oost	14,9%	41,4%
De Waag	Binnenstad	14,6%	29,1%
Grote Kerkbuurt	Binnenstad	31,9%	32,1%

Heechterp	Heechterp & Schieringen	17,8%	44,9%
Helicon	Vossepark & Helicon	23,5%	46,5%
Hoek	Binnenstad	-5,9%	13,2%
Hollanderwijk	Huizum-West	13,3%	40,0%
Indische buurt	Oud-Oost	17,3%	68,4%
Jan van Scorelbuurt	Huizum-West	13,1%	40,4%
Molenpad	Oud-Oost	47,7%	39,5%
Nieuwestad	Binnenstad	13,2%	19,3%
Oldegalileën	Oud-Oost	12,6%	39,2%
Oldehove	Binnenstad	79,5%	33,1%
Oranjewijk	Potmargezone	51,3%	29,2%
Rengerspark	Sonnenborgh e.o.	7,1%	15,1%
Schepenbuurt	Potmargezone	18,1%	1,4%
Schieringen	Heechterp & Schieringen	18,8%	58,2%
Tulpenburg	Potmargezone	0,6%	16,9%
Valeriuskwartier	Sonnenborgh e.o.	16,8%	35,4%
Vrijheidswijk-Oost	Vrijheidswijk	16,1%	45,1%
Vrijheidswijk-West	Vrijheidswijk	15,9%	40,4%
Welgelegen	Oud-Oost	27,5%	41,3%
Wielenpôlle	Potmargezone	25,7%	72,3%
Zaailand	Binnenstad	2,4%	27,1%
Zeeheldenbuurt	Oud-Oost	49,5%	34,7%
Leeuwarden		19,2%	50,1%

5.3 RQ3: What projects relating to urban greening have been implemented in the gentrified regions of the city of Leeuwarden?

5.3.1 Urban greening in Leeuwarden

Leeuwarden has been working on urban greening for a number of years. This includes, but is not limited to: green roofs and- walls, green strips, public gardens, and tree planting (Gemeente Leeuwarden, 2020). One of the policy programs set up by the municipality is the programma volhoudbaar (program sustainable), in which a number of strategies are discussed to meat global sustainability goals and to keep Leeuwarden livable in the face of climate change (Gemeente Leeuwarden, 2020). Besides greening the public space of Leeuwarden, the municipality also stimulated greening of private space by means of programs such as the TegelTaxi (tile taxi), Operatie steenbreek (operation tilebreak), and subsidies for green initiatives in private space such as green roofs to lower the barrier to private greening (Gemeente Leeuwarden, sd). Leeuwarden has integrated ‘social

impacts' into its programma volhoudbaar to make sure the social realm pertaining to vulnerable groups is accounted for, including those considered living near or below the poverty line (Gemeente Leeuwarden, 2020). These are thought to be more vulnerable to the effects of climate change in an urban setting as they have a lower adaptive capacity than people with more financial means (Kimaateffectatlas, n.d.).

One of Leeuwarden's main goals surrounding greening is to increase shadow within the city using trees to combat the urban heat island effect. The focus is therefore presumably on the areas in the city that suffer most from this phenomena (Gemeente Leeuwarden, 2020). The effect increases in severity as proximity to the city center decreases (Kimaateffectatlas, n.d.).

This greening can have a positive impact on property values (Szczepańska, et al., 2016; Wu, et al., 2014), and possibly lead to gentrification. The gentrified areas resulting from RQ2 are therefore analyzed regarding vegetation presence. An assessment of the amount of greenspace is made for each of the gentrified parts of the city of Leeuwarden. Using enhanced infrared images, a color analysis followed by a visual analysis is performed. Using this method, an estimate is made of the percentage of the respective areas that is covered in vegetation in both 2016 and 2021. These numbers are subsequently compared and the change in greenspace can be determined. This results in evidence on whether or not the various areas have undergone significant greening in the period of gentrification.

5.3.2 Greening in Districts

5.3.2.1 Huizum-West

The analysis of the aerial images of Huizum-West point at a decrease in greenspace. In 2016, vegetation covered 34,74% of the area. In 2021, this has decreased to 26,57% (table 11). Part of this decrease can be attributed leaf cover and image quality. To calculate the extend of distortion caused by leaf cover in Huizum-West, 3 control patches from 2016 and from 2021, without new visible greenspace, have been analyzed. The average difference between both years that can be attributed to leaf cover and quality is 6,73%. The change in vegetation is calculated by taking the difference between 2016 and 2021 and correcting for the distortion value.

$$(34{,}74\text{-}26{,}57) + 6{,}73 = -1{,}44$$

Huizum-West experienced a decrease in vegetation cover of 1,44% over the course of 2016-2021.

Map 2 Vegetation presence in district Huizum-West (Left 2016, Right 2021)

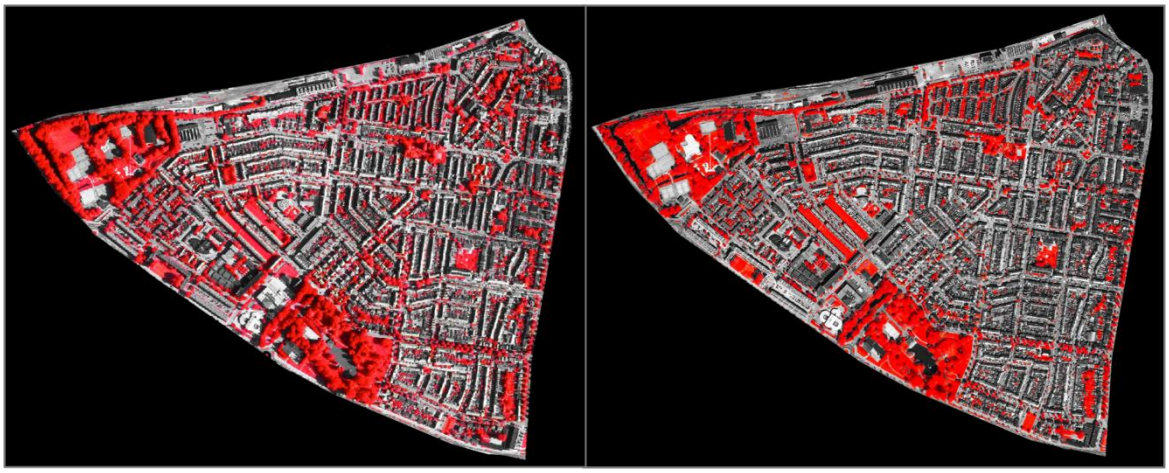


Table 8 Vegetation presence Huizum-West (red k-means indicate the presence of vegetation, bold/underlined numbers are classified as vegetation)

Huizum-West 2016 Land use in percentage	K-means	Huizum-West 2021 Land use in percentage	K-means
20,95%		24,20%	
19,23%		22,33%	
16,00%		19,28%	
11,77%		**9,70%**	
11,50%		**8,87%**	
11,47%		**8,00%**	
9,09%		7,61%	

5.3.2.2 Heechterp & Schieringen

The analysis of the aerial images of Heechterp & Schieringen point at a decrease in greenspace. In 2016, vegetation covered 62,22% of the area. In 2021, this has decreased to 50,57%. Part of this decrease can be attributed leaf cover and image quality. To calculate the extend of distortion caused by leaf cover in Heechterp & Schieringen, 3 test patches from 2016 and from 2021 without new visible greenspace were analyzed. The calculated difference between both years that can be attributed to leaf cover and quality is 6,77%.

The change in vegetation is calculated by taking the difference between 2016 and 2021 and correcting for the distortion value.

$$(62,22\text{-}50,57) + 6,77 = -4,70$$

In Heechterp & Schieringen, vegetation cover decreased by 4,70%. This change is visible in the bottom right of Map 3 in locations 1 and 2.

Map 3 Vegetation presence in district Heechterp & Schieringen (Left 2016, Right 2021)

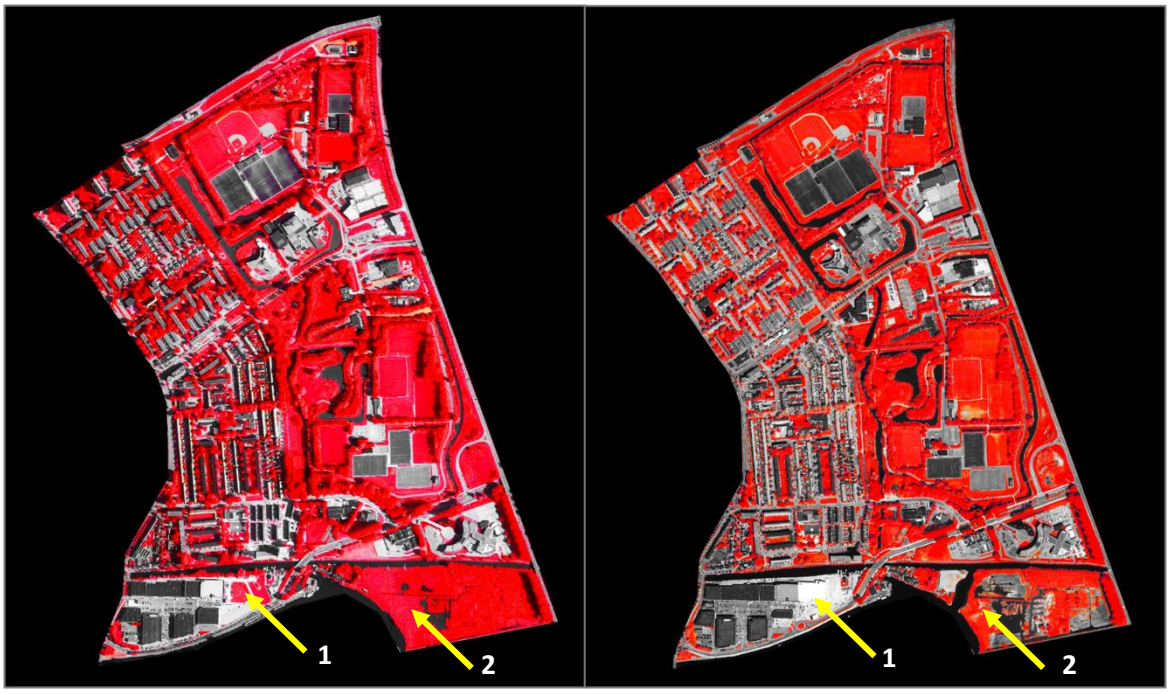


Table 9 Vegetation presence Heechterp & Schieringen (red k-means indicate the presence of vegetation, bold/underlined numbers are classified as vegetation)

Heechterp & Schieringen 2016 Land use in percentage		Heechterp & Schieringen 2021 Land use in percentage	
29,50%		**23,09%**	
15,37%		**15,52%**	
11,76%		13,94%	
11,62%		12,80%	
11,45%		12,53%	
10,96%		**12,14%**	
9,34%		9,98%	

5.3.3 Greening in Neighborhoods

5.3.3.1 Blokhuisplein

The analysis of aerial imagery of Blokhuisplein points to 11,47% of the area being covered by vegetation. In 2021, the share of vegetation adds up to 8,40% The change in vegetation is calculated by taking the difference between 2016 and 2021 and correcting for the distortion value.

$$(11,47\text{-}8,40) + 1,96 = -1,11$$

The change in vegetation at Blokhuisplein is 1,11% over the course of the study period. Part of this decrease in vegetation can be seen in the bottom of the area (Map 4, location 1) where greenery was replaced by a terrace.

Map 4 Vegetation presence in neighborhood Blokhuisplein (Left 2016, Right 2021)

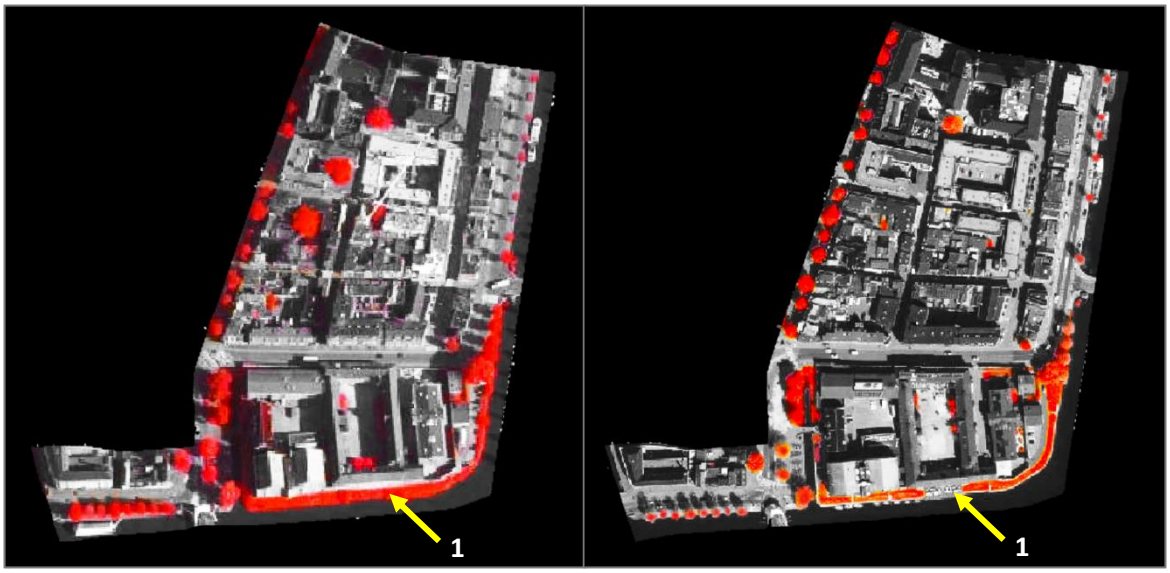


Table 10 Vegetation presence Blokhuisplein (red k-means indicate the presence of vegetation, bold/underlined numbers are classified as vegetation)

Blokhuispoort 2016		**Blokhuispoort 2022**	
Land use in percentage		**Land use in percentage**	
26,59%		21,51%	
21,50%		18,43%	
19,80%		18,18%	
15,69%		17,36%	
6,58%		16,13%	
4,94%		**4,30%**	
4,89%		**4,10%**	

5.3.3.2 Wielenpôlle

The analysis of aerial imagery of Wielenpôlle indicates to a vegetation cover of 55,23%. In 2021, the share of vegetation adds up to 40,75%. The change in vegetation is calculated by taking the difference between 2016 and 2021 and correcting for the distortion value.

$$(55{,}23\text{-}40{,}75) + 9{,}44 = -5{,}04$$

This results in a decrease of vegetation in the neighborhood of 5,04%. Part of this can be attributed to the installation of a solar panel field (Map 5, location 1) and the building of a structure in a formerly vegetated area (Map 5, location 2).

Map 5 Vegetation presence in neighborhood Wielenpôlle (Left 2016, right 2021)

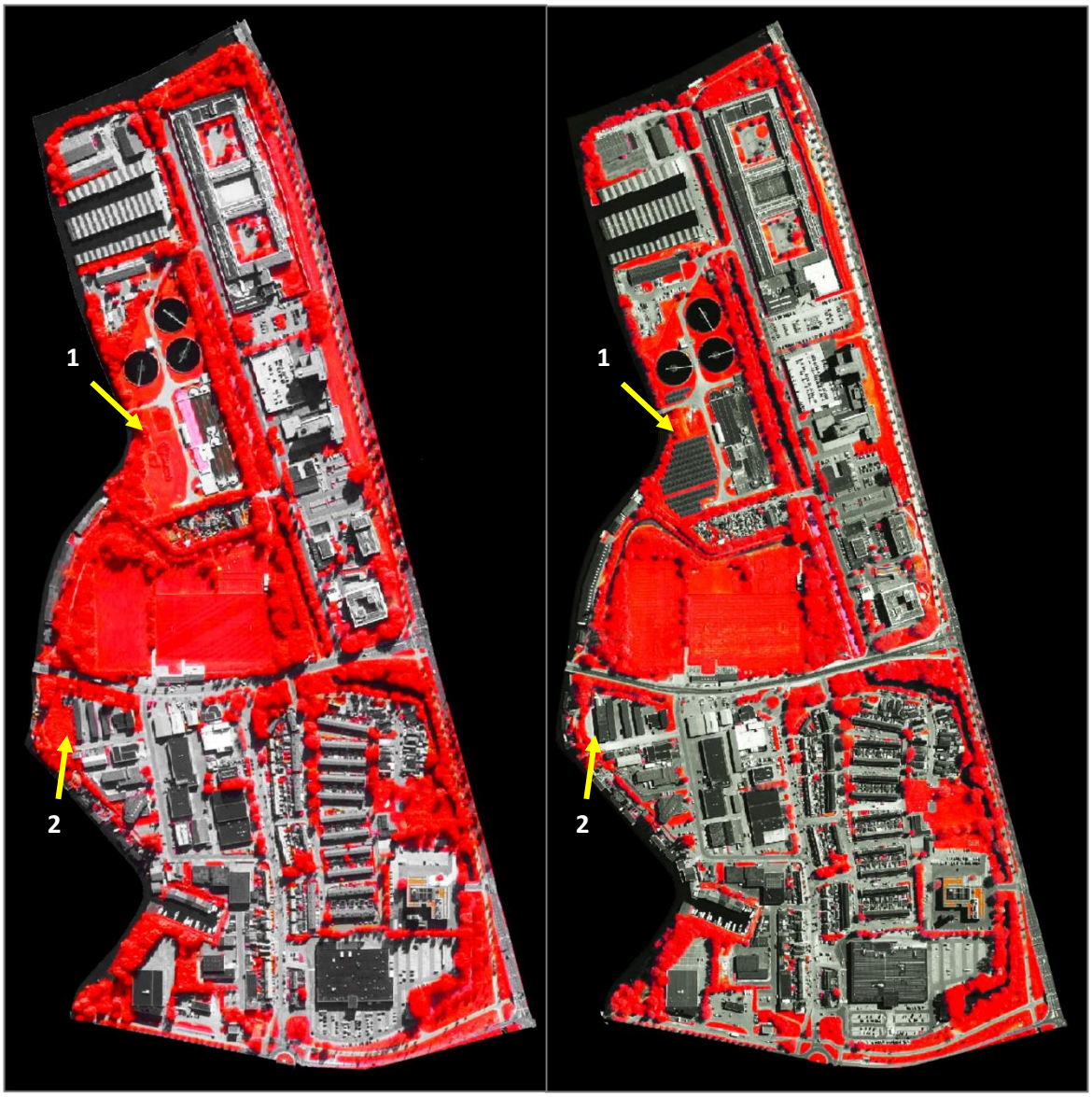


Table 11 Vegetation presence Wielenpôlle (red k-means indicate the presence of vegetation, bold/underlined numbers are classified as vegetation)

Wielenpôlle 2016 Land use in percentage		**Wielenpôlle 2021** Land use in percentage	
27,37%		**20,91%**	
18,29%		20,27%	
14,96%		16,89%	
12,41%		16,14%	

11,52%		**11,23%**	
8,43%		**8,61%**	
7,02%		5,95%	

Although Leeuwarden has been implementing greening for a number of years throughout the city, vegetation cover in none of the gentrified areas has increased during the study timeframe based on the color analysis of infrared aerial images. All studied areas have seen a decrease in vegetation cover (Table 10). Both Heechterp & Schieringen and Wielenpôlle had a vegetation cover of more than half of the area. This may be an explanation for the lack of investment in greening these locations as more urbanized locations take priority (Gemeente Leeuwarden, 2020).

Table 12 Overview results of vegetation analysis for the gentrified areas

Vegetation cover per location		**Change 2016-2021**	**Leaf cover & quality correction**	**Change after correction**
Huizum-West 2016	**Huizum-West 2021**			
34,74%	26,57%	-8,17%	+6,73%	-1,44%
Heechterp & Schieringen 2016	**Heechterp & Schieringen 2021**			
62,22%	50,57	-11,47%	+6,77%	-4.70%
Blokhuisplein 2016	**Blokhuisplein 2021**			
11,47%	8,40	-3,07%	+1,96%	-1,11%
Wielenpôlle 2016	**Wielenpôlle 2016**			
55,23%	40,75%	-14,48	+9,44%	-5.04%

6. Discussion

The aim of this study was to answer the following question: *What are the effects of nature based solutions on the housing market in the city of Leeuwarden?* Gentrification in Leeuwarden has been measured using house value (WOZ) and average household income (AHI). Results indicate that 6 districts and 30 neighborhoods are eligible to gentrify based on being below the AHI of the larger study area Leeuwarden at the beginning of the study period. Of these districts, 2 are found to have experienced an increase in both AHI and WOZ-value, indicating that gentrification mechanisms are at work. When looking at the neighborhood level, of the 30 neighborhoods that are eligible to gentrify, there are 2 neighborhoods that have gentrified based on AHI and WOZ-value. Interesting is that neither of these neighborhoods are located in the gentrified districts. By subdividing the various districts in Leeuwarden into neighborhoods, the data provides different results. Grouping the neighborhoods together into districts, the results are skewed. Extremes from separate neighborhoods

distort the outcome on a district-level. Research is therefore thought to best conducted on a smaller [than district level] spatial scale for more accurate representation of the results.

The gentrified districts and neighborhoods do not show a significant increase in greenspace. Analysis of aerial photographs actually indicate a decrease in greenspace in the researched locations. Gentrification can therefore not be linked to greening in Leeuwarden. The locations have likely undergone transformations or adaptations of another kind that have warranted added desirability to resign is the respective areas. In light of the absence of green gentrification in Leeuwarden, a related topic of study would be to investigate the drivers of gentrification in Leeuwarden.

Gentrification is linked to social justice issues as it entails the processs of changing the demographic fabric of an area through an influx of residents with a higher social standing at the expense of economically vulnerable groups. Social justice issues do not seem to arise in Leeuwarden when related to implementing NBS by urban greening. A question that does arise is whether or not less affluent districts and neighborhoods are disinvested in when it comes to greening and increasing climate resilience, seeing that none of the less affluent, gentrified neighborhoods have seen significant investment in public greenspace.

The gentrification at Blokhuisplein could potentially be linked to the redesign of neighborhood in 2017 (Ohpen Ingenieurs, 2017), the redesign of the former prison in the area as cultural hub, and the proximity of the neighborhood to the city center.

Oftentimes, green gentrification studies focus on large scale projects such as the effect of the establishment of a park on gentrification mechanisms. This study differentiates itself by studying the effects of small scale green project implementation. Studies on green gentrification have varying results which typically vary between cities, as not all cities show strong signs of gentrification. Some studies find compelling evidence for the role of greening on gentrification in cities (Anguelovski, et al., 2018; Garcia-Lamarca, et al., 2020). According to Chen, et al. (2021), large green space is more likely to generate gentrification than small ones. This could be an explanation to the limited manifestation of gentrification and non-existence of green gentrification in Leeuwarden as no large green spaces have been established during the study period.

Limitations were encountered in data availability. District boundaries extended past city limits and therefore encompasses data not entirely relevant to the study area. This caused differences in city income and WOZ-value data, calculated from district-level data and neighborhood level-data. Results may be skewed due to the inadvertent incorporation of data outside city limits. The color analysis would have preferably been conducted over a longer period starting 5 years before the study timeframe of 2016-2023. Most green gentrification studies study greening in a period predating gentrification in

order to link greening and subsequent gentrification. Due to unavailability of aerial photography predating 2016, the decision was made to perform a real-time analysis of greenspace development and subsequent gentrification processes. This may have affected the outcome of the study.

Although all calculations and analysis have been carefully preformed, this study could potentially be more robust. As gentrification can be measured using a variety of measures, it could be argued that further research should be performed using a larger array of measures. This would be done to increase reliability of the work.

Due to the limited manifestation of gentrification in Leeuwarden, it is difficult to indisputably link the instances of gentrification to greening preformed in the city. Gentrification studies are often preformed in large urban regions, however Leeuwarden is relatively small in size and number of inhabitants. Due to the small size of Leeuwarden, gentrification may not be as present as in larger urban areas. It is also difficult to link this to greening, partly because no large scale greening projects have been implemented in the study area. Using small scale greening projects in this study area has limitations as the causal relationship between greening and gentrification is more challenging to demonstrate. Although Leeuwarden have been working on greening for a number of years, many of the urban greening measures are set in the future (Stoffers, 2023). Green gentrification could therefore potentially present itself in the future as a result the rapid increase of greening projects in the period 2020-2030 (Gemeente Leeuwarden, 2020).

An opportunity for future research presents itself in the redevelopment of the Cambuurstadion area. This region is to undergo a transformation from sports and shopping facilities to a public park and residential area. The subsequent effects this park may have the surrounding neighborhoods holds potential for future research. Due to the size of the projects, the effects of this intervention may be greater than the effects of the smaller standalone greening projects researched in this study. Existing literature argues that gentrification generally happens in historically disinvested neighborhoods (Anguelovski, et al., 2018). This project is situated in the district Oud-Oost, which consists of 9 neighborhoods, most of which fall into the category eligible to gentrify and could be considered disinvested. The district is fairly urbanized with little room for greenspace (Leeuwarden Oost, sd). This redevelopment project may have negative effects on its current residents by increasing the value of housing in the surrounding neighborhoods. This makes for an interesting subject for future research on the effects of implementing large scale green space on gentrification mechanics in Leeuwarden.

If the city of Leeuwarden can prevent gentrification from happening in the region surrounding the project could indicate that Leeuwarden has well established policies surrounding the protection of residents against such phenomena.

7. Conclusion

The aim of this study has been to study the effects of NBS in the form of urban greening as an adaptation strategy, on the housing market in the city of Leeuwarden. Through analysis of the literature, this study found the most frequently used indicators of gentrification, which were subsequently used to analyze the presence of gentrification in Leeuwarden. The results of this indicate that 2 districts and two neighborhoods present evidence of gentrification. Subsequently a color analysis was conducted in infrared imagery to quantify the change in greenspace in gentrified parts of Leeuwarden over the period 2016-2021. The change in greenspace has been quantified for each district/neighborhood in Leeuwarden. For each district/ neighborhood this is then compared to the data on gentrification. If a significant increase in green space in a district/neighborhood correlates with gentrification in said space, gentrification is potentially linked to greening.

From this analysis, it has become apparent that no significant increases in greenspace have occurred over this period in any of the gentrified areas. Districts and neighborhoods that have seen an increase in greenspace do not show signs of gentrification. This leads to the conclusion that there is no evidence for green gentrification in Leeuwarden.

The implementation of urban greenery has thus far not affected housing value or been a driver of gentrification processes in the city of Leeuwarden according to the results of this study. This adaptation strategy is therefore thought to be a fitting solution in reaching climate goals and adaptation and mitigation with regards to climate change in the context of Leeuwarden. Areas that have potentially seen a significant increase in greenspace have not experienced gentrification. However, although thus far no evidence of green gentrification can identified, it may present itself in the future as a result of further green development in Leeuwarden. Though no social justice issues arise in Leeuwarden as a result green gentrification at this time, this issue does present itself in other cities. Future research on the further development of gentrification and potential green gentrification in Leeuwarden is advisable. Other research opportunities present itself regarding the drivers of gentrification in Leeuwarden if it is not caused by greening, as well as a further exploration of the current governance practices in place that do well in protecting vulnerable populations.

Leeuwarden appears to have established sound policy on the protection of vulnerable groups and is mindful of these communities in their adaptation strategies. Potentially, the city could serve as an example case for the implementation of NBS in cities across the Netherlands. It is unclear whether or not policy makers of Leeuwarden are conscious of green gentrification at present, however it is believed to be vital that policy makers are aware of the issue and potential implications of green gentrification to ensure just adaptation governance will remain the norm in this, and in other cities.

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9. Appendix

Appendix 1 Table of gentrification indicators and their frequency of use

Measures of gentrification	Frequency of use	Frequency in %
Income	38	13,2%
Housing value	32	11,1%
Level of education	31	10,8%
Ethnicity/race	24	8,4%
Gross rent	20	7,0%
Age	17	5,9%
Poverty rate	15	5,2%
Professional occupation	11	3,8%
Home ownership	10	3,5%
Population density	9	3,1%
Change in local commerce	8	2,8%
Share of renters	6	2,1%
Residential mobility	5	1,7%
Vacancy rate	5	1,7%
Nr of new residential buildings	5	1,7%
Family composition	5	1,7%
Employment status	4	1,4%
Gender	3	1,0%
Property age	3	1,0%
CBD access	3	1,0%
Governmental aid	3	1,0%
Dwelling type	3	1,0%
Unchanged residence	3	1,0%
Nr of sales	3	1,0%
Marital status	3	1,0%
Local physical improvements	2	0,7%
Architectural value	2	0,7%
Commuting means	2	0,7%
Vehicle ownership	2	0,7%
Proximity to amenities	2	0,7%
Airbnb listings	2	0,7%
Monthly expenditure	1	0,3%
Level of congestion	1	0,3%
Working hours	1	0,3%
Household size	1	0,3%
Nr of pictures of site on social media	1	0,3%
Property tax	1	0,3%

Appendix 2 Average Household income comparison between 2016-2021 on neighborhood level

Neighborhood	District	AHI 2016	AHI 2021	Change AHI
Achter de Hoven	Potmargezone	€ 22.467	€ 24.864	10,7%
Bilgaard	Bilgaard	€ 19.954	€ 23.090	15,7%
Bloemenbuurt	Oud-Oost	€ 21.278	€ 23.127	8,7%
Blokhuisplein	Binnenstad	€ 15.397	€ 20.795	35,1%
Cambuur	Oud-Oost	€ 17.111	€ 17.333	1,3%
Cambuursterpad	Oud-Oost	€ 22.071	€ 25.365	14,9%
De Waag	Binnenstad	€ 20.361	€ 23.341	14,6%
Grote Kerkbuurt	Binnenstad	€ 19.672	€ 25.952	31,9%
Heechterp	Heechterp & Schieringen	€ 16.557	€ 19.509	17,8%
Helicon	Vossepark & Helicon	€ 18.851	€ 23.274	23,5%
Hoek	Binnenstad	€ 15.704	€ 14.774	-5,9%
Hollanderwijk	Huizum-West	€ 22.615	€ 25.628	13,3%
Indische buurt	Oud-Oost	€ 18.960	€ 22.242	17,3%
Jan van Scorelbuurt	Huizum-West	€ 21.534	€ 24.359	13,1%
Molenpad	Oud-Oost	€ 18.079	€ 26.704	47,7%
Nieuwestad	Binnenstad	€ 21.704	€ 24.576	13,2%
Oldegalileën	Oud-Oost	€ 19.745	€ 22.223	12,6%
Oldehove	Binnenstad	€ 16.400	€ 29.446	79,5%
Oranjewijk	Potmargezone	€ 20.945	€ 31.682	51,3%
Rengerspark	Sonnenborgh e.o.	€ 18.674	€ 19.996	7,1%
Schepenbuurt	Potmargezone	€ 14.397	€ 17.009	18,1%
Schieringen	Heechterp & Schieringen	€ 19.073	€ 22.652	18,8%
Tulpenburg	Potmargezone	€ 18.071	€ 18.182	0,6%
Valeriuskwartier	Sonnenborgh e.o.	€ 16.528	€ 19.307	16,8%
Vrijheidswijk-Oost	Vrijheidswijk	€ 18.139	€ 21.052	16,1%
Vrijheidswijk-West	Vrijheidswijk	€ 21.040	€ 24.382	15,9%
Welgelegen	Oud-Oost	€ 18.871	€ 24.065	27,5%
Wielenpôlle	Potmargezone	€ 10.900	€ 13.698	25,7%
Zaailand	Binnenstad	€ 22.167	€ 22.689	2,4%
Zeeheldenbuurt	Oud-Oost	€ 15.456	€ 23.111	49,5%
Leeuwarden		€ 22.837	€ 27.218	19,2%

Appendix 3 WOZ value comparison between 2016-2021 on a neighborhood level (2016-2021)

Neighborhood	District	WOZ 2016	WOZ 2021	Change WOZ
Achter de Hoven	Potmargezone	€ 103.000	€ 144.000	39,8%
Bilgaard	Bilgaard	€ 100.000	€ 136.000	36,0%
Bloemenbuurt	Oud-Oost	€ 94.000	€ 127.000	35,1%
Blokhuisplein	Binnenstad	€ 53.000	€ 97.000	83,0%
Cambuur	Oud-Oost	€ 118.000	€ 158.000	33,9%
Cambuursterpad	Oud-Oost	€ 99.000	€ 140.000	41,4%
De Waag	Binnenstad	€ 117.000	€ 151.000	29,1%
Grote Kerkbuurt	Binnenstad	€ 112.000	€ 148.000	32,1%
Heechterp	Heechterp & Schieringen	€ 69.000	€ 100.000	44,9%
Helicon	Vossepark & Helicon	€ 155.000	€ 227.000	46,5%
Hoek	Binnenstad	€ 76.000	€ 86.000	13,2%
Hollanderwijk	Huizum-West	€ 105.000	€ 147.000	40,0%
Indische buurt	Oud-Oost	€ 76.000	€ 128.000	68,4%
Jan van Scorelbuurt	Huizum-West	€ 89.000	€ 125.000	40,4%
Molenpad	Oud-Oost	€ 114.000	€ 159.000	39,5%
Nieuwestad	Binnenstad	€ 119.000	€ 142.000	19,3%
Oldegalileën	Oud-Oost	€ 79.000	€ 110.000	39,2%
Oldehove	Binnenstad	€ 124.000	€ 165.000	33,1%
Oranjewijk	Potmargezone	€ 137.000	€ 177.000	29,2%
Rengerspark	Sonnenborgh e.o.	€ 73.000	€ 84.000	15,1%
Schepenbuurt	Potmargezone	€ 74.000	€ 75.000	1,4%
Schieringen	Heechterp & Schieringen	€ 79.000	€ 125.000	58,2%
Tulpenburg	Potmargezone	€ 118.000	€ 138.000	16,9%
Valeriuskwartier	Sonnenborgh e.o.	€ 79.000	€ 107.000	35,4%
Vrijheidswijk-Oost	Vrijheidswijk	€ 91.000	€ 132.000	45,1%
Vrijheidswijk-West	Vrijheidswijk	€ 114.000	€ 160.000	40,4%
Welgelegen	Oud-Oost	€ 92.000	€ 130.000	41,3%
Wielenpôlle	Potmargezone	€ 83.000	€ 143.000	72,3%
Zaailand	Binnenstad	€ 140.000	€ 178.000	27,1%
Zeeheldenbuurt	Oud-Oost	€ 124.000	€ 167.000	34,7%
Leeuwarden		€ 128.207	€ 192.496	50,1%

Appendix 4 Indicators of gentrification neighborhood level

	Neighborhood	District	AHI 2016	Eligible to gentrify	AHI 2021	Change AHI	WOZ 2016-2021
1	Achter de Hoven	Potmargezone	€ 22.467	Yes	€ 24.864	10,7%	39,8%
2	Bilgaard	Bilgaard	€ 19.954	Yes	€ 23.090	15,7%	36,0%
3	Bloemenbuurt	Oud-Oost	€ 21.278	Yes	€ 23.127	8,7%	35,1%
4	Blokhuisplein	Binnenstad	€ 15.397	Yes	€ 20.795	35,1%	83,0%
5	Cambuur	Oud-Oost	€ 17.111	Yes	€ 17.333	1,3%	33,9%
6	Cambuursterpad	Oud-Oost	€ 22.071	Yes	€ 25.365	14,9%	41,4%
7	De Waag	Binnenstad	€ 20.361	Yes	€ 23.341	14,6%	29,1%
8	Grote Kerkbuurt	Binnenstad	€ 19.672	Yes	€ 25.952	31,9%	32,1%
9	Heechterp	Heechterp & Schieringen	€ 16.557	Yes	€ 19.509	17,8%	44,9%
10	Helicon	Vossepark & Helicon	€ 18.851	Yes	€ 23.274	23,5%	46,5%
11	Hoek	Binnenstad	€ 15.704	Yes	€ 14.774	-5,9%	13,2%
12	Hollanderwijk	Huizum-West	€ 22.615	Yes	€ 25.628	13,3%	40,0%
13	Indische buurt	Oud-Oost	€ 18.960	Yes	€ 22.242	17,3%	68,4%
14	Jan van Scorelbuurt	Huizum-West	€ 21.534	Yes	€ 24.359	13,1%	40,4%
15	Molenpad	Oud-Oost	€ 18.079	Yes	€ 26.704	47,7%	39,5%
16	Nieuwestad	Binnenstad	€ 21.704	Yes	€ 24.576	13,2%	19,3%
17	Oldegalileën	Oud-Oost	€ 19.745	Yes	€ 22.223	12,6%	39,2%
18	Oldehove	Binnenstad	€ 16.400	Yes	€ 29.446	79,5%	33,1%
19	Oranjewijk	Potmargezone	€ 20.945	Yes	€ 31.682	51,3%	29,2%
20	Rengerspark	Sonnenborgh e.o.	€ 18.674	Yes	€ 19.996	7,1%	15,1%
21	Schepenbuurt	Potmargezone	€ 14.397	Yes	€ 17.009	18,1%	1,4%
22	Schieringen	Heechterp & Schieringen	€ 19.073	Yes	€ 22.652	18,8%	58,2%
23	Tulpenburg	Potmargezone	€ 18.071	Yes	€ 18.182	0,6%	16,9%
24	Valeriuskwartier	Sonnenborgh e.o.	€ 16.528	Yes	€ 19.307	16,8%	35,4%
25	Vrijheidswijk-Oost	Vrijheidswijk	€ 18.139	Yes	€ 21.052	16,1%	45,1%
26	Vrijheidswijk-West	Vrijheidswijk	€ 21.040	Yes	€ 24.382	15,9%	40,4%
27	Welgelegen	Oud-Oost	€ 18.871	Yes	€ 24.065	27,5%	41,3%
28	Wielenpôlle	Potmargezone	€ 10.900	Yes	€ 13.698	25,7%	72,3%
29	Zaailand	Binnenstad	€ 22.167	Yes	€ 22.689	2,4%	27,1%
30	Zeeheldenbuurt	Oud-Oost	€ 15.456	Yes	€ 23.111	49,5%	34,7%
	Leeuwarden		€ 22.837		€ 27.218	19,2%	50,1%
31	Aldlân-Oost	Aldlân & De Hemrik	€ 25.812	No	€ 29.892	15,8%	35,3%
32	Aldlân-West	Aldlân & De Hemrik	€ 24.935	No	€ 27.720	11,2%	23,3%
33	Blitsaerd	-	€ 38.494	No	€ 42.153	9,5%	33,1%

34	Bonifatius	Sonnenborgh e.o.	€ 28.810	No	€ 41.291	43%	61,2%
35	Camminghaburen-Midden	Camminghaburen e.o.	€ 25.834	No	€ 28.947	12,1%	31,4%
36	Camminghaburen-Noord	Camminghaburen e.o.	€ 24.987	No	€ 29.393	17,6%	31,0%
37	Camminghaburen-Zuid	Camminghaburen e.o.	€ 32.623	No	€ 37.286	14,3%	31,0%
38	Gerard Dou	Huizum-West	€ 25.265	No	€ 30.003	18,8%	37,7%
39	Havankpark	Weisteinde e.o.	€ 27.682	No	€ 32.065	15,8%	40,5%
40	Huizum-Bornia	Potmargezone	€ 23.116	No	€ 27.436	18,7%	0,7%
41	Huizum-Dorp	Potmargzone	€ 29.147	No	€ 33.433	14,7%	38,4%
42	Julianapark	Huizum-West	€ 27.107	No	€ 32.460	19,7%	38,4%
43	Nijlân	Nijlân & de Zwette	€ 23.005	No	€ 25.569	11,1%	40,4%
44	Rapenburg	Aldlân & De Hemrik	€ 27.427	No	€ 30.669	11,8%	5,8%
45	Sonnenborgh	Sonnenborgh e.o.	€ 24.883	No	€ 29.235	17,5%	47,3%
46	Techum	De zuidlanden	€ 31.450	No	€ 35.084	11,6%	44,8%
47	Transvaalwijk	Sonnenborgh e.o.	€ 30.813	No	€ 35.685	15,8%	42,5%
48	Vogelwijk	Sonnenborgh e.o.	€ 28.471	No	€ 33.403	17,3%	40,3%
49	Vossepark	Vossepark & Helicon	€ 28.830	No	€ 33.899	17,6%	46,9%
50	Westeinde	Westeinde e.o.	€ 25.533	No	€ 30.029	17,6%	34,8%
51	Zamenhofpark	Oud-Oost	€ 23.542	No	€ 27.529	16,9%	40,2%
52	Zuiderburen	Hempens/Teerns & Zuiderburen	€ 35.788	No	€ 42.872	20%	33%
53	**Barrahûs**	Middelsee		No data	-	-	18,9%
54	**Buitengebied De Zwette**	Nijlân	-	No data	-	-	-
55	**Buitengebied Hempens**	Hempens/Teerns & Zuiderburen	-	No data	-	-	-
56	**Buitengebied Noordwest**	Westeinde e.o.	-	No data	-	-	-
57	**Buitengebied West**	Nijlân	-	No data	-	-	-
58	**De Centrale**	Heechterp & Schieringen	-	No data	-	-	-
59	**De Fellingen**	Middelsee		No data	-	-	-
60	**De Groene Ster**	Camminghaburen e.o.	-	No data	-	-	-
61	**De Klamp**	De zuidlanden	-	No data	-	-	-
62	**De Werp**	De zuidlanden	-	No data	-	-	0,0%
63	**De Zuidlanden**	De zuidlanden	-	No data	-	-	-
64	**De Zwette I Harlingervaart**	Nijlân	-	No data	-	-	-
65	**De Zwette II Zwettehaven**	Nijlân	-	No data	-	-	-
66	**De Zwette III Schenkenschans**	Nijlân	-	No data	-	-	-
67	**De Zwette IV Businesspark**	Nijlân	-	No data	-	-	-
68	**De Zwette V Newton**	Nijlân	-	No data	-	-	-

69	**De Zwette VI Deinumerpolder**	Nijlân	-	No data	-	-	-
70	**EnergieCampus Sylsterrak**	Nijlân	-	No data	-	-	-
71	**Grote Wielen**	Camminghaburen e.o.	-	No data	-	-	-
72	**Harlingervaart Noord**	Vossepark & Helicon	-	No data	€ 30.488	-	-
73	**Havenstêd**	Middelsee	-	No data	-	-	-
74	**Hempens/Teerns**	Hempens/Teerns & Zuiderburen	-	No data	-	-	43,0%
75	**Hemrik**	Aldlân & De Hemrik	-	No data	-	-	-
76	**Huizum-Badweg**	Potmargezone	-	No data	-	-	28,0%
77	**Huizum-Sixma**	Potmargezone	-	No data	-	-	-
78	**Magere Weide**	Sonnenborgh e.o.	-	No data	-	-	-
79	**Snakkerburen**	Snakkerburen	-	No data	-	-	36,1%
80	**Stationskwartier**	Binnenstad	-	No data	€ 24.786	-	-31,0%
81	**Vierhuisterweg e.o.**	Westeinde e.o.	-	No data	-	-	49,4%
82	**Wetterstêd**	Middelsee		No data	-	-	-
83	**Wiarda**	De zuidlanden	-	No data	€ 39.243	-	-

Appendix 5 Used databases

Dataset	Source	Indicator	Link
Kerncijfers wijken en buurten 2016	CBS	AHI	https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83487NED/table?fromstatweb
Kerncijfers wijken en buurten 2021	CBS	AHI	https://opendata.cbs.nl/#/CBS/nl/dataset/85039NED/table
Woningwaarde per wijk	AlleCijfers	WOZ value per District	https://allecijfers.nl/ranglijst/hoogste-en-laagste-woningwaarde-per-wijk-in-de-gemeente-leeuwarden/
Woningwaarde per buurt	AlleCijfers	WOZ value per Neighborhood	https://allecijfers.nl/ranglijst/hoogste-en-laagste-woningwaarde-per-buurt-in-de-gemeente-leeuwarden/