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Active Transport in Groningen: An Analysis of Street Redesign and Urban Planning Strategies

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Illustration front page: Redesigned Astraat in Groningen ('Astraat', 2018)

Abstract

This paper examines the impact of street redesign on active transport in Groningen, focusing on the principles of visibility, accessibility, and safety. Using a combination of quantitative and GIS spatial analysis, the study investigates the relationship between street design elements and active transport patterns among residents of Groningen. The research problem addresses the limited understanding of how street design elements influence the encouragement of active transportation.

The main research question explores the influence of street redesign on active transport in Groningen, with sub-questions related to visibility, accessibility, and safety principles, as well as current patterns and preferences of active transport among residents. A convenience sample of 52 participants was surveyed to collect data on demographics, mode of transport, and perceptions of safety, accessibility, and visibility. GIS software was used to analyze street layouts, lighting, width, and traffic signs.

Findings indicate that the street redesign measures in Groningen have improved accessibility and safety for active transport. Participants reported feeling safer and found it easier to access desired locations on the redesigned streets. The study highlights the importance of prioritizing visibility, accessibility, and safety in urban design to promote active transport. These results contribute to the development of sustainable and healthy mobility solutions. Further research can delve into specific design elements that enhance active transport.

Key concepts: active transport, street redesign, urban planning

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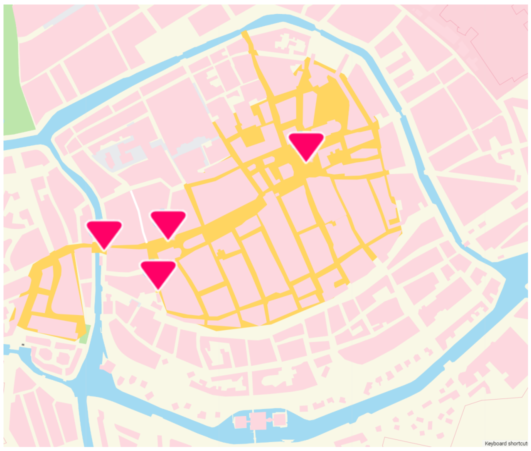
1. Introduction

1.1 Street Redesign

Urban planning is the process of designing and organizing the physical arrangements in cities and towns for the health, safety, and practical social needs of its population (LeGates and Stout, 2020). Urban planning is a broad field that includes a wide range of activities related to the development, management, and design of cities and towns. Spatial interventions are essential components of urban planning, as they refer to a range of changes made to the physical environment to improve its functionality, accessibility, or overall quality (Leary and McCarthy, 2013). These interventions can range from micro-scale, such as changes to street design, public spaces, and housing, to macro-scale such as national infrastructure improvements (Boyce, 2010). On a micro-scale, street redesign is a form of spatial intervention that can be an effective tool for creating more liveable, sustainable, and vibrant communities, as well as promoting safety, accessibility, and social interaction among residents. Specifically, to create safer and more accessible spaces for users of active transportation, which refers to modes of transportation such as walking and cycling. Incorporating bike lanes, crosswalks, and traffic safety measures can help to encourage more active transport and reduce reliance on cars, which can lead to improved health outcomes and reduced traffic pollution (Barbarossa, 2020). Unfortunately, many cities still face challenges in promoting active transport, due to limited infrastructure and safety concerns (Hensley, Mateo-Babiano and Minnery, 2014). Similarly, Dhanani, Tarkhanyan and Vaughan (2017) states that physical environmental characteristics, in other words, 'street design', are widely accepted as a method for assessing the urban environment's potential for encouraging active transport modes. Therefore, to overcome these challenges, street redesign interventions have become an essential strategy for maintaining and improving the quality of active transport infrastructure.

1.2 Case Study: Groningen

In the city of Groningen, located in the north of the Netherlands, renowned for its innovative approach to urban planning and transportation, active transport has been a focal point of development. In the 1970s, Groningen began implementing a traffic circulation plan to create a car-limited inner city and offer more space to active transportation, which includes pedestrians, public transport, and cyclist (Tsubohara, 2007). Since then, the inner city has been developing its network of cycling paths and pedestrianized areas, which resulted in Groningen being known for its extensive network of cycling paths. However, in recent years, the city has faced challenges in maintaining and improving its active transport infrastructure. These challenges are due to factors such as urbanization, population growth, and a shift in mobility patterns, which refers to transportation choices and travel habits (Gemeente Groningen, 2023). With more people living and working in the city, along with a growing demand for active transportation options, the existing infrastructure is experiencing increasing pressure. The Dutch Central Government provides 1.8 billion euros a year for provinces to spend on projects that will tackle these challenges (Pucher and Buehler, 2008). With this aid, Groningen has undertaken various street redesign initiatives to prioritize active transport; to improve the principles of safety, accessibility, visibility; and appeal of the existing infrastructure. Since 2017, public transport no longer runs through the western inner city and the space that this has created has been redesigned to give more space to pedestrians and cyclists (see Figures 1 and 2). The streets are designed from facade to facade with a profile consisting of a walking zone and a carriageway ('Astraat', 2018). These initiatives serve as a response to the challenges faced in the maintenance and improvement of active transport infrastructure in light of urbanization and shifting mobility patterns.



Figures 1 and 2 - Before and after street redesign Astraat (left) and map that shows all streets (in yellow) for street redesign projects (right) (‘Astraat’, 2018)

1.3 Research Problem

Despite the growing awareness of the benefits of active transport, including improved health outcomes, reduced traffic congestion, and lower emissions, many cities still struggle to promote non-motorized modes of transportation (Booth, Norman and Pettigrew, 2019). Street redesign has been identified as a potential solution, yet limited research exists on the street design elements that encourage active transportation. While previous studies (Boyce, 2010; Hensley, Mateo-Babiano and Minnery, 2014; Dhanani, Tarkhanyan and Vaughan, 2017; Booth, Norman and Pettigrew, 2019; Barbarossa, 2020) have established a correlation between street design and active transport, there remains a significant research gap in understanding the specific design elements within the spatial context of streets that contribute to the promotion of active transportation. This research aims to address this gap by focusing on three key design elements: street lighting, street width, and traffic signs. These elements have been identified as significant contributors to the overall street design and are expected to have a substantial influence on the promotion of active transport (Phillips et al., 2018; Gössling and McRae, 2022). By analyzing these design elements, this research aims to shed light on their relationship with active transport behavior and their alignment with the principles of visibility, accessibility, and safety.

The primary objective of this research is to examine the influence of street redesign on active transport in Groningen. It involves an analysis of the current streets within the inner city of Groningen, with an emphasis on their physical characteristics and the opportunities they offer for promoting active transportation among residents. Additionally, this research aims to evaluate the effectiveness of street redesign in facilitating active transport and to provide insights into optimizing urban planning strategies for active transport promotion in cities. By addressing these objectives, this study will contribute to the existing body of knowledge on active transport promotion and offer practical implications for urban planners and policymakers. This will be accomplished through an analysis of Groningen as a case study and by answering the central question of this research, which is:

> *“What is the influence of street redesign on active transport in Groningen?”*

The sub-questions are:

1. What are the current patterns and preferences of active transport among residents of Groningen?

2. To what extent do the spatial elements of street lighting, street width, and traffic signs align with the principles of visibility, accessibility, and safety in Groningen?
3. How do the principles of visibility, accessibility, and safety contribute to promoting active transport in Groningen?

1.4 Structure of Thesis

This paper is structured to provide an exploration of the relationship between active transportation and street redesign. It begins with a definition of active transportation and its significance in the urban context, emphasizing its key relationship with the principles of visibility, accessibility, and safety for promoting active transport. The analysis focuses on the active transportation infrastructure's three street design elements: street lighting, street width, and traffic signs, examining their influence on urban planning principles and their role in promoting and facilitating active transport. The research employs an analytical framework to guide the analysis, ensuring a systematic approach to data collection and analysis. The case study in Groningen provides primary and secondary data, which will be presented and analyzed to highlight the connections between different aspects of the active transportation process and its outcomes.

2. Theoretical framework

2.1 What is Active Transport?

In the article of Booth, Norman and Pettigrew (2019), 'active transport' as refers to transport options that involve physical activity, such as walking or cycling. As well as public transport, where these journeys especially involve walking or cycling for a portion of the trip. Active transport is associated with many individual and societal-level benefits (World Health Organization, 2022). At the individual level, active transport can contribute to health shaping, including physical fitness, increased energy levels, and reduced risk of chronic diseases such as diabetes, obesity, and heart disease. At the societal level, active transport can contribute to reducing greenhouse gas emissions by reducing car dependence, with also the reduction of traffic congestion, noise pollution, and the demand for fossil fuels (UNEP, 2022).

2.1.2 Principles of Visibility, Accessibility, and Safety on Active Transport

The revitalization of urban places depends heavily on all three principles of visibility, accessibility, and safety, and are highly intertwined with each other. The design of streets should support safe environments, but not at the expense of accessibility (LeGates and Stout, 2020). The article by Stoker *et al.* (2015) discusses the risks associated with poor visibility for pedestrians, particularly at night or under low-light conditions. They emphasize the importance of visibility for pedestrian safety and suggest strategies to mitigate the risks associated with poor visibility. It portrays that pedestrian fatalities increase as illumination decreases, with twilight and the first hour of darkness being the most dangerous times for pedestrian activity. Pedestrians are partaking in active transport through walking, however, both pedestrians and cyclist face risks associated with poor visibility, but the nature may differ depending on the situation. Creating visibility is an important aspect of street design to create a positive influence on participation in active transport.

An essential aspect of using public transport is its accessibility. Dhanani, Tarkhanyan, and Vaughan (2017) discuss the relationship between transportation accessibility, specifically public transport accessibility, and pedestrian activity in urban areas, with a focus on street design. The study used various transport locations (bus stops, tram stops, railway, and underground stations) within London to generate accessibility surfaces and then evaluated the relationship between transport accessibility and pedestrian density. The study found that transport accessibility has a strong correspondence to levels of pedestrian activity. The study also emphasizes the importance of public transport to all aspects of city processes that rely on pedestrian activity and accessibility. Additionally, accessibility, addressed as physical barriers posed by an environment (Boyce, 2010), is being used a lot within studies as a measurement for e.a. densities, social inclusion, and safety (Boyce, 2010; Stoker *et al.*, 2015; Barbarossa, 2020). Therefore, also within this paper, accessibility will be highlighted within street designs.

2.2 Elements of Street Redesign: Street Lighting, Street Width, and Traffic Signs

Street lighting, street width, and traffic signs are considered elements of active transportation infrastructure and road sign interventions in street redesign (Phillips et al., 2018). These interventions include, among other things, managing infrastructure and signage, creating road layouts to reduce motor traffic impact, maintaining pavements, cycle tracks, and roads, using signal control techniques, and ensuring good road sign implementation.

Porchia et al. (2014) conducted a systematic review focusing on the effect of improving cyclists' visibility on the risk of nighttime collisions. According to their findings, street lighting can prevent road traffic collisions, injuries, and fatalities, while also improving pedestrians' night-time visibility. Street lighting has been suggested as an intervention to enhance the visibility of pedestrians and cyclists. Retting et al.'s (2003) literature review also finds evidence that street lighting can reduce the risk of a pedestrian motor vehicle collision. In line with these findings, it is important to consider the minimum distance of lighting poles in residential areas. As outlined in the 'Requirements of street and road lighting' (DEFA, 2021) document, the minimum distance of lighting poles in residential areas should be 25 meters. This standard ensures adequate lighting coverage to enhance visibility and improve the safety of pedestrians and cyclists in these areas.

Street width is an important element of street design according to Gössling and McRae (2022). Wider cycle lanes and sidewalks are generally perceived more positively and receive higher safety approval compared to narrow situations. Research by Gössling and McRea (2022) suggests that wider lanes, particularly those measuring 3.5 meters in width instead of the standard 2 meters, not only enhance cyclist safety but also contribute to increased feelings of safety. Additionally, their research suggests that sidewalks wider than 2.5 meters are perceived to be safer for pedestrians. LeGates and Stout (2020) also highlight that the justification for the implementation of wider streets and wide, sweeping curves, instead of narrow ways and sharp corners is driven by safety concerns for both cyclists and pedestrians. Therefore, wider pavements and streets have a positive impact on pedestrians' and cyclists' safety and comfort.

While street lighting and street width are recognized as important elements of street design that can positively impact active transport, it is crucial to consider the effectiveness of traffic signs (Phillips et al., 2018; Gössling and McRae, 2022). While traffic signs are generally beneficial, an overabundance of signs and variations in user interpretation can potentially hinder their effectiveness. Furthermore, the impact of traffic signs is influenced by contextual factors such as street design and the presence of other infrastructure elements (Retting, Ferguson and McCartt, 2003; Porchia *et al.*, 2014). Addressing the limitations and contextual factors is essential in providing a comprehensive analysis of spatial elements and their alignment with the principles of visibility, accessibility, and safety in Groningen.

2.3 Existing Street Redesign Concepts for Active Transport in Groningen

In examining the relationship between street redesign and active transport, it is essential to consider the physical environmental characteristics, which include elements such as buildings, sidewalks, streets, parks, and other features that significantly influence human behavior and health outcomes. (Boyce, 2010; Hensley, Mateo-Babiano, and Minnery, 2014; Stoker et al., 2015; Dhanani, Tarkhanyan and Vaughan, 2017). Factors like land use, accessibility, transportation, infrastructure, and urban design, offer valuable insights into individuals' transportation choices, influencing mode choice, travel behavior, health and well-being, and environmental impact. Notably, the consideration of these physical environmental characteristics and their influence on transportation choices has guided the Dutch approach to street design (Ben-Joseph, 2007). Within this approach, two prominent concepts emerge, the 'Fietsstraat' and the 'Woonerf' concepts (van der Burgh, 2018). The Fietsstraat, a bicycle street, is a concept that designates certain streets primarily for bicycles while still allowing motor vehicle access. These streets prioritize the safety and comfort of cyclists by giving priority over motor vehicles, therefore they contribute to creating a cyclist-friendly infrastructure and promoting active transport. Woonerf, a living street, refers to a residential street designed with a shared space concept. In Woonerfs, pedestrians, cyclists, and vehicles share the same space, typically with low-speed limits. They prioritize the needs of pedestrians and cyclists while accommodating motor vehicles, encouraging active transport, and enhancing the quality of the living environment (*Dutch Cycling Embassy - Cycling for everyone*, 2023). These concepts exemplify the efforts to create inclusive and safe environments for active transport, considering the needs of all road users and enhancing the quality of the living environment.

2.4 Hypothesis

- The spatial elements of street design, including wider street width, adequate street lighting, and clear traffic signs, are expected to have a positive influence on the encouragement of active transport.
- The principles of visibility, accessibility, and safety contribute to promoting active transport in Groningen by enhancing the street environment and encouraging its use for active modes of transportation.
- Residents' perceptions of the street environment, including factors such as aesthetics, perceived safety, and comfort, significantly impact their preference for active transport modes.

2.5 Conceptual Model

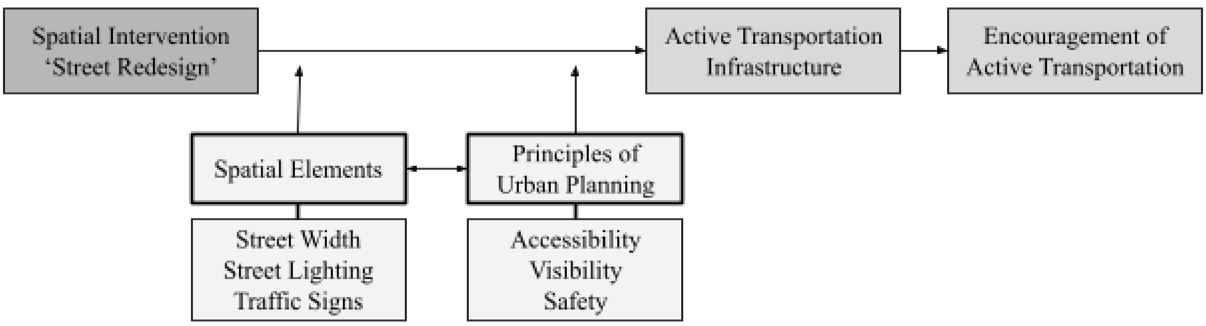


Figure 3 - A conceptual model for street redesign and its influence on the encouragement of active transportation.

The conceptual model (see Figure 3) illustrates the relationship between key elements in promoting active transportation. It starts with spatial intervention, specifically street redesign, which includes changes to street width, street lighting, and traffic signs. These interventions shape the creation of active transportation infrastructure like bike lanes and crosswalks. The model emphasizes the bidirectional relationship between spatial elements and principles of urban planning. Spatial elements, guided by the principles inform the design choices in street redesign. Similarly, the principles of urban planning influence the selection and implementation of spatial elements to achieve desired outcomes and promote active transportation. The resulting active transportation infrastructure serves as a foundation for encouraging active modes of transport and providing dedicated facilities. It signifies that the presence and quality of the infrastructure created through street redesign can positively influence and encourage people to engage in active transportation.

3. Methodology

This paper aims to investigate the impact of street redesign on active transport in Groningen through a combination of quantitative analysis and spatial analysis. The primary objective is to understand the relationship between street redesign and active transport outcomes, focusing on patterns and preferences observed in the data. Instead of focusing on formal statistical significance, this study aims to provide a comprehensive understanding of the data. After careful consideration, the chosen approach of quantitative and spatial analysis proves to be appropriate for achieving the research objective. Quantitative analysis provides statistical insights, while spatial analysis examines the physical aspects of the street environment and their implications for active transport. Qualitative interviews were not selected due to their potential limitations in capturing the larger-scale patterns and preferences. Groningen was chosen as a case study because of its well-known extensive cycling network, active involvement in street redesign initiatives to prioritize active transport and proximity to the researcher's location.

The study emphasizes evaluating the practical significance and real-world implications, aligning the identified patterns and relationships with existing knowledge, theories, or spatial research in the field. The data collection process was designed to capture a broad range of information without specifically targeting statistical hypothesis testing. Taking into consideration that human behavior is a complex phenomenon, additional variables such as gender, age, and education level are measured to account for possible influences on transportation choices. The theory and data are examined together to ensure accurate interpretation of the findings.

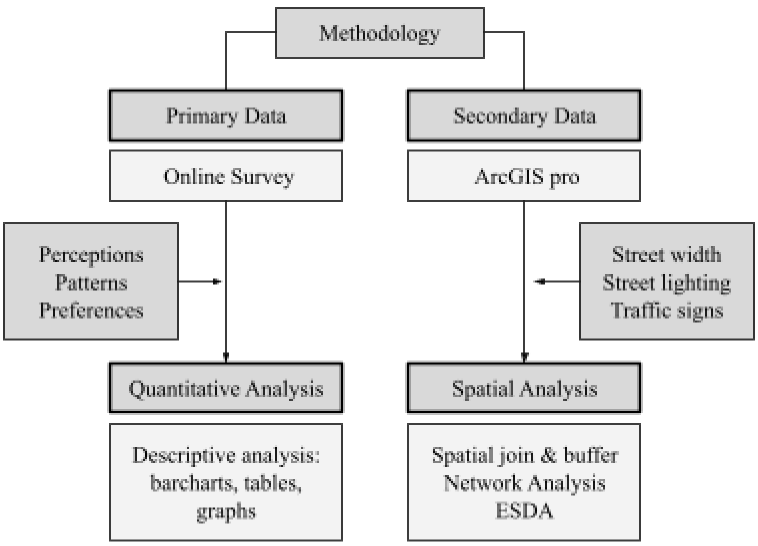


Figure 4 - Visualization of the methodology used, including primary and secondary data and their respective analysis method

3.1 Quantitative analysis - primary data

In order to understand active transport habits and street redesigns of the city as perceived by its citizens, a self-reported survey was distributed. The individuals' perspectives on their surroundings were chosen as the criteria for judging the quality of the surroundings. The purpose of the collection of primary data through an online survey is to:

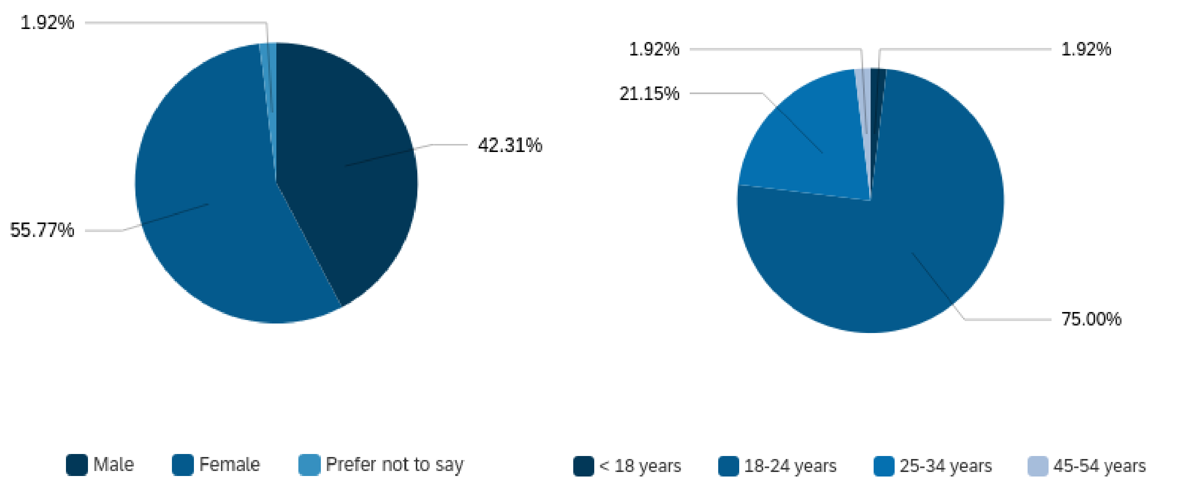
- *Analyze the current patterns and preferences of active transport among residents.*
- *Identify the influence of street redesign on people's perception of safety, accessibility, and visibility.*

3.1.1 Data Analysis Scheme

The survey data will be analyzed using descriptive statistics to determine the frequency and distribution of responses obtained from the survey participants. Descriptive statistics such as frequency distributions can be used to summarize the responses to ordinal questions. To enhance the clarity and visual appeal of the results, tables, graphs, and charts will be used as effective tools for presenting the findings derived from the data analysis. Through this approach, a comprehensive understanding of the survey results will be attained and effectively conveyed.

3.1.2 Respondents

The sample was composed of a research group of 52 participants, all of whom took part in this study on a voluntary basis. The survey is administered online to residents of Groningen who use the streets in the inner city of Groningen and use active transport regularly. Qualtrics XM platform is used for the creation of the online survey. Participants were chosen in a convenience sample and were recruited through the spread of the online survey via Whatsapp and Instagram. The survey was available to the participants for 12 days, allowing them to complete it at their convenience. The estimated completion time is set at 5-10 minutes. Demographic data was collected to assess the possible control of confounding variables. The demographic description of the sample is presented in Figures 5 and 6 (and Table 1, Appendix C). Data about age, gender, and education level, are presented with frequencies and percentages from the research population.



Figures 5 and 6 - Distribution of age (left) and gender (right) categories of the research population (N=52)

3.1.3 Instruments

The results section presents the findings obtained from analyzing the responses to the online survey questionnaire. The survey aimed to gather information regarding various aspects related to active transport and the recent street redesign in Groningen. The questions covered four blocks (see Appendix D) on the respondents' demographic characteristics, their active transport behaviors, observations of street design changes, and perceptions of the impact of the redesign on safety, accessibility, and visibility. Most questions are ordinal questions with a few options to specify using text.

The questions in the questionnaire were influenced by the literature review and the researcher's experience. The questionnaire was examined by a group of classmates for recommendations and improvement before being used. The survey starts with an introduction that defines "active transport" and "street redesign". In the introduction, it will also state that the participants will be asked about their use of active transport, and supporting evidence of their active transport habits. Additionally, it will state that the survey includes questions about demographic information, that will be used to control for potential surprising variables in the analysis and to better understand the factors that may influence active transport behavior. Additionally, the participants were reminded of their rights to participation, including; informed consent, data privacy, and confidentiality.

3.1.4 Ethical Considerations

1. By proceeding with the survey, informed consent was obtained from all participants before their inclusion in the study. A detailed information introduction was provided explaining the purpose of the study, their rights as participants, their freedom to withdraw, and their voluntary participation.
2. To ensure data quality, data validation checks were applied to identify and rectify any missing or inconsistent responses.
3. Participant data were treated with strict confidentiality throughout the study. All survey responses were anonymized, and any identifying information was kept separate from the survey data. Access to the data was limited to the researcher, and all electronic data files were password-protected. Only data without any personally identifiable information were reported in the final analysis and thesis write-up.

Source: (KNAW *et al.*, 2018)

3.2 GIS spatial analysis - secondary data

Geographic Information System (GIS) technology enables the analysis of spatial data, such as street layouts, street lighting, street width, and traffic signs, as well as data on the street network, public transit routes, and bicycle infrastructure. The data will be collected through existing datasets in GIS, including ESRI Nederland, PDOK basisregistratie, and OpenStreetMap, which will be transferred into ArcGIS Pro.

3.2.1 Data analysis scheme

The spatial analysis techniques that will be used include spatial join, buffer analysis, network analysis, and exploratory spatial data analysis (ESDA). These techniques enable a comprehensive analysis of the street design variables, transportation connectivity, and factors influencing active transport behavior. ESDA allows for the analysis and visualization of text-based data within maps. The variables of street lighting, street width, and traffic signs will be identified through maps.

- Existing light location data in GIS will be used to measure the coverage of street lights. Buffers of 25 meters will be drawn to assess the adequacy of lighting in different areas of the city (DEFA, 2021).
- GIS (mapping tool) will be used to determine the average width of streets in different areas of Groningen, looking into variables such as lane and sidewalk width.
- Data from the municipality will be used to assess the presence and quantity of traffic signs. GIS spatial analysis will examine the relationship between current traffic incident locations and the presence or absence of traffic signs, highlighting any correlation between traffic accidents and traffic signs.

This combined methodology will enhance the research's rigor and provide a multidimensional analysis of street redesign and active transport. The quantitative analysis and GIS spatial analysis will generate informational insights, facilitating a comprehensive assessment of the research questions and sub-questions.

3.3 Quality of the Data

The quality of data in this study is ensured through a methodology combining quantitative analysis and GIS spatial analysis. The study considers complex human behavior by including variables like gender, age, and education level. Ethical considerations are addressed, and data validation checks are applied. The quantitative analysis section uses a self-reported survey, while the GIS spatial analysis section uses existing datasets in GIS.

The survey aimed to achieve a high response rate and representative sample. The response rate was monitored closely, and efforts were made to reach out to specific demographic groups to ensure diversity in the sample. However, it is important to note that the survey was conducted online, which may introduce a potential bias towards individuals with internet access and digital literacy skills.

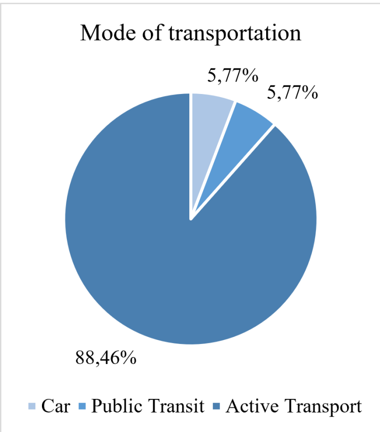
Several limitations should be acknowledged in interpreting the findings of this study. Firstly, the sample size was limited to 52 participants from a specific geographical area, which may restrict the generalizability of the results to a broader population. Additionally, the reliance on self-reported survey data introduces the possibility of response bias and recall errors. It is important to consider these limitations when extrapolating the findings to other contexts or populations.

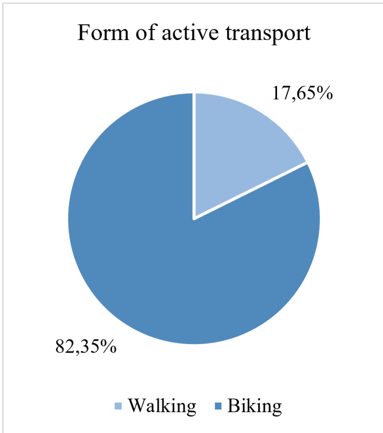
4. Results

In this section, to elaborate on the study´s central objective, which is to examine the influence of street redesign on active transport in Groningen, a comprehensive analysis of the collected data from the inner city of Groningen is presented. Here, different insights will be highlighted along the adopted framework consisting of the *street redesign elements* and the *principles of urban planning* (sections 4.2 and 4.3). But first, in section 4.1, the descriptive statistics of the research variables were obtained from the second block of the survey 'Questions about Active Transport' (See Appendix D).

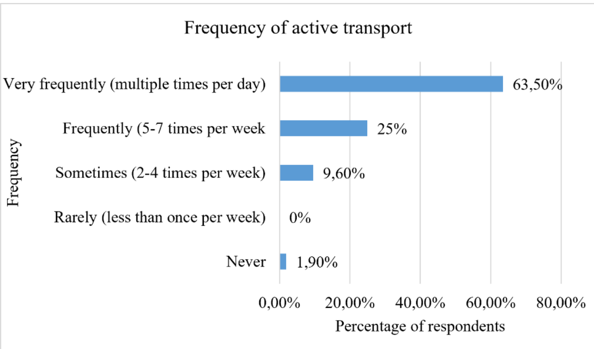
4.1 Active Transport Behavior

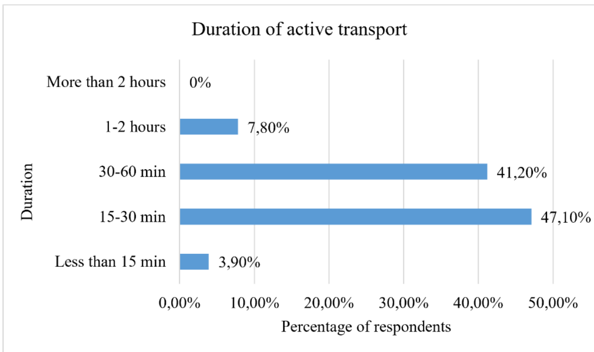
A majority of 88,46% of the participants indicated their preference for active transport, such as walking and cycling, as their primary mode of commuting, as shown in Figure 7 (and Table 2, Appendix C). Biking emerged as the favored mode of active transportation (82.35%) (see Figure 8). It is noteworthy that 63.5% of participants engage in active transport multiple times per day for various purposes, including work, school, and other destinations (see Figure 9). Only one participants reported not using any form of active transportation. The duration of these trips varied among participants, with the majority (47.1%) falling within the 15-30 minute range, while others reported longer durations of 30-60 minutes (41.2%) or even 1-2 hours (7.8%) (see Figure 10). These findings highlight the widespread adoption and regular use of active transportation into daily routines. Therefore this observation emphasizes the need to explore and understand the elements and principles that can further encourage active transport, this will be further analyzed later on (4.2 and 4.3).





Figures 7 and 8 - Piecharts distribution transport (left) and active transport (right) patterns





Figures 9 and 10 - Bar charts frequency (left) and duration (right) of active transport

4.2 Street Redesign Elements in Groningen

Since 2017, the inner city of Groningen is working on a street redesign project called 'Ruimte voor jou', translated into 'Space for you' to provide residents with a city center that is attractive and accessible, with a particular focus on more space for active transportation ('Projecten Binnenstand Groningen', 2023). The positive impact of this street redesign project is evident, with the majority of respondents (88%) acknowledging noticeable recent changes in the street design of the inner city of Groningen (see Figure 13). It is worth noting that while the vast majority noticed these changes, a small proportion (12%) did not report perceiving any specific alterations in the street design. Further investigation is needed to understand the factors contributing to this observation and to address any potential reasons behind the lack of perceived changes among this group. In line with the project goals, Groningen has been working on providing more space by removing the majority of the bus routes. The streets are also designed to be more for pedestrians and bicycles, where the car is a guest. This is done through a replacement of the pavement with yellow bricks, to indicate priority to cyclists and pedestrians (see Figures 11 and 12). This aligns with the survey responses, where the change in street material was reported to be noticed the most out of the street redesign changes among the respondents. As can be seen in Figure 13, roughly 47% indicated that the street material had changed, of which 83% indicated that the streets are now made out of bricks (Table 3, Appendix C). Most streets are now, as mentioned before, designed from facade to facade with a profile consisting of a walking zone and a carriageway. The new design ensures limited mixing of pedestrians and other traffic, as well as a clear and safe comfort zone for pedestrians and cyclists, and it becomes more attractive and spacious for pedestrians and cyclists (*Concept inrichtingsplan Astraat-Brugstraat-Munnekeholm*, 2017). These ambitions were not in vain, the respondents indicated that the change in street material added 'a somewhat better' (43.9%) or 'much better' (17.1%) change to the overall quality of the street (see Table 5, Appendix C).

Figures 11 and 12 - Redesigned Munnekeholm Street before (left) and after (right), done in 2019 ('Munnekeholm', 2021)

Additionally, the perception of the cities' efforts towards an attractive and motorized-traffic-reduced inner city through street redesign is not consistent among respondents. When asked about the impact of street redesign on traffic flow and congestion, respondents had mixed opinions. Some were uncertain or didn't know (35%), while others believed it improved traffic flow and reduced congestion (35%). A smaller percentage noticed no significant difference (17%), and a few felt that it worsened traffic flow and increased congestion (13%). Similarly, opinions varied regarding the street redesign's contribution to the city's overall aesthetic appeal. However, the majority of participants (45.7%) felt that street redesign made a moderate contribution to the aesthetic appeal of the city (see Table 4, Appendix C).

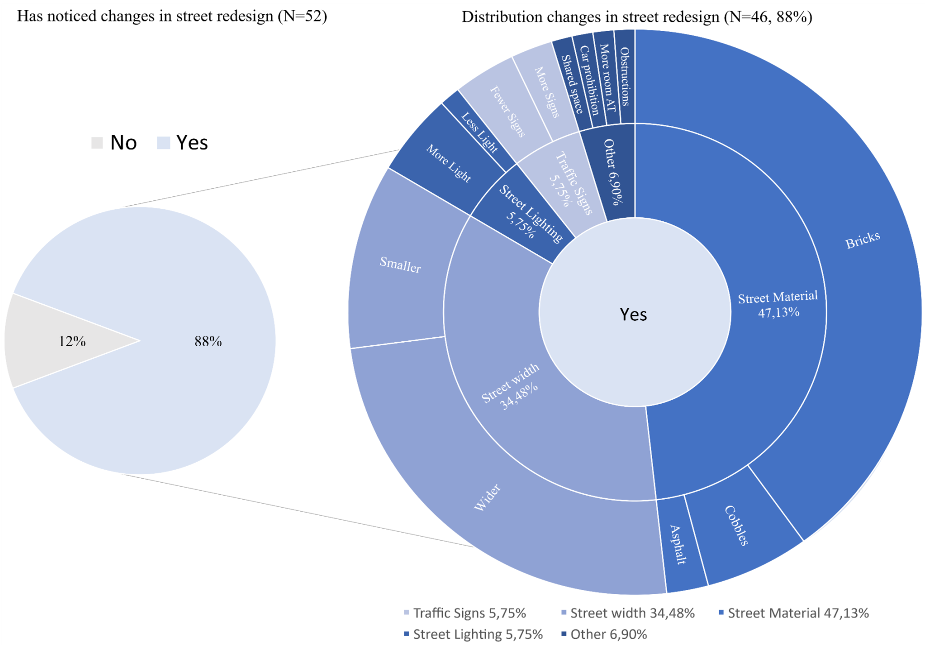


Figure 13 - Pie chart and Sunburst chart of distribution notices in street redesign in Groningen

4.2.1 Street Width

Map 1 displays close-ups of two streets in Groningen with before and after measurements, showcasing the changes in street width resulting from the street redesign initiative mentioned before ('Projecten Binnenstand Groningen', 2023). Streets in the inner city, including Monnikholm, Astraat, Brugstraat, and Hoger der A, have undergone redesign, resulting in a minimum roadway width of 3.5 meters, as observed in the cross-section (see Figure 14). These streets also feature a hybrid zone for pedestrians and cyclists, measuring 0.5 meters, along with a minimum 2.5 meters walking zone adjacent to it.

The wider streets were reported by 21 out of 30 individuals who noticed the changes in street width (see Table 3, Appendix C), which aligns with Groningen's aim to provide more space for active transportation users. According to the survey results (see Figure 13), the change in street width was the second most noticed street redesign change, as reported by 34.48% of the respondents. Additionally, based on the perceptions of the participants (see Table 5, Appendix C), the overall quality of the redesigned streets, including the widened sections, was perceived to be of "Adequate/appropriate width" by 67.7% of the participants. This indicates that the widened streets were well-received and considered suitable for their intended purpose. The observations and feedback from the respondents demonstrate that the changes in street width were effective in creating a noticeable impact on the streetscape.

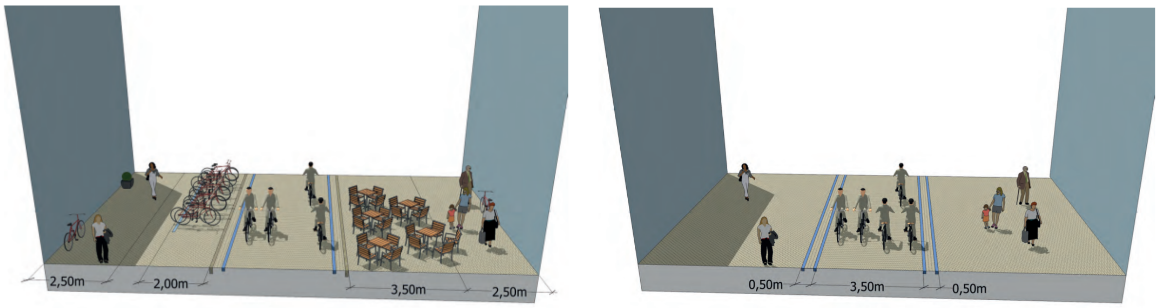


Figure 14 - Crosssections with measurements of redesigned streets including Monnikholm, Astraat, Brugstraat, and Hoger der A (*Concept inrichtingsplan Astraat-Brugstraat-Munnekeholm*, 2017)

4.2.2 Street Lighting

Results from the survey do not show a significant notice of a change in street lighting throughout the inner city (5.75%) (see Figure 13), therefore this data will be left out from the result and conclusion section. However, the analysis of street lighting in the inner city of Groningen using GIS has shown significant results. The analysis of the distribution of street lighting in relation to their 25-meter buffers enables the identification of potential gaps or deficiencies in the lighting infrastructure. Therefore, Map 2 (Appendix A) displays the precise locations of light poles throughout the area, obtained from the dataset *Openbare verlichting gemeente Groningen | Data overheid* (2022), along with their corresponding 25-meter buffers. Furthermore, the map incorporates the classification of streets based on their functions, providing a comprehensive understanding of the urban layout. Notably, the map highlights streets with insufficient lighting by marking them in yellow. Additional insights from bar chart 1 (Appendix B) reveal that a total of 19 pedestrian street segments on 2 streets (Naberstraat, Nieuwe Markt) lack adequate lighting. This finding shows that the street redesign plans in these certain areas are lacking the implementation of more street lighting.

4.2.3 Traffic Signs

The results for traffic signs (5.75%) (see Table 3) show a similarly insignificant notice to be included in the result and conclusion section. To explore the relationship between traffic signs and traffic accidents, areas of traffic incidents will be mapped against the existing distribution of traffic signs. This analysis aims to assess the impact of traffic signs on accident occurrence, considering the potential hindrances caused by an overabundance of signs and variations in user interpretation. The locations of traffic incidents and the number of traffic signs at sensitive spots are visualized in Map 3 (Appendix A) using ArcGIS Pro (*Verkeersongevallen - Overzicht*, 2023; *Verkeersborden (NDW) - Overzicht*, 2023). The map displays the distribution of traffic incidents with a 15-meter buffer, shown in green, along with the locations of traffic signs. The analysis of the distribution of traffic incidents and traffic signs within this buffer in Groningen reveals two key conclusions:

- *Presence of Traffic Signs:* Out of the 85 traffic incident locations studied, 34 locations within the 15-meter buffer do not have traffic signs, indicating a potential lack of signage in those areas. This highlights the need for attention and the potential installation of traffic signs in these locations to improve safety and reduce the risk of accidents.
- *Distribution of Signs:* Among the 53 incident locations that have traffic signs within the 15-meter buffer, there is a varied distribution in the number of signs present. The accompanying Bar chart 2 (Appendix B) displays this distribution, indicating the number of incident locations (y-axis) associated with different quantities of signs (x-axis). Indicating that while an excessive number of signs may cause visual clutter and distract drivers, the absence of signs can also pose risks.

4.3 Guiding Principles of Urban Planning

The guiding principles of accessibility, visibility, and safety that are being used as a main focus within this paper, were included in the survey among other factors that could influence respondents' decision to use active transport. The factors included accessibility, safety, visibility, convenience, cost, health benefits, and environmental concerns. This gave an indication of what influences people's decision to use active transport. The results show how participants ranked the factors, indicating how many respondents (count) put a certain factor in that place/order. For the visual distribution see Figure 15. To further elaborate, ‘convenience’ has been put by most people on spot 1, being the most influential, whereas ‘visibility’ ended on the last spot, being put there by 19 respondents.

1. Convenience (count: 22 (44%))
2. Accessibility (count: 16 (32%)
3. Cost (count: 19 (38%))
4. Health benefits (count: 11 (22%))
5. Environmental concerns (count: 11 (22%))
6. Safety (count 14 (28%))
7. Visibility (count 19 (38%))

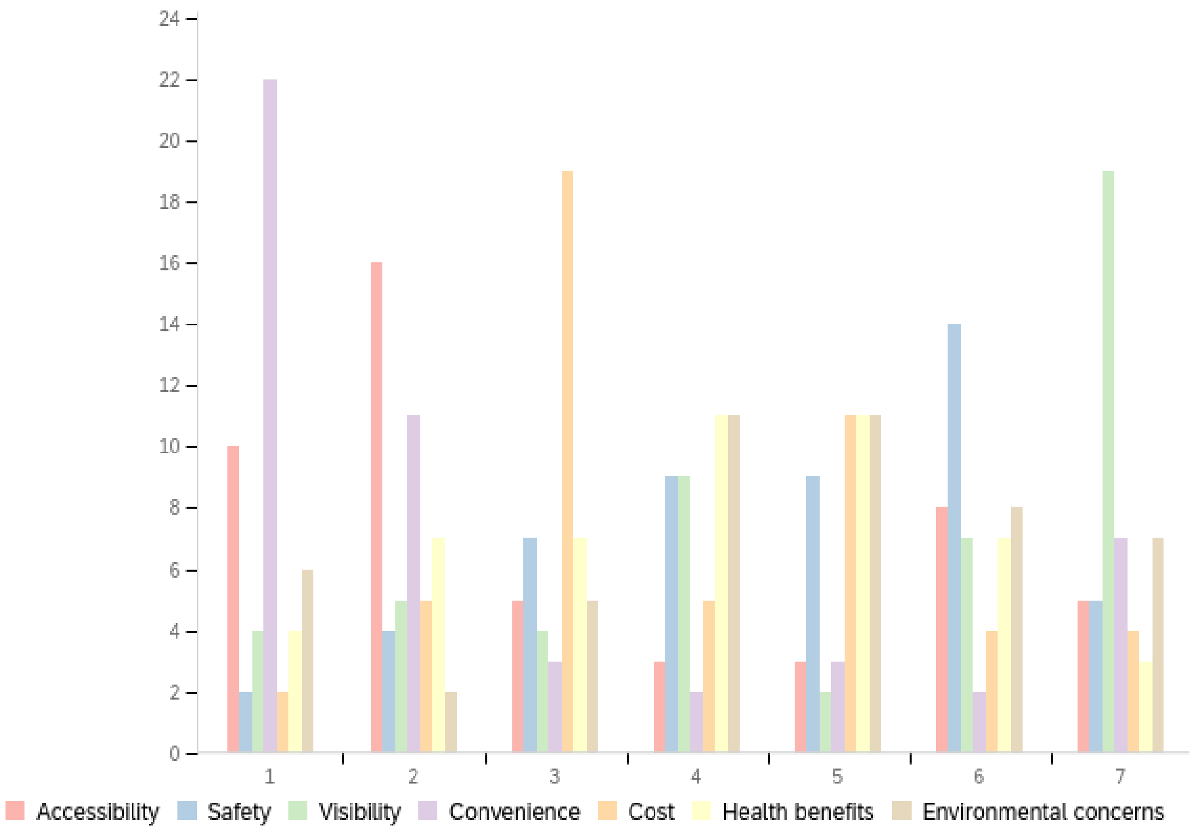


Figure 15 - Distribution of the factors that influence the decision to use active transport

Additionally, these findings highlight the importance of factors such as convenience, accessibility, and costs to encourage their decision in using active transport. It can be seen that safety and visibility have less of an influence on people than expected, compared to the other factors.

5. Discussion

5.1 Accessibility, Visibility, and Safety

Accessibility on redesigned streets were found to be satisfactory. Respondents found it ‘somewhat’ (44.4%) or ‘extremely’ (40%) easy to access the places they need to go to using active transport (see Table 6, appendix C). Additionally, in general, wider streets are perceived to be better accessible than narrower streets (LeGates and Stout, 2020; Gössling and McRae, 2022). The theoretical framework suggests a minimum width of 3.5 meters (lanes) and 2.5 meters (sidewalks) for optimal access, and the cross-sections in Figure 14 and Map 1 demonstrate that Groningen has good street width, ensuring optimal accessibility.

While Groningen is generally well-lit in terms of street lighting, the study revealed certain parts of the city are lacking adequate lighting infrastructure. However, it is important to recognize the government’s efforts (‘Ruimte voor jou’ project) in improving the overall street design and accessibility. Although survey participants did not prominently notice changes in street lighting, the GIS analysis demonstrated significant results. By addressing this issue and improving street lighting, active transport users would benefit from enhanced visibility, leading to a safer and more secure environment for their commuting activities.

Redesigned streets in Groningen have shown an increase in safety among the respondents, with 51.1% feeling 'somewhat safe' and 35.6% feeling 'very safe' (see Table 6, Appendix C). This aligns with Groningen's intentions to redesign its streets (‘Projecten Binnenstand Groningen’, 2023). However, certain areas within the inner city still lack adequate lighting, as mentioned earlier. Addressing the 19 street segments with insufficient lighting could further enhance people's perception of safety while engaging in active transport. Additionally, the distribution of traffic signs across the traffic accident areas indicates that an excessive number of signs ‘may cause visual clutter and distract drivers, the absence of signs can also pose risks’ (section 4.2.3).

Overall, participants agreed that the redesigned streets have improved visibility, accessibility, and safety for active transport, with a majority (81.82%) strongly or somewhat agreeing with this statement. Furthermore, participants expressed a high likelihood of continuing to use active transport on the redesigned streets (see Table 6, Appendix C). These findings emphasize the importance of designing urban spaces that prioritize these principles to encourage active transport and accommodate the preferences of active transport users.

6. Conclusion

In conclusion, this research aimed to investigate the influence of street redesign on active transport in Groningen, with a focus on the street design elements and the principles of visibility, accessibility, and safety. The findings indicate that street redesign in Groningen has had a positive impact on active transport behavior and aligns with the municipality’s objectives of promoting sustainable and active modes of transportation.

The implemented street redesign elements in Groningen have positively influenced active transport behavior by enhancing the street quality, accessibility, and appeal to pedestrians and cyclists. While participants did not significantly notice improvements in street lighting and traffic signs, further analysis identified areas where enhancements could improve safety and visibility, such as addressing inadequate lighting in certain locations and optimizing the distribution of traffic signs. The redesign provided a strong foundation for promoting active transport and aligning with the principles of visibility, accessibility, and safety. Prioritizing these principles and considering the preferences of active transport users, cities can create environments that encourage and facilitate active transport.

It is crucial to continue monitoring and addressing areas of improvement to ensure the ongoing success of the street redesign in promoting and accommodating active transport options. Therefore, these findings contribute to the growing body of knowledge on sustainable and healthy mobility in urban areas, supporting the promotion of active transport on urban agendas.

7. Reflection

The methodology employed in this study aimed to investigate the impact of street redesign on active transport in Groningen through a combination of quantitative analysis and spatial analysis. While formal statistical tests were not used for hypothesis testing, the focus was placed on gaining insights into present patterns and preferences observed in the data, as well as evaluating the practical significance and real-world implications. The findings presented in this research provide valuable insights into the influence of street redesign on active transport in Groningen. However, it is important to acknowledge the limitations of not using statistical tests for formal hypothesis testing (Frank, Tam and Rhee, 2021). By not conducting such tests, potential sources of bias and alternative explanations may arise, which could affect the interpretation of the results.

Firstly, the absence of statistical tests limits the ability to establish causal relationships between street redesign elements and active transport behavior. While this paper reveals associations and patterns between the variables examined, it is essential to recognize that other factors beyond street redesign could contribute to the observed outcomes. The absence of statistical tests makes it difficult to establish a direct causal relationship between the observed changes and the street redesign efforts.

Furthermore, the research's reliance on self-reported survey data introduces the possibility of response bias and recall errors. The sample size was limited to 52 participants from a specific geographical area, which may restrict the generalizability of the results to a broader population. Additionally, the survey was conducted online, potentially introducing a bias toward individuals with internet access and digital literacy skills. These limitations should be taken into consideration when interpreting the findings and extrapolating them to other contexts or populations.

To mitigate these limitations, the study incorporated demographic data collection to assess the possible control of confounding variables such as gender, age, and education level. The data analysis employed descriptive statistics, which provided a summary of the responses obtained from the survey participants.

Despite these limitations, the combined methodology of quantitative analysis and GIS spatial analysis strengthens the research's rigor and provides a multidimensional analysis of the relationship between street redesign and active transport. The findings derived from this approach, while not statistically tested, can still offer valuable insights and inform future research and decision-making processes in urban planning and transportation policy. It is important to acknowledge these limitations and approach the results with caution, considering alternative explanations and potential confounding factors. Further research using more robust methodologies and larger sample sizes would be beneficial to validate and strengthen the findings.

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8.1.1 Website References

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11.2 GIS data collection

Openbare verlichting gemeente Groningen | Data overheid (2022). Available at: https://data.overheid.nl/dataset/groningen-openbare-verlichting-gemeente-groningen, https://data.overheid.nl/dataset/groningen-openbare-verlichting-gemeente-groningen (Accessed: 4 June 2023).

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8.3 Figures
Figures 1 and 2 - ‘Astraat’ (2018) *Binnenstad Groningen*. Available at: https://ruimtevoorjou.groningen.nl/project/5-herinrichting-astraatbrugstraat-gereed-2017/ (Accessed: 2 June 2023).

Figures 11 and 12 - ‘Munnekeholm’ (2021) *Binnenstad Groningen*, 22 December. Available at: https://ruimtevoorjou.groningen.nl/project/6-herinrichting-munnekeholm/ (Accessed: 15 June 2023).

Figure 14 - *Concept inrichtingsplan Astraat-Brugstraat-Munnekeholm* (2017) *Binnenstad Groningen*. Available at: https://ruimtevoorjou.groningen.nl/nieuws-item/concept-inrichtingsplan-astraat-brugstraat-munnekeholm/ (Accessed: 29 June 2023).

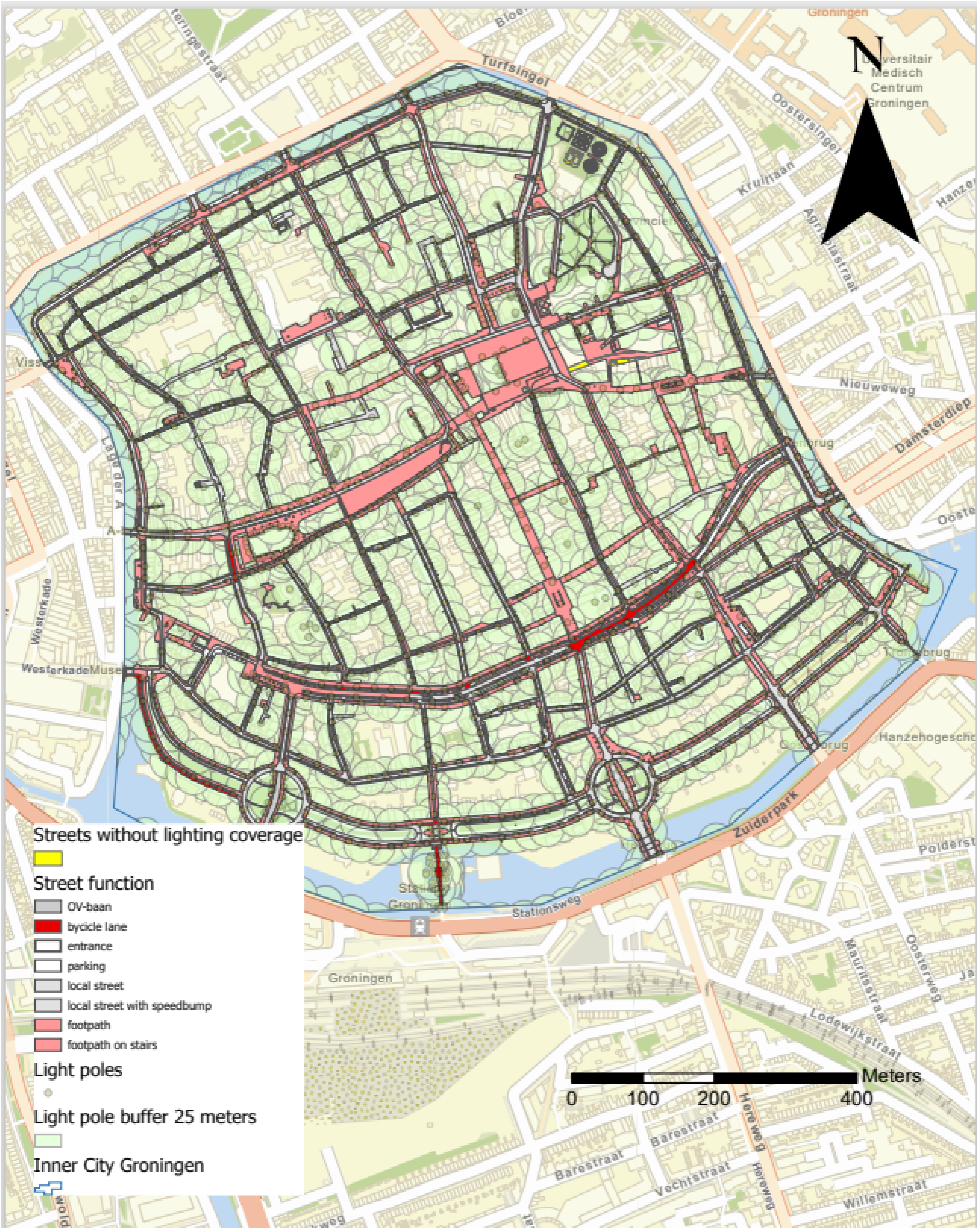
Figure 15 - Esri 2021, ArcGIS Pro, Version 3.1 (2021). Available at: https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview.

9. Appendix

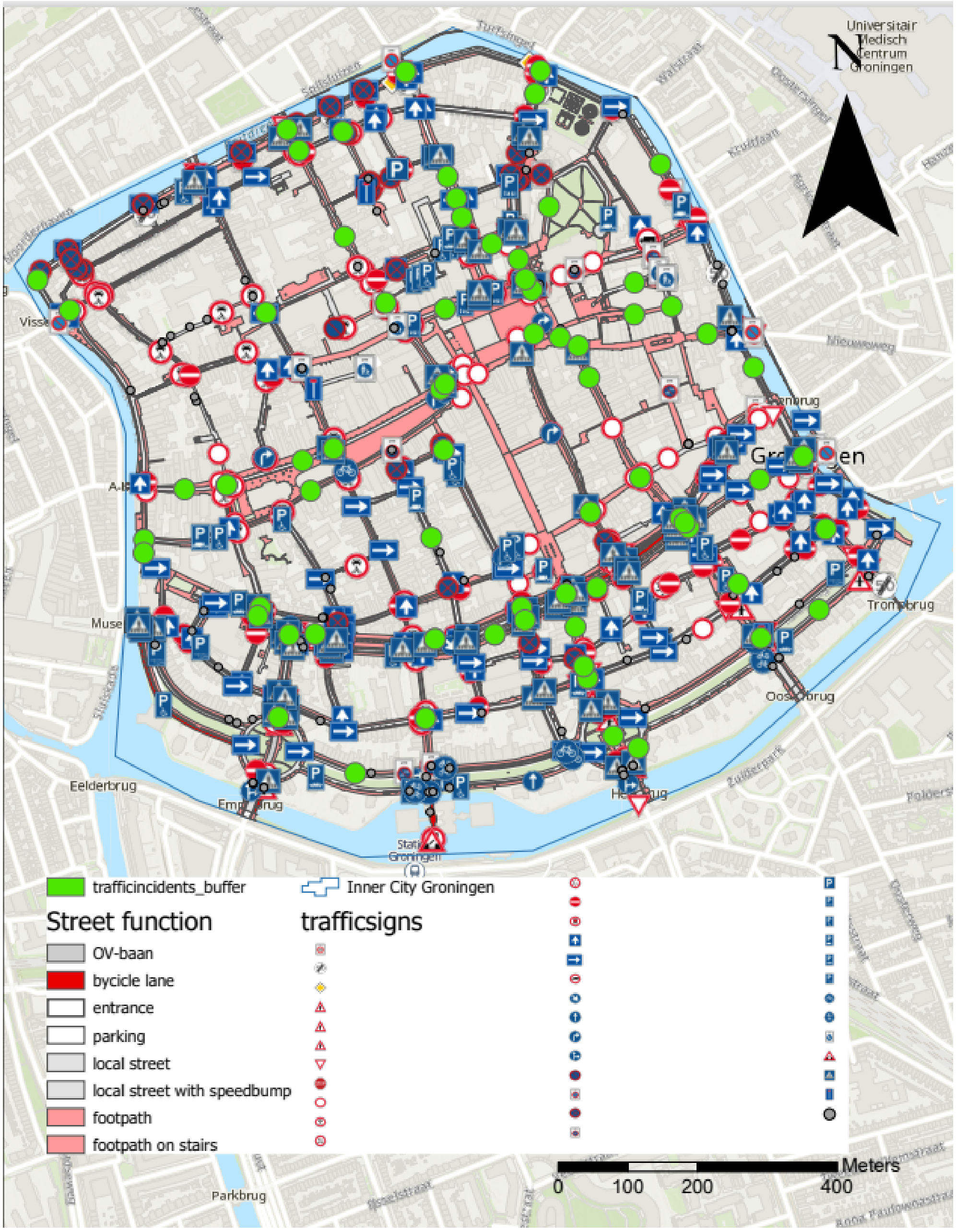
9.1 Appendix A - ArcGIS Pro maps

Map 1 - Inner City of Groningen, close-up display of street widths before 2016 (blue) and after 2023 (green)

Map 2 - Inner City of Groningen, display of street lighting with buffer and street functions

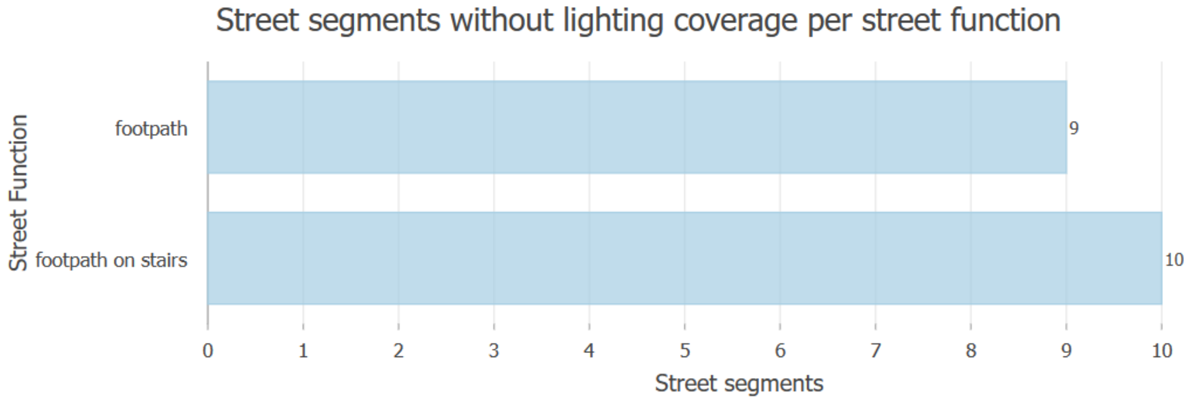


Map 3 - Inner City of Groningen, display of traffic signs and traffic incident buffers

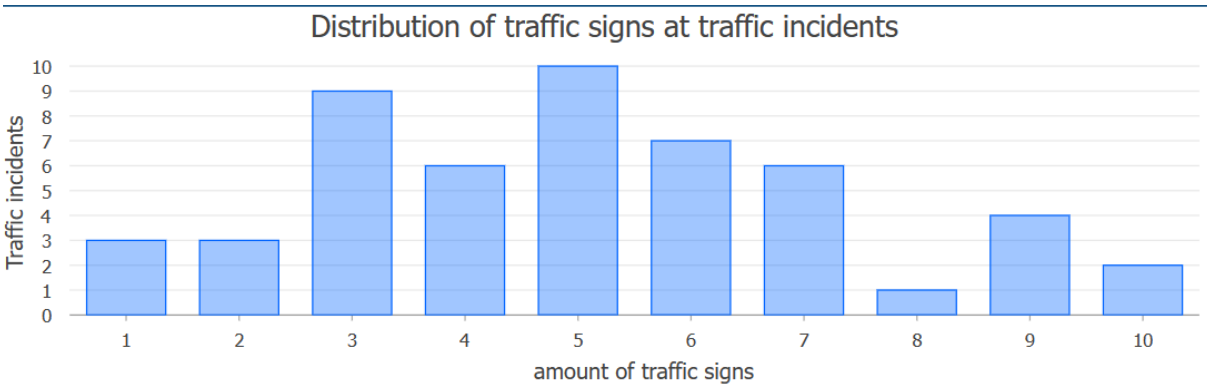

trafficincidents_buffer
Inner City Groningen
Street function
OV-baan
bycicle lane
entrance
parking
local street
local street with speedbump
footpath
footpath on stairs
trafficsigns
Meters
0
100
200
400
N

9.2 Appendix B - Bar charts

Bar chart 1 - Street segments without adequate lighting per street function (N=19)



Bar chart 2: Distribution of traffic signs at traffic incident locations with a buffer of 15 meters



9.3 Appendix C - Survey Tables

Table 1: Summary statistics of the research population (N = 52)

Variables	Categories	Total N (%)
Age (year)	< 18	1 (1.92)
	18-24	39 (75)
	25-34	11 (21.15)
	45-54	1 (1.92)
Gender	Male	22 (43.31)
	Female	29 (55.77)
	Prefer not to say	1 (1.92)
Level of education	High school diploma or equivalent	25 (48.08)
	Some college or associate degree	5 (9.62)
	Bachelor's degree	19 (36.54)
	Master's degree or higher	3 (5.77)

Table 2: Active Transport Patterns (N=52)

		Number	Percent (%)
Mode of transportation	Car	3	5,77%
	Public Transit	3	5,77%
	Active Transport	46	88,46%
	Other	0	0%
Form of active transport	Walking	9	17,65%
	Biking	42	82,35%
	Skateboarding	0	0%
	Other	0	0%
Frequency of active transportation	Never	1	1,90%
	Rarely (less than once per week)	0	0%
	Sometimes (2-4 times per week)	5	9,60%
	Frequently (5-7 times per week	13	25%
	Very frequently (multiple times per day)	33	63,50%
Duration of active transport	Less than 15 min	2	3,90%
	15-30 min	24	47,10%
	30-60 min	21	41,20%
	1-2 hours	4	7,80%
	More than 2 hours	0	0%

Table 3 - Distribution notices in street redesign (N=46)

Changes in Street Design	Count	Percent (%)	Specific Change	Count2	Percent (%)2
Traffic Signs	5	5,75%	More Signs	2	40%
			Fewer Signs	3	60%
Street width	30	34,48%	Wider	21	70%
			Smaller	9	30%
Street Material	41	47,13%	Bricks	34	82,90%
			Asphalt	2	4,90%
			Sand	0	0%
			Cobbles	5	12,20%
			Other	0	0%
Street Lighting	5	5,75%	More Light	4	80%
			Less Light	1	20%
Other (self-generated answer)	6	6,90%	Obstructions	1	16,70%
			More room for active transport	1	16,70%
			Car prohibition	1	16,70%
			Shared space	1	16,70%

Table 4 - Results questions 11 and 12

Variables	Categories	Count	Percent (%)
Affect on traffic flow and congestion	Improved traffic flow and reduced congestion	16	34.8
	Worsened traffic flow and increased congestion	6	13
	no noticeable difference	8	13.4
	unsure or do not know	16	34.8
Improvement of the overall aesthetic appeal	None at all	1	2.2
	A little	7	15.2
	A moderate amount	21	45.7
	A lot	14	30.4
	A great deal	3	6.5

Table 5 - Results on questions 16 and 18

Variables	Categories	Count	Percent (%)
Street quality due to street material	Much worse	0	0.0
	Somewhat worse	4	9.8
	About the same	12	29.3
	Somewhat better	18	43.9
	Much better	7	17
Street width	Too narrow	0	0.0
	Slightly narrow	4	13.3
	Adequate / appriopriate width	20	66.7
	Slightly wide	5	16.7
	Too wide	1	3.3

Table 6 - Results on questions 13, 14, 19 and 20

Variables	Categories	Count	Percent (%)
Perception on safety while using active transport	Extremely unsafe	0	0.0
	Somewhat unsafe	2	4.4
	Neither safe nor unsafe	48.9	
	Somewhat safe	23	51.1
	Very safe	16	35.5
Perception on accessibility while using active transport	Extremely difficult	0	0.0
	Somewhat difficult	3	6.7
	Neither easy nor difficult	4	8.9
	Somewhat easy	20	44.4
	Extremely easy	18	40
Improved visibility, accessibility, and safety on redesigned streets for active transport	Strongly disagree	1	2.2
	Somewhat disagree	5	11.1
	Neither agree nor disagree	10	22.2
	Somewhat agree	25	55.6
	Strongly agree	4	8.9
Likelihood to continue using active transport on redesign streets	Extremely unlikely	0	0.0
	Somewhat unlikely	0	0.0
	Neither likely nor unlikely	1	2.2
	Somewhat likely	6	13.3
	Extremely likely	38	84.5

9.4 Appendix D - Survey Questions

Demographic Questions

1. What is your age range? (nominal)
   a) < 18 years
   b) 18-24 years
   c) 25-34 years
   d) 35-44 years
   e) 45-54 years
   f) 55-64 years
   g) 65 years >

2. What is your gender? (ordinal)
   a) Male
   b) Female
   c) Non-binary / third gender
   d) Prefer not to say

3. What is your highest level of education? (ordinal)
   a) Less than a high school diploma
   b) High school diploma or equivalent
   c) Some college or associate degree
   d) Bachelor's degree
   e) Master's degree or higher

Questions about Active Transport - *Active Transport are transport options that involve physical activity, such as walking, cycling, and public transport (specifically the trip taken towards public transport using walking or cycling).*

4. What is your typical mode of transportation for commuting to work, school, or other destinations in Groningen? (nominal)
   a) Car
   b) Public transit
   c) Active transport (walking, cycling, etc.)
   d) Other (please specify)

5. How often do you use active transport (e.g., walking, cycling) to travel to work, school, or other destinations? (ordinal)
   a) Never
   b) Rarely (less than once a week)
   c) Sometimes (2-4 times a week)
   d) Frequently (5-7 times a week)
   e) Very frequently (multiple times per day)

Only answerable if **not** chosen *never* for question 5:

6. Which form of active transport do you use most frequently? (nominal)
   a) Walking
   b) Biking
   c) Skateboarding
   d) Other (please specify)

7. On average, how long do you travel on foot or by bike per day?
   a) Less than 15 minutes
   b) 15-30 minutes
   c) 30-60 minutes
   d) 1-2 hours
   e) More than 2 hours

8. What factors influence your decision to use active transport?
On a scale of 1 to 5, please rank the following factors based on how influential they are in your decision to use active transport, with 7 being the most influential and 5 being the least influential: (drag and order)

1. Accessibility
2. Safety
3. Visibility
4. Convenience
5. Cost
6. Health benefits
7. Environmental concerns

Questions about Street Redesign - in the inner city of Groningen (within the city canals)
9. Have you noticed any recent changes in the street design of the inner city of Groningen?
   a) yes
   b) no

Only answerable if chosen *yes* for question 9:
10. what kind of changes have you noticed? (possible to choose more than one)
   a) Change of street width
   b) Change of street material (e.g. bricks, asphalt, sand, cobbles)
   c) Change of traffic signs
   d) Change in street lighting
   e) Change in something else (please specify)

Only answerable if chosen one or more options in street changes
10.1 (change of street width) The street is now:
   a) smaller
   b) wider
10.2 (change of street material) The street is now made of:
   a) bricks
   b) asphalt
   c) sand
   d) cobbles
   e) others, specify:
10.3 (change of traffic signs) The street has now:
   a) more signs
   b) fewer signs
10.4 (change in street lighting) The street has now:

a) more lighting
b) less lighting

11. How do you think the street redesign in Groningen has affected traffic flow and congestion?
a) Improved traffic flow and reduced congestion
b) Worsened traffic flow and increased congestion
c) No noticeable difference
d) Unsure or do not know

12. On a scale of 1 to 5, how much do you think the street redesign in Groningen has contributed to improving the overall aesthetic appeal of the city?
a) None at all
b) A little
c) A moderate amount
d) A lot
e) A great deal

Only answerable if **not** chosen *never* for question 5 & if chosen *yes* for question 9:
Questions about the Perception of Safety, Accessibility, and Visibility - when using the redesigned streets

13. On redesigned streets, how safe do you feel when using active transport? (ordinal)
a) Extremely unsafe
b) Somewhat safe
c) Neither safe nor unsafe
d) Somewhat safe
e) Very safe

14. On redesigned streets, how easy is it for you to access the places you need to go to using active transport? (ordinal)
a) Extremely difficult
b) Somewhat difficult
c) Neither easy nor difficult
d) Somewhat easy
e) Very easy

Only answerable if *change in street lighting* is chosen in question 10
15. On redesigned streets, how satisfied are you with the quality of the street lighting?
a) Extremely dissatisfied
b) Somewhat dissatisfied
c) Neither satisfied nor dissatisfied
d) Somewhat satisfied
e) Extremely satisfied

Only answerable if *change of street material* is chosen in question 10
16. On redesigned streets, how much have the changes made to the street material added to the overall quality of the street?
a) Much worse

b) Somewhat worse
c) About the same
d) Somewhat better
e) Much better

Only answerable if *change of traffic signs* is chosen in question 10
17. On redesigned streets, how easy do you find it to navigate the traffic signs?
a) Extremely difficult
b) Somewhat difficult
c) Neither easy nor difficult
d) Somewhat easy
e) Extremely easy

Only answerable if *change of street width* is chosen in question 10
18. On redesigned streets, how do you feel about the street width?
a) Too narrow
b) Slightly narrow
c) Adequate / appropriate width
d) Slightly wide
e) Too wide

Only answerable if **not** chosen *never* for question 5 & if chosen *yes* for question 9:
19. Overall, do you agree that the redesigned streets have improved visibility, accessibility, and safety for active transport?
a) Strongly disagree
b) Somewhat disagree
c) Neither agree nor disagree
d) Somewhat agree
e) Strongly agree

20. How likely are you to continue using active transport on the redesigned streets?
a) Extremely unlikely
b) Somewhat unlikely
c) Neither likely nor unlikely
d) Somewhat likely
e) Extremely likely