Evaluating the effectiveness of sustainable measures in achieving driving behaviour compliance on GOW30 roads

A driving simulator experiment based on the Zaagmolenstraat in Rotterdam, the Netherlands

Master's thesis

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Evaluating the effectiveness of sustainable measures in achieving driving behaviour compliance on GOW30 roads

by

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Preface

This research forms a critical component of my Master's thesis for the MSc programme in Transport, Infrastructure, and Logistics at the Faculty of Civil Engineering and Geosciences, Delft University of Technology. The project was conducted in collaboration with Witteveen+Bos, an engineering consultancy firm.

When I embarked on this project, my goal was to contribute meaningfully to society while expanding my knowledge on various fronts. Reflecting on this journey, I am pleased with the outcomes—not only in terms of my deepened understanding of road design but also in personal growth, particularly in managing setbacks and recruiting participants for my study. Additionally, I enhanced my technical skills, learning to use new software such as Blender and Unity, delving into coding with C# and employing Python and R for data analysis. This multidisciplinary project allowed me to engage with many professionals and learn from their expertise. My interviews with professionals from the municipality of Rotterdam and road designers at Witteveen+Bos provided me with valuable insights into current guidelines and key considerations in road design.

I am deeply grateful to the XRZone at TU Delft and E. Bosman from Witteveen+Bos for their support in developing the driving simulation experiment. I would also thank Lisa Volberda for her guidance within the company, our weekly meetings, and the constructive feedback that helped shape this project. I also extend my sincere thanks to my TU Delft supervisors: Haneen Farah, Eleonora Papadimitriou and Amir Hossein Kalantari for their expert feedback, and providing me with direction throughout the project. Furthermore, their availability during the summer holidays was crucial in the final phase of my thesis, for which I thank them as well. Additionally, without the support from Amir Pooyan Afghari, my defense would not have been possible, for which I extend my appreciation.

Finally, this study would not have come to fruition without the participation of numerous individuals and support from friends and family. I would like to thank all participants and my personal network for their time, interest, and willingness to provide detailed feedback on their preferences for road designs and traffic behaviour.

In closing, I hope that this research provides meaningful insights into the interaction between sustainable measures and driving behaviour. Such understanding can support the development of sustainable and safe road designs that will ultimately benefit society as a whole.

Benjamin van Burik

Delft, October 4, 2024

Summary

In recent years, the Netherlands has focused its road design policies on improving traffic safety and sustainability, particularly in built-up urban areas. One such policy is the GOW30-policy, which lowers the maximum speed limit on certain distributor roads from 50 km/h to 30 km/h.

This policy primarily targets roads that are characterized by a mismatch between design, intended function and actual use. If there is a mismatch between road design and maximum driving speeds, vulnerable road users are exposed to disproportionate traffic risk. The need for GOW30 roads has grown in response to the growing population and a rise in cyclist-related incidents, making it imperative to implement policies that address these safety concerns. Only this way, safety for vulnerable road users can be increased. However, the rapid pace of urbanization presents significant challenges for city planners and policy makers to find a balance between accessibility and spatial quality, particularly environmental sustainability.

As urban areas expand and become more dominated by concrete and asphalt, they face negative effects like increased heat stress and reduced biodiversity. Integrating green spaces into urban landscapes is a promising solution to mitigate these issues and enhance overall livability. While these sustainable measures can improve environmental quality and reduce urban heat stress, sustainable measures such as thick trees increase severity of traffic accidents. Also, while the effect of greenery has been studied in suburban roads, effects of greenery in urban areas remain largely unclear.

For these reasons, this research investigates the relationship between sustainable measures and driving behaviour on GOW30 roads. The study addresses a critical knowledge gap concerning the impact of sustainable measures on driving behaviour. This is done by providing an answer to the main research question, which is formulated as follows:

Which sustainable measures are effective in improving driving behaviour compliance and risk perception of car drivers for GOW30?

Should these measures prove effective in reducing driving speeds, they could enhance the credibility of newly imposed speed limits and modify habitual driving behaviours. Conversely, if found ineffective, these measures might lead to increased driving speeds, compromising traffic safety. The integration of greenery, such as trees and grass strips along roads, is a critical area of focus in this study.

In order to clarify the relationship between green infrastructure and driving behaviour both quantitatively and qualitatively, a driving simulator experiment together with a survey was conducted. This experiment together with a survey assessed changes in driving behaviour amongst different road segments. These road segments varied in road width (a narrow road width of 6 meters and a wide road width of 7 meters) parking height (level parking and elevated parking) and greenery type (grass strips, marram grass strips and Populus trees, varying in thickness). All measures were selected by means of literature review, interviews with road design experts and a survey. As participants drove through 14 selected segments, their driving behaviour was recorded by means of their speed profiles and lateral position on the road.

The key findings of the simulation experiment and the post-experiment survey reveal a clear relationship between road width and driving speed. Solely increasing road width revealed higher driving speeds in the experiment. This finding was confirmed by participants reporting to drive faster on wide roads, due to the increased distance from roadside objects. A similar speed-enhancing effect is observed when low-height greenery, such as grass, is introduced along the roadside, particularly on narrow roads. According to participants, the primary reason for this effect is greater visibility on the sidewalk compared to parked cars along the road. This visibility allows car drivers to better anticipate pedestrian actions, which in turn increases their comfort.

Drivers also tend to position themselves closer to the center of the road when high greenery is present between parked cars on both sides of the road. This behaviour is also observed on road segments where cars are parked on both sides without greenery, suggesting that the perceived risk of parked vehicles may outweigh any calming effects of roadside greenery.

Conversely, when cars are replaced by planters with Populus trees along the road, drivers position their vehicles closer to the right edge, although this adjustment does not correspond with an increase in speed. When cars are removed, and grass strips are placed alongside the road, drivers also shift to the right, though to a lesser extent compared to with Populus trees. The inclusion of grass strips does lead drivers to exhibit higher driving speeds. These findings suggest that while high roadside objects guide vehicle positioning, they do not necessarily encourage slower driving if no parked cars are present.

In summary, increased road width and enhanced visibility on the sidewalk result in decreased compliance with the 30 km/h speed limit. To counteract this, road designers should consider road-narrowing measures. If possible, incorporating high and dense types of greenery in between parked cars has the potential to reduce driving speeds. It was found that the density of greenery directly influences driving speed by reducing sidewalk visibility, while the height of greenery primarily affects lateral vehicle positioning. Increasing road width or incorporating low-height greenery is thus not recommended if speed compliance is the primary goal of the road design.

Also, the road designs in this study adhered to GOW30 practices, which typically exclude centerlines. While this can allow drivers to veer away from roadside objects, the inclusion of centerlines on low-traffic road segments may enhance the effectiveness of greenery in reducing speeds by limiting lateral movement, since drivers veer away from roadside objects. However, future research on this matter should provide conclusive recommendations. Although traffic conditions were also not varied in this study, it is anticipated that drivers would feel more restricted constrained on two-lane roads with higher traffic volumes, potentially enhancing the speed-reducing effects of (dense) greenery.

It is important to note that these findings are based on a driving simulation, which approximates reality. As such, the results may not fully translate to real-world driving behaviour, where risk perception and situational awareness differ. Nonetheless, these insights provide valuable direction for estimating driving behaviour on GOW30 roads in conjunction with sustainable road design measures. Future research should explore driving behaviour in real-world conditions, which can vary by season and weather, to better understand how sustainable measures influence long-term driving behaviour. Key variables to investigate include vegetation type and the interaction between greenery and other road features such as cycling lanes. A deeper understanding of these dynamics is essential for developing future-proof urban environments that balance road safety and sustainability.

Contents

1 Introduction

In recent years, policies in the Netherlands regarding road design in the built-up area have focused on increasing traffic safety and sustainability (SWOV, 2018a). A policy that aims to increase traffic safety is the GOW30 policy. With this policy, the maximum speed limit is reduced from 50km/h to 30km/h on roads that fall in between two existing classifications: ETW30 and GOW50. Here, ETW30 is an access road with a speed limit of 30 km/h and GOW50 a distributor road with a speed limit of 50km/h. On grey roads, a mismatch between maximum speed limit and road function increases accident risk for vulnerable road users.

In this chapter, the principles of road design in the Netherlands will be briefly discussed. Then, the issues with current practices are highlighted, from which the motivation to conduct this research stems. Following this, a problem definition is formulated. Based on this problem definition, the scope of this research is defined. Finally, the objectives and research questions that this research aims to answer are elaborated.

1.1 Background information

1.1.1 Sustainable safety

The Dutch Sustainable Safety framework is structured around three design principles and two organizational principles, as detailed below (SWOV, 2018b; SWOV, 2019):

- Functionality: This principle ensures that road segments and intersections are designed to fulfill a singular traffic function, either facilitating movement (flow) or enabling interaction (exchange) across all modes of transportation. The network is hierarchically organized to enhance safety and efficiency. For example, roads designed for flow should minimize interactions with surrounding environments, while roads designed for exchange allow for frequent stops and interactions. Mixing these functions is avoided as it compromises safety.
- Biomechanics: This principle focuses on minimizing differences in speed, mass, direction, and size among road users to prevent severe accidents. It involves designing road environments and vehicles that are compatible with each other, providing necessary protections based on the characteristics of different road users. For instance, separating motorized traffic from pedestrians and cyclists or reducing speeds in areas with vulnerable users helps to ensure that all road users can navigate safely. The design should also consider additional protective measures, especially for the most vulnerable, such as children and the elderly.
- Psychology: Road designs should be intuitive, aligning with the expectations and competencies of road users, particularly older individuals. This principle emphasizes the importance of making road layouts and traffic signals self-explanatory and easily understandable, thereby encouraging predictable and safe behaviour. For example, clear signage, road markings, and logical layouts that guide drivers and pedestrians help in reducing errors and enhancing safety. This principle recognizes that when road users can easily comprehend and anticipate the traffic environment, they are more likely to behave safely.
- Responsibility: This principle underscores the importance of clearly defining the roles and responsibilities of all parties involved in road design and maintenance. By assigning clear tasks to each stakeholder, from planners and engineers to policymakers and

maintenance crews, it ensures that accountability is maintained throughout the lifecycle of the road. This clarity helps to ensure that safety considerations are prioritized at every stage of road design and operation, reducing the likelihood of errors or oversights.

- Learning and Innovation: Continuous learning from traffic incidents is vital for improving road safety. This principle advocates for the regular assessment of traffic accidents and near-misses to identify patterns and areas for improvement. Based on these assessments, stakeholders are encouraged to develop and implement innovative solutions aimed at reducing accidents and enhancing overall road safety. This might involve technological advancements, changes in road design or updated safety protocols. The emphasis is on creating a dynamic system where safety practices evolve based on real-world data and emerging trends.

1.1.2 Grey roads and GOW30

"Grey roads" refer to roadways where the intended function, design, and actual use are not properly aligned. For instance, a 50 km/h shopping street is considered a "grey road" due to the mismatch between its design and usage, as discussed in the principles of functionality and biomechanics. The foundational principle for safe road design and usage is ensuring that each road's function is clearly defined, leading to the categorization of roads within a hierarchical and efficient network structure. However, since the Sustainable Safety program originally only supported ETW30 roads (residential access roads with a 30 km/h limit), there emerged a need for the introduction of GOW30 roads. In practice, this would mean that lower maximum speeds are maintained compared to GOW50, but higher traffic volumes are accommodated compared to ETW30.

In 2021, CROW published guidelines for implementing GOW30 roads. To operationalize this policy, a framework was developed to illustrate the categorization of the roads in the built-environment. In figure 1: Decision-making framework for GOW30, it can be seen that the GOW30 policy is aimed at access roads where conflicts with vulnerable road users cannot be mitigated by separating traffic types or changing road function.

The implementation of this policy that targets grey roads is crucial, especially seen the increased frequency of cyclist incidents and population greying. The rise in cyclist accidents can be explained by a rise in electric bicycle use among the elderly (Westerhuis et al., 2024). Additionally, according to Davis (2001), the likelihood of a fatal accident at 50 km/h for individuals aged 60 and above is estimated at 65%, whereas at 30 km/h, this likelihood drops significantly to 4%. More generally speaking, lower driving speeds are associated with lower fatality risks for all types of pedestrians: Rosén et al. (2011) found in a literature study that fatality risk for pedestrians decreases 10% if impact speeds with car collisions are reduced from 50km/h to 30km/h. Factors that influence fatality risk other than driving speed are the age of the pedestrian and specific area of the body impacted during the collision. Reducing driving speeds on urban roads is thus a relevant development.

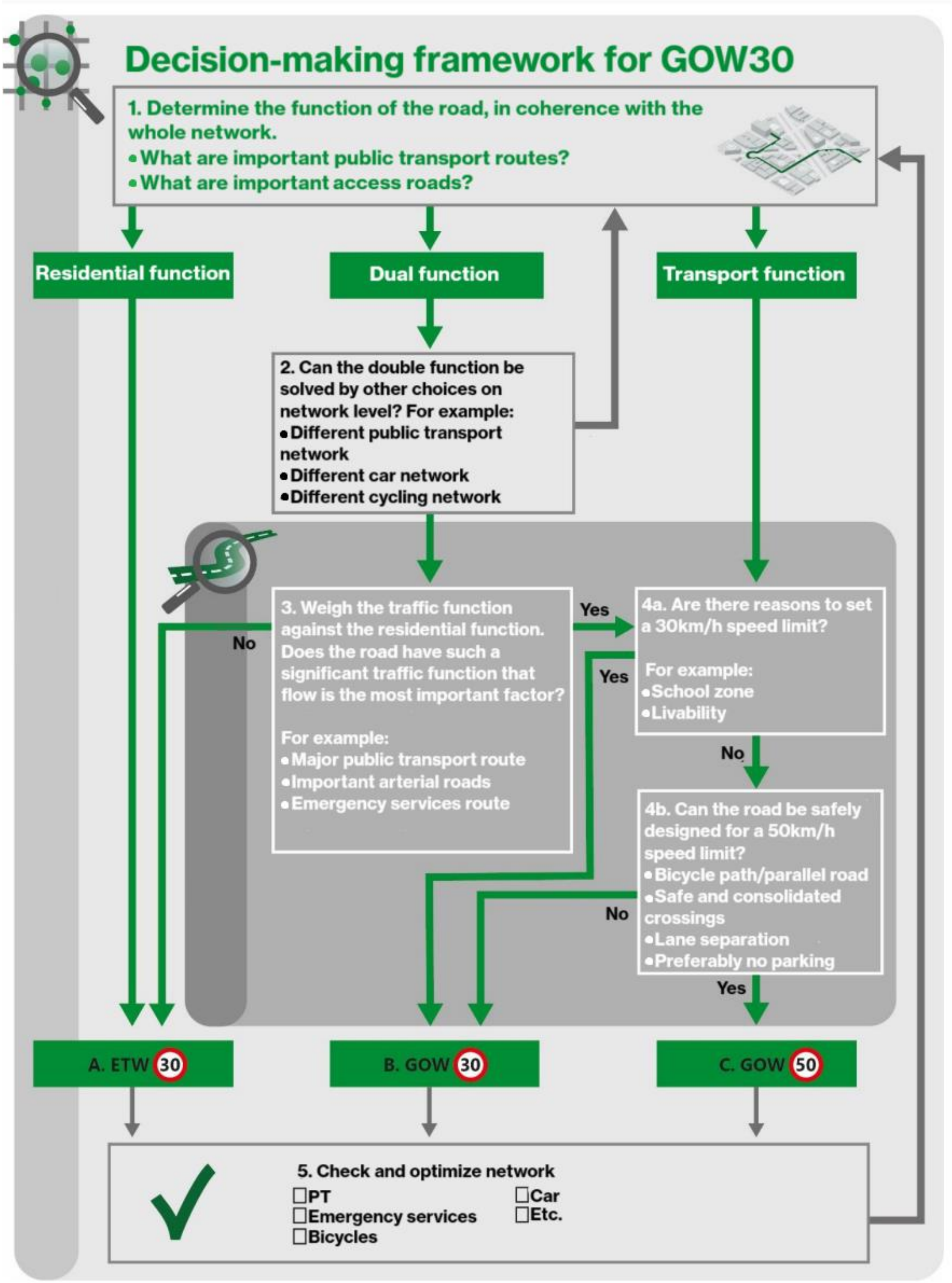

Figure 1: Decision-making framework for GOW30. Translated from CROW (2021).

1.1.3 Sustainability goals

The rapid pace of urbanization presents significant challenges for urban planners, developers, and policymakers, especially in terms of health and environmental sustainability. As urban areas become increasingly dominated by concrete and asphalt, they face several adverse effects such as elevated heat stress. Integrating green spaces into urban landscapes offers a promising solution to mitigate these issues and enhance overall livability.

First, research from Wageningen University & Research (WUR) highlights the considerable positive impacts of urban greenery on health, climate resilience, and other societal benefits. However, the effectiveness of these green elements is influenced by factors such as their design, quality, scale, and community involvement. This indicates that a one-size-fits-all approach may be insufficient; rather, tailored solutions are necessary to meet the specific needs of various urban contexts (Veerkamp et al., 2023).

Empirical studies support the psychological advantages of green environments. Green settings have been linked to lower anxiety levels, increased enjoyment, and improved cognitive outcomes. For instance, research shows that green natural environments foster recovery and subjective well-being (Kaplan, 2001; van den Berg et al., 2003).

Green spaces are also crucial in mitigating the urban heat island effect. They help cool the surrounding environment, absorb pollutants, and manage stormwater runoff, thus enhancing a city's resilience to climate change (Dadvand et al., 2016). Furthermore, they promote alternative modes of transportation, such as walking and cycling, which can reduce reliance on cars and lower urban carbon emissions.

The COVID-19 pandemic underscored the importance of urban green spaces for public health and well-being. During lockdowns, parks and green areas became vital for physical activity and social interaction, highlighting the need for accessible and well-maintained green spaces in urban settings (Venter et al., 2020). These spaces not only support physical health but also foster mental well-being by providing areas for relaxation and socialization.

In summary, incorporating green infrastructure into urban development is crucial for addressing the challenges of urbanization and promoting sustainability. Green spaces offer extensive environmental, health, and social benefits, which are essential for creating vibrant and resilient cities. As urban areas continue to expand, it is imperative to approach urban growth and environmental sustainability as interconnected issues, requiring integrated and strategic solutions to ensure a balanced and thriving urban future (Jabbar et al., 2021).

1.1.4 Shared space principle

For many years, scholars have mentioned that streets should serve the community and be walkable and livable (Appleyard, 1981; Whyte, 1980). This is primarily applicable to residential streets. The concept of shared space involves reducing or eliminating traditional traffic control elements like road markings and signs, thus encouraging road users to navigate and interact with each other more intuitively and cautiously (Moody & Melia, 2011).

Shared space operates on the principle that minimizing visual cues, such as road signs and markings, fosters a more natural and interactive environment among road users. This approach aims to balance various urban functions, including transportation and pedestrian access, by making the space less about strict regulation and more about mutual awareness and responsibility. For example, a study on the Amalias Street in Nafplio, Greece, demonstrates this concept by comparing a conventional road section with a shared space section. In this study, pedestrian crossing rates increase due to the greater number of crossing points available compared to conventional roads (Tzouras et al., 2023). Furthermore, Ben-Joseph, E. (1995) found that shared paved space by multiple road users reduces traffic speed and improves safety.

Shared space principles align with sustainability goals by fostering environments that prioritize pedestrian and environmental considerations. The principle of 'Sustainable Safety', which emphasizes predictable and recognizable road layouts, contrasts with shared space's approach. While Sustainable Safety relies on clear signage and physical traffic calming measures to regulate behaviour, shared space seeks to achieve similar outcomes through more organic interactions and reduced visual clutter. The goal is to create spaces where traffic conflicts are managed through increased awareness and mutual understanding rather than formal regulations. Shared spaces are most effective when they serve as destination or activity hubs rather than high-traffic routes, and when vehicle volumes are manageable and not overwhelming (CROW, 2023b).

An extension of the shared space principle is the woonerf concept. On woonerfs, car drivers share space with other roads users but are subordinate to them. To define what a woonerf is, the Dutch Ministry of Transport in the Netherlands defined a set of criteria in 1976. According to Kraay (1986) these criteria primarily entail that woonerfs are residential areas which must only carry vehicular traffic with an origin or destination within that particular woonerf. Also, there should be no continuous difference in cross sectional elements along the road, enough parking space accompanied with adequate lighting and vertical elements such as plant tubs and shrubs must not restrict visibility. A key difference with the shared space principle is that woonerfs are regulated spaces, with clear signage that make car drivers aware of entering a woonerf zone, which makes these zones self-explaining (Theeuwes, J., 2021). In an example study (Nalmpantis et al., 2017), the application of the woonerf concept to the campus of Aristotle University in Greece was shown to reduce tension between car drivers and pedestrians, which led to a sustainable campus environment that found a medium between a car-oriented space and a car-free zone. Driving speeds reduced naturally, since drivers recognized the chances of a sudden conflict.

In summary, by shifting focus from traditional traffic management to more dynamic and user-focused designs, shared space contributes to achieving broader sustainability objectives, including reduced vehicle speeds, enhanced pedestrian safety and improved urban livability (Haaze, 2019).

1.2 Problem definition

GOW30 roads, which have transitioned from a 50 km/h to a 30 km/h speed limit, pose unique challenges due to insufficient data on the effectiveness of safety measures. These roads require interventions that enhance speed limit credibility and modify driving behaviour, since these roads are converged from another road category to GOW30. There is a notable gap in understanding how infrastructural changes impact driving behaviour for these roads, prompting calls from non-governmental organizations for more research.

Additionally, the integration of sustainable measures, such as adding greenery, can conflict with traffic safety goals. While sustainable features can improve environmental quality, they may inadvertently increase injury severity in accidents. Behavioural adaptation further complicates this issue, as modifications in road design can lead to unintended increases in driving speed due to a perceived sense safety.

To address these challenges, it is crucial to quantify how environmental factors influence speed limit credibility and driving behaviour. With this knowledge, safety measures can be refined and aligned with sustainability goals.

1.3 Research Scope and Objectives

This study investigates GOW30 within the Netherlands, a policy specific to the Dutch urban context. The study selects Rotterdam as the focal case due to its relevance: the city is undergoing substantial population growth, resulting in increased traffic volumes and a more diverse mix of road users, including automobiles, bicycles, mopeds, scooters, pedestrians, public transport and freight vehicles. Furthermore, Rotterdam's municipal strategy to transition 115 roads to a 30 km/h speed limit by 2025 underscores the significance of this case study (Gemeente Rotterdam, 2024).

Interviews with experts reveal that 80% of traffic-related injuries in Rotterdam occur on 50 km/h roads, a proportion that is higher than the national average of 30% (Rijkswaterstaat, 2024). Consequently, this research focuses on a specific corridor in Rotterdam, starting from the Bosdreef and extending to the Walenburgerweg. This corridor has been identified as hazardous, with plans to convert the Zaagmolenstraat segment to a GOW30 by 2025. This road is located in a high-density built environment and characterized by the presence of tram tracks, limited pedestrian space, narrow sidewalks and a paucity of greenery, rendering it vulnerable to urban heat island effects.

The objective of this research is to examine the relationship between the presence of greenery and driving behaviour in the context of GOW30 roads. Existing policies predominantly aim to reduce vehicle speeds through lower speed limits and infrastructural modifications, often without adequately addressing the broader road environment and climate objectives. This study underscores the necessity of fostering sustainable development that satisfies current needs without compromising the ability of future generations to meet their own. It seeks to promote ecological integrity, mitigate urban heat stress, and advocate for the responsible utilization of resources, with a particular emphasis on reinvesting in natural resources where applicable.

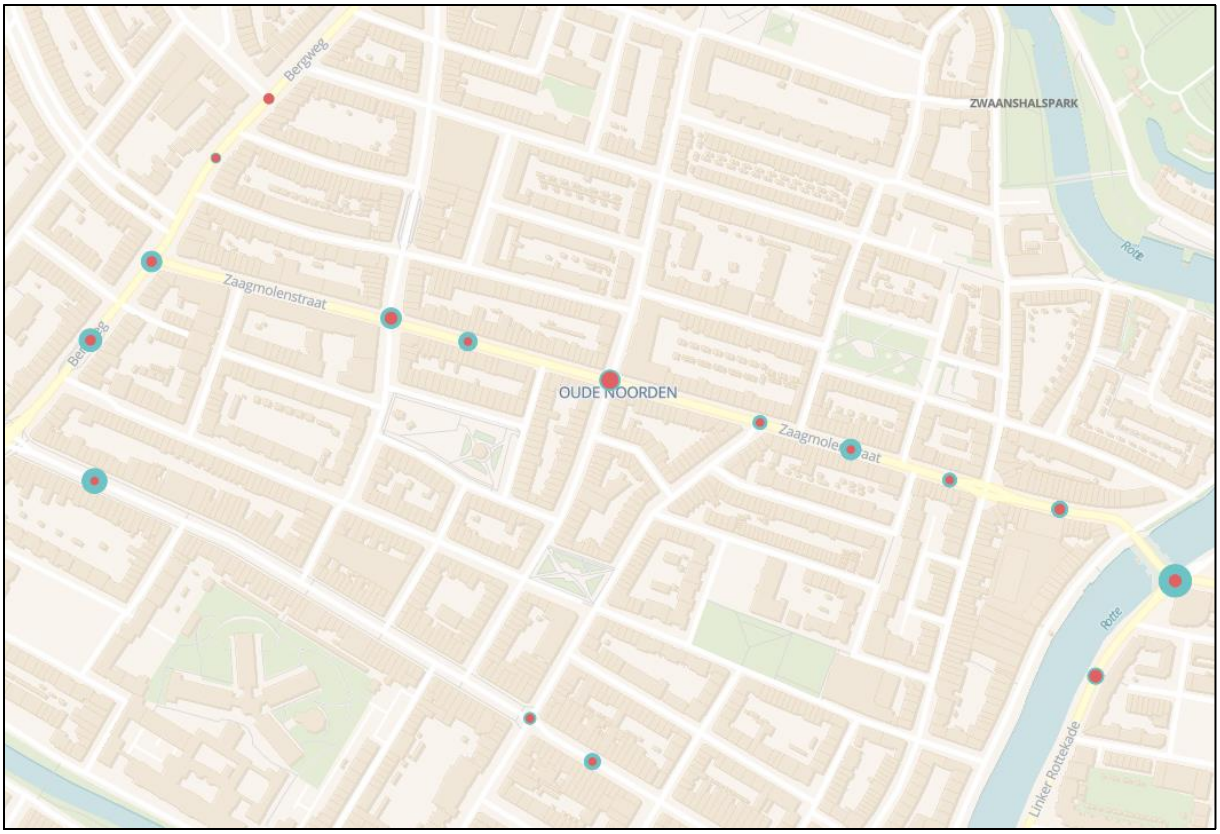

Figure 2: Accident hotspots on the Zaagmolenstraat in Rotterdam, with a lower bound of 2 injury-related accidents (red) and a lower bound of 1 material-related injury (blue) from 2019 onwards. (STAR, 2024).

1.4 Research questions and hypotheses

In this paragraph, the research questions that will guide the thesis are outlined. These research questions will build on the research gaps, mentioned in the previous chapter. The main research question focuses on identifying sustainable measures to mitigate driving speeds specifically for GOW30 roads. This question is formulated as follows:

Which sustainable measures are effective in improving driving behaviour compliance and risk perception of car drivers for GOW30?

To comprehensively answer this main research question, the following sub-questions have been formulated:

SQ1: What are the most promising characteristics of sustainable measures that influence speed limit credibility?

Here, the focus shifts to identifying features of sustainable measures that can enhance the credibility of speed limits on GOW30 roads, potentially influencing driver behaviour. These findings will result from literature research, interviews with road design experts and landscape architects and a survey.

SQ2: What is the impact of these sustainable measures on the driving speeds of car drivers on GOW30 roads?

This sub-question examines the direct impact of implementing sustainable infrastructural measures on driving speeds, providing insight into their effectiveness. It is hypothesized that larger types of greenery influence driving speeds negatively, since larger objects pose a higher risk to crash into and reduce visibility.

SQ3: What is the impact of these sustainable measures on lateral position of car drivers on GOW30 roads, without presence of a centerline?

This sub-question investigates how the selected sustainable measures influence lateral position with the absence of a centerlines, since this is a common road design feature for GOW30 roads. Furthermore, it is chosen to examine this behaviour with infrequent oncoming traffic, to approximate free-flow driving behaviour.

SQ4: In what way do sustainable measures influence the risk perception of car drivers?

Lastly, this sub-question explores how infrastructural adjustments affect drivers' risk perception, which can in turn influence their driving behaviour.

By addressing these sub-questions, the thesis aims to achieve its overarching objective of evaluating the effectiveness of sustainable infrastructural measures in reducing driving speeds and improving driving behaviour. It is hypothesized that increasing drivers' perception of risk through infrastructural adjustments will lead to a decrease in driving speeds, contributing to safer road conditions on GOW30. To investigate the state-of-the-art with regards to road design and sustainable measures, a literature review will be presented in the next chapter.

2 Literature review

To delve deeper into the concept of GOW30, policy documents have been looked up with the search terms (‘GOW30’ OR ‘30km/h’ AND ‘50km/h’) on the Google Search engine for policy documents and on Google Scholar for scientific literature. Then for specific literature, the search query (‘liveability’ OR ‘traffic safety’ OR ‘speed calming’ OR ‘calming’ OR ‘traffic safety’ OR ‘urban traffic’ OR ‘urban roads’ OR ‘self-explaining roads’ OR ‘trees’ AND ‘traffic’) was used.

2.1 Road design factors influencing driving behaviour

A study that analyzed the relationship between road characteristics and user compliance with speed limits was carried out by Yao et al. (2020). In this driving simulator study, it was found that road layout and roadside environment affected the driven speeds. In 8 scenarios developed for rural highways, road layout was varied in multiple levels: straight or curved alignments, with or without a cycling lane and with or without an emergency lane. Therefore, this study leaves room for further research into different scenarios, especially with regards to a highly urbanized area instead of rural roadways.

This knowledge can be supported by research carried out by Aarts & van Schagen (2006) who also found that road design elements such as road geometry, cross-sections, alignment, and the immediate road surroundings influence the selection of speed by drivers. To be precise, drivers choose higher speeds on wider roads with emergency lanes, fewer curves, smooth surfaces, clear road markings, fewer buildings and less greenery in the surrounding road environment. Additionally, factors such as driver personality, vehicle characteristics, driving task complexity, driving ability and trip purpose play significant roles. Male drivers generally drive faster than female drivers, while older drivers and females tend to comply more readily with speed limits (Aarts & van Schagen, 2006).

To add to this, research on the impact of posted speed limit changes (Silvano & Bang, 2016; Silvano et al., 2020) found with a regression analysis that road characteristics such as carriageway width, road environments and the presence of on-street parking and sidewalks heavily influence free-flow speed. A decrease in the posted speed limit from 50km/h to 40km/h led to a reduction of 1.6km/h in the mean free-flow speed. Then, an increase in posted speed limit from 50km/h to 60km/h led to an increase of 2.6km/h in the mean free-flow speed. Another study that revealed different responses depending on the traffic intervention was performed by Goralzik and Vollrath (2017). This study found that speed limit compliance is dependent on the level of the speed limit on simulated German urban roads. Also, participants of the experiment revealed that driving speed was reduced when the roadway became narrower or curved on a 50km/h-road but did not respond to these changes under a 30km/h speed limit.

Throughout the Netherlands, approximately 55% to 60% of vehicles exceed the speed limit on roads with a speed limit of 50, 60 and 70 km/h. Then, on 30km/h roads throughout Europe these estimates range from 62% to 90% (SWOV, 2021). It could be motivated that these estimates are higher on GOW30, since these roads are primarily converged from GOW50 with characteristics that encourage higher driving speeds. Also, research by Goralzik & Vollrath (2017) found that drivers show different behaviour on 50km/h- and 30km/h-roads. This study was aimed at estimating differences in driving speed with different road curvatures for 30- and 50km-roads. The results showed that driving speed did not change when road curvature and lane width were varied on 30km-h roads, but did change on 50km/h-roads. This implies that in order for driving speeds to be influenced on 30km/h-roads, other measures should be taken. In addition to this, Distefano, N. & Leonardi, S. (2019) motivate that simply lowering speed limits from 50km/h to 30km/h in urban areas, may not achieve the desired effect unless combined with information campaigns and police enforcement. A recent example of a road in Rotterdam, the Netherlands, that was converted to a GOW30 but still faces speeding issues is the Walenburgerweg. According to Merkelbach et al. (2023a), after the redesign, the V85 speed decreased from 41.2 km/h to 39.3 km/h—still exceeding the intended limit. The changes to the road included adding cycling lanes, introducing speed-reducing plateaus, and removing the centerlines, but these measures have not fully curbed speeding.

In order to test whether speed limits are credible, the *Veilige Snelheden, Geloofwaardige Snelheidslimieten (VSGS)* method is used. In 2022, Kint et al. tested the validity of this model. Their findings were that only road width and straight alignment can explain the free-flow velocity of traffic. Other variables in this method correlate with each other and cannot explain free flow speed on their own. In table 1, factors that influence speed limit credibility are mentioned per source.

Table 1: Mentioned measures according to source.

Source	**Measures**	**Effects**
Aarts & Van Schagen (2006)	• Wide roads • Emergency lanes • Fewer curves • Smooth road surfaces • Clear road markings • Fewer buildings • Less greenery	• All of the mentioned measures increase driving speeds
CROW. (2021)	• Density of surrounding buildings • Road surrounded by educational buildings or shops • Road width • Road hardening • Presence of speedbumps • Length of straight alignment	• A higher density leads to lower speeds • The presence of educational buildings or shops reduces speeds • Wide roads increase speed • Asphalt increases speed whereas bricks decrease speed • Speedbumps decrease speed • The longer the straight horizontal alignment, the higher the driving speeds
Distefano & Leonardi (2019)	• Speed tables • Chicanes • Road narrowing	• The presence of speed tables, chicanes and road narrowing positively impact the likelihood in pedestrian injuries, ranging from 33% for road narrowing up to 50% for speed tables in Catania.
Kint et al. (2022)	• Cross alignment • Road width • Road view • Density of the environment • Length of straight alignment • Environment (land use and building type) • Parking and parking changes • Number (or share) of companies • Density of intersections • Type of road hardening • Presence of cycling lanes • Speed reducers • Separation of driving directions • Traffic intensity	• Directions not mentioned

Merkelbach et al. (2023b)	• Smoothness of road surface • Road width • Road lining • Greenery such as planters or decoration • Images of people or moving elements along roads • Waiting areas for oncoming traffic • Presence of zebra crossings • Presence of a central reservation • Mixed traffic	• Asphalt increases speed whereas bricks decrease speed • Small width leads to lower speeds • Central lining increases speeds • Planters or green borders that reduce road width can reduce speeds • The presence of images and moving elements decreases speed • Waiting areas decrease speed • Zebra crossings decrease speed • A central reservation increases speeds • A high traffic mix decreases speed
Thompson et al. (2006)	• Transverse rumble strips	• Transverse rumble strips lower driving speeds significantly, however this is less or equal to 1.6km/h on rural highways.
Yao et al. (2020).	• Density of surrounding buildings • Width • Smooth road surface • Vegetation • Road markings • Increasing risk perception	• Higher density leads to lower speeds • Small width leads to lower speeds • Smooth surface increases speed • Less vegetation leads to higher speeds • Clear road markings increase speed • A higher risk perception decreases speed

Little is known about the effectiveness of these measures in the context of GOW30 roads. These roads are unique because they were originally designed for a speed limit of 50 km/h and have since been modified to accommodate a lower speed limit of 30 km/h. This means that the existing road infrastructure must be adapted to enhance speed limit credibility and alter drivers' habitual speeds. Given that GOW30 is a relatively new concept, its impact on traffic safety, driver satisfaction, and overall livability remains largely unexplored (Goudappel, n.d.).

As shown in table 1, few of these measures are considered sustainable. While vegetation, greenery, and planters are mentioned as potential factors that influence driving behaviour, their actual effectiveness in reducing driving speeds in urban settings is not well understood in practice. Additionally, it is unclear whether different types of vegetation vary in their ability to influence driving behaviour. Understanding how these environmental elements contribute to speed reduction and their relative effectiveness is an area that requires further investigation.

2.2 Sustainable measures and road safety

To elaborate on the relation between sustainable measures and road safety, first the definition of sustainability needs to be defined. According to the United Nations (1987), sustainability is defined as *meeting the needs of the present without compromising the ability of future generations to meet their own needs*. In an urban context, this could mean mitigating heat stress and reducing pollution for healthy living conditions.

However, sustainable measures and road safety do not always go hand-in-hand. Think for example of standards developed with regards to tree placement along roads, for which minimum distances between road surface and tree placement should be considered. If these standards are not respected, view on the roadside is reduced and collision probability with these trees is increased. The existence of these standards was recently supported by Cheng et al. (2020), who found that a larger the spacing of trees and a smaller diameter of these trees reduce injury risk of car drivers. In addition to this research on injury risk for car drivers, Zhu et al. (2022) found that pedestrian injury decreases with increased density and tree canopy cover. This is likely due to reduced exposure risk to trees, since these trees act as a barrier between cars and pedestrians.

Another source that investigated the impact of curb-side trees in a (sub)urban environment is Naderi et al. (2006). In this study, a four-scenario driving simulation was conducted on 31 participants. These scenarios varied in landscape (urban and suburban) and presence of trees along the road (absent and present). Results indicated that people perceived suburban streets with trees as most safe (4.45 on a scale from 0 to 6) and urban streets without trees as least safe (3.38 on a scale from 0 to 6). Furthermore, the addition of curbside trees on suburban streets significantly increased driver perception of spatial edge and reduced driving speeds with 4.87 km/h. Sample size however was too small to provide conclusive insights and speed differences for the other scenarios could not be estimated.

Then, placement and presence of trees have also been shown to reduce driving speeds on rural roads by Fitzpatrick et al., (2014). This real-life study in Massachusetts revealed that utility poles and vegetation density reduce car driving speeds significantly with an average speed reduction of 2 mph on highways. In addition to this study, a simulation study based on the highway experiment in Massachusetts (Fitzpatrick et al., 2016) found that the width of the clear zone was observed to influence driving speed. Drivers tended to drive closer to the center when the clear zone was narrower and there were no significant differences in tangential positions based on varying vegetation densities. The study examined six combinations of clear zone width and vegetation density, focusing on trees and their placement along highways. It was noted that vehicle positioning was significantly affected by clear zone width and vegetation density on left curves and tangents, but not on right curves, likely due to better visibility on the left side.

Another driving simulator study on the effects of trees on driving speed and lateral position for two-lane rural roads (Calvi, 2015) found that driver performance was influenced by tree configurations. The findings revealed that drivers used roadside trees as guidance while also considering the potential hazards these trees posed. When trees were distant at a 4.0 meter offset, drivers prioritized the sense of direction provided by the trees and increased their speeds, similar to the findings of Naderi et al. (2008). However, as trees came closer to the road edge with a 1.5 meter offset, drivers perceived them as risky obstacles, prompting them to slow down and veer away from these objects.

Also, in this experiment the spacing of trees was found to have an impact on driving speed. Here, the author refers to the concept optical flow as a potential cause. The concept of optical flow states that the distribution of objects along a road influence the patterns of light perceived by the human eye. If the speed of this pattern is increased, this indicates a faster driving speed. The findings in the study by Calvi (2015) exclusively considered large diameter trees within flat grass areas for the clear zone.

Based on the findings from Fitzpatrick et al. (2014, 2016) and Calvi (2015), the tree offset along a road influences driving behaviour. This effect cannot be explained by the density of the vegetation, which was defined as the number of trees on a given surface. Recent insights by Wu et al. (2023) further add to this knowledge with insights from a study on transition zones from rural to small town roads. Namely, it was found that a narrow road, narrow road with short vegetation, normal lane with tall vegetation in different spacings had an effective speed reducing effect. Despite these previous insights, it still remains unclear how driving behaviour is influenced by greenery in the urban context.

2.3 Conclusion

Limited knowledge exists regarding the performance of various measures on GOW30, which are unique because previously they primarily were GOW50, with a 50km/h speed limit. This means that effective measures need to enhance speed limit credibility and alter habitual driving speeds. Non-governmental organizations emphasize that there is a necessity for additional information on the effects of infrastructural changes on traffic safety for GOW30.
Furthermore, governments and municipalities strive to achieve sustainable development goals, yet many measures lack sustainability. Then, it has been shown that sustainable measures such as placing trees along roads increase the severity of injuries in case of a collision between a car and a tree. But, placing trees in between the road and the sidewalk is shown to reduce pedestrian injuries. This stresses that balancing safety and sustainability is crucial to achieve future-proof cities.

Understanding the effects of sustainable measures on driving behaviour is paramount, considering that driving behaviour is of large influence in traffic accidents (McCarty & Kim, 2024). Also, when changing road infrastructure, the concept of behavioural adaptation should be mentioned. This concept suggests that unintended behaviours may occur, such as increased driving speed in response to a safer road environment, as drivers perceive the area as less risky (Rudin-Brown & Jamson, 2013). An example of this is found in research by Andriesse, R. (2021), which showed that the presence of large trees, hedges, lampposts, and tall facades forming lanes is associated with higher driving speeds. This is surprising, as these elements, being close to the road, should theoretically reduce the perceived road width and decrease speed. It is hypothesized that drivers may associate these features with more luxurious and typically wider streets. However, the relationship between the presence of trees, hedges, and lampposts, and speed limit credibility in GOW30 zones remains unclear and is not addressed in policies or current practices.

To do this, the relationship between the environment, speed limit credibility and driving speed needs to be quantified. This will improve safety and sustainability for urban environments, which is in line with safety and sustainability ambitions. In the next paragraph, the conceptual framework for this research is developed and explained.

2.4 Conceptual framework

As stated before, a factor that influences speeding behaviour is speed limit credibility. According to Schagen et al. (2006), a credible speed limit is one that meets the expectations raised by the road characteristics and road environment, so that drivers are more inclined to comply with them.

A theoretical model that explains the relationship between road characteristics and driver behaviour is the Task- Capability Interface model by Fuller, R. W. (2000). In this model, the author contrasts the capability of a driver with task demands. If the task demand is closer to the driver capability, a task will be perceived as more difficult (Fuller et al., 2008). Fuller (2000) proposes that drivers usually opt for a speed which leaves a margin of capability, which the driver can use if an increase in demand unexpectedly is needed. The inverse is also true, if the margin of capability is too high given the traffic situation, the driving speed will increase. However, in the TCI model by Fuller (2000), the effect of a road environment on driving behaviour is not included explicitly, despite Schagen et al. (2006) having mentioned that speed limit credibility is a result of the raised expectations by the road environment and road characteristics. Road environment is therefore likely to influence driving behaviour as well. Furthermore, choosing a driving speed and road position is a dynamic process, given a specific traffic situation and driver preferences. This should be adequately addressed in a conceptual model that explains the relationship between the physical environment and the effect on driving behaviour. Based on Fuller (2000), Schagen et al. (2006) and Wickens et al. (2013), the below conceptual model was developed that represents the relations between factors that influence driving behaviour.

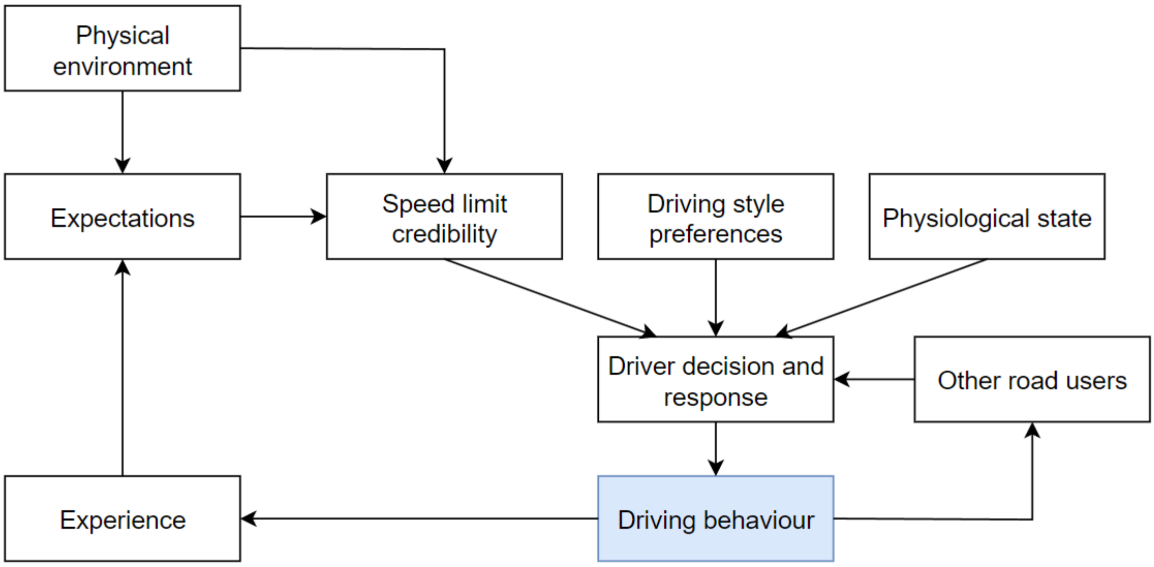

Figure 3: Conceptual model on driving behaviour. Based on Fuller, R.W. (2000), Schagen et al. (2006) & Wickens C.D. et al. (2013)

First, it is important to mention that the above model aims to illustrate factors that relate to driving behaviour, where driving behaviour is defined as the longitudinal and lateral movements a driver makes. Then, it is important to mention that this research is not aimed at estimating a relation between driver capability and task demands. Fuller (2000) offers valuable insights in factors that contribute to driving behaviour, such as that driver capability is limited by human factor variables and experience. Here, human factor variables such as fatigue, stress and emotional state have a direct impact on decision and response of a driver. The inclusion of human factor variables is further motivated by Davidse et al. (2010). In a literature study on status recognition, physiological state is motivated to be included as a part of driving behaviour. This is because physiological state is influenced by intoxication, tiredness and stress. Then, to account for speeding behaviour, individual driving style preferences should also be considered in the conceptual model on driving behaviour. This way, the conceptual model also includes a disposition to show risky traffic behaviour or differences in driving behaviour amongst drivers. Other road users furthermore also play a role in the model of Fuller (2000). Think for example of cars driving in front of each other, influencing each other's speed or a sudden steering movement from a car that passes by, which influences lateral positioning of the car next to this. Furthermore, one's driving behaviour also impacts other road users, which is why a loop between driving behaviour, other road users and driver decision and response can be seen.

Finally, the relationship between road environment and expectations as mentioned by Schagen et al. (2006) is included too. Here, expectations are built upon experience such as education, training and years of driving experience, often also dependent on age. For example, literature has shown that differences exist in driving behaviour among different age groups. According to SWOV (2021), younger drivers, particularly those aged 18-24, are 4.5 times more likely to be involved in traffic accidents compared to more experienced drivers aged 30-65. The primary factors contributing to this increased risk include lower driving experience, the tendency for younger drivers to operate older vehicles, and the fact that the part of the brain responsible for risk regulation is not fully developed until the age of 25. Similar findings stem from Abdel-Aty, Chen, & Schott (1998), who found that driver age has a statistically significant impact on injury severity. Especially drivers in the age groups 15-19 years old and 20-24 years old speed more often, leading to a higher traffic incident risk.

Then, according to Wickens C.D. et al. (2013), human information processing is a complex system that processes information and chooses a response based on formed expectations and previous experiences. This could motivate why it might be more difficult for car drivers to adapt their speed on a road that is converged from a GOW50 road to a GOW30 road; if a road environment does not match the expectations, a speed limit is not perceived as credible. Here, the concept of self-explaining roads is also relevant. A self-explaining road is characterized by its structural safety, which is influenced by two key factors: self-explaining properties and inherent safety. Self-explaining properties refer to design features that align with the expectations of road users, while inherent safety involves reducing potentially dangerous encounters (Theeuwes & Godthelp, 1995). Therefore, road design should consider human capacity limitations, as proposed by the principles of Sustainable Safety. Rather than individual objects or environments, people store an abstract representation of the world containing typical properties. Consistency in the physical appearance of objects and environments is crucial for ensuring coherence in how individuals perceive and navigate their surroundings. Only this way roads correspond to the formed expectations, which leads to speed limit credibility.

3 Methodology

This chapter outlines the methodology employed in this study. First, the recruitment process in accordance with TU Delft guidelines is explained. Next, the chosen research method is further clarified, highlighting how driving behaviour data was safely collected in a controlled simulation road environment. In subsection 3.4, the experimental procedure is explained which was followed up by questionnaire in subsection 3.5. Finally, the data collection method is mentioned in 3.6. This chapter comes to a close with paragraph 3.7, which explains the data analysis approach.

3.1 Participants

A total of 47 participants participated in this study. These participants were recruited through advertisements on social media, at the Witteveen + Bos office in Rotterdam, the Netherlands and on the TU Delft campus in Delft, the Netherlands. All participants were required to hold a valid driver's license and be free of any medical conditions that could pose a risk during the simulation experiment, as outlined by Anses (2021). Such risk factors include pregnancy, susceptibility to migraines, motion sickness, and epilepsy. These risks were clearly communicated to potential participants in the recruitment materials, as detailed in Appendix E: Recruitment advertisement.

Prior to participation, all participants signed an informed consent form which made participants once again aware of the risks. This informed consent form received approval from the TU Delft Human Research Ethics Committee (2023), as detailed in Appendix F: Instructions and informed consent form. In case of experiencing nausea, dizziness or eye strain that severely impacted the wellbeing of participants, they were able to quit the experiment. This happened in 2 cases, which are left out from the sample since their results were impacted by these symptoms. Also, a participant who did not disclose their gender was left out from the sample.

3.2 Driving simulator

The chosen method for this study is a driving simulator experiment, followed by a survey. A driving simulator allows for a controlled environment whilst minimizing exposure to real-life risk in traffic. It should be taken into consideration that the face validity of driving simulators is a widely discussed topic. For example, de Winter et al. (2012) mention that the elimination of exposure to real-life traffic risk is eliminated in driving simulator experiments, which gives participants a false perception of safety. In a recent study by Wynne et al. (2019), simulation fidelity is influenced by field of view, with low field of view simulators not being able to achieve validity for line crossing behaviour. Also, drivers may engage in riskier behaviour since minimal consequences follow as a result of noncompliance. These limitations will further be mentioned in the discussion of the results.

The experiment was conducted using two fixed-based driving simulators located at the Faculty of Civil Engineering and Geosciences at TU Delft and the Witteveen + Bos office. At the Faculty of Civil Engineering, the simulator setup included three 4K high-resolution screens, providing approximately 180-degree vision. The setup also featured the Fanatec BMW Clubsport V2 steering wheel and Fanatec ClubSport V3 pedals. For the simulation at the Witteveen + Bos office, a CTOUCH Riva 4K 65" touchscreen was utilized, along with the Playseat Evolution ActiFit and Logitech G920 Driving Force controllers. The use of two different simulators allowed for a higher number of participants, as the experiment was conducted primarily during vacation periods in the Netherlands.

To maintain consistency between the two setups, the view was adjusted in both simulators to make them as comparable as possible. It is worth noting that while the touchscreen offers a larger overall display and a broader view of the environment, the view is approximately 120 degrees. This is not expected to have influenced the outcomes of the driving simulation, as the task did not involve lane-changing behaviour, but should be considered in the analysis of the results.

Figure 4: Driving simulator of the faculty of Civil Engineering and Geosciences at TU Delft.

Figure 5: Driving simulator at Witteveen + Bos

3.3 Simulation design

3.3.1 Case: Zaagmolenstraat

To evaluate the effectiveness of sustainable measures for GOW30 roads, an existing road was selected as a test site. The chosen road for the analysis is the Zaagmolenstraat in Rotterdam, the Netherlands, which is a road with accident hotspots according to Smart Traffic Accident Reporting (2024) and the municipality of Rotterdam. This street is situated in highly urbanized environment and accommodates various types of traffic, including trucks, cars, and vulnerable road users such as cyclists and pedestrians. According to an interview with employees from the municipality of Rotterdam, primary reasons for these high incident numbers are the presence of public transport, the high population density and parking spaces. No clarity can be given with regards to the nature of the accidents.

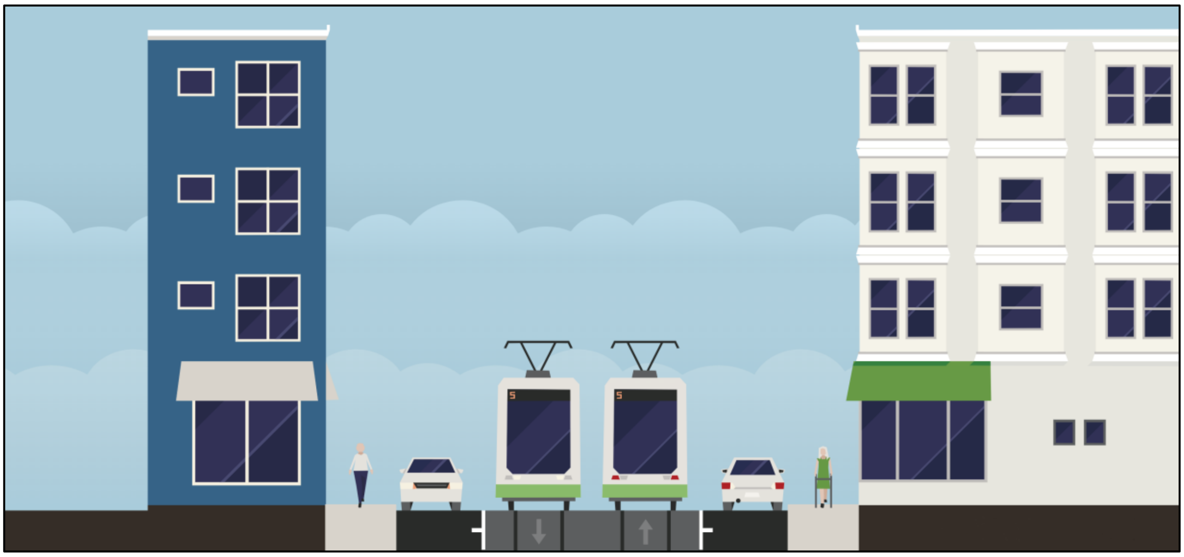

Figure 6: Cross-section based on the Zaagmolenstraat. (designed with Streetmix)

The above image presents a cross-section of Zaagmolenstraat. As can be seen in the image, multiple traffic modes are present such as vulnerable road users, public transport and motorized vehicles. Since this road is a public transportation route, the road width is approximately 6 meters. Furthermore, parking spaces have a width of approximately 2.6 meters. The remainder of the space is designated for pedestrians, which is often narrower than 1.8 meters. This is too narrow according to guidelines of CROW (2023a), which recommend a sidewalk width of minimally 1.8 meters to ensure adequate passing of wheelchairs and oncoming pedestrians. Since the built-environment cannot be changed, the incorporation of sustainable features would directly reduce space for other traffic modes on the Zaagmolenstraat. Consequently, lane width is also not a variable that can be easily adjusted in real-world scenarios on this road. However, given that lane width is an effective variable in reducing driving speeds, this will be varied in the simulated environment to ensure wider applicability of the derived results.

3.3.2 Road environment in the experiment

Since this research is aimed at investigating the influence of greenery in the context of GOW30 roads, this provides a direction for the simulated environment. To develop the road designs, the simulated environment was modeled after a high-density urban area with buildings of 3 to 4 stories, similar to those found in Rotterdam and other Dutch cities where the GOW30 policy is implemented. The building types were the same for each road segment, but placement was randomized across all scenarios.

3.3.3 Road design in the experiment

The previous chapter has shown that road width is a key factor influencing drivers' speed choices, making it a crucial variable in the simulation experiment. To test which variables would be most promising to investigate, a preliminary survey was conducted on 42 participants, who did not necessarily take part in the driving simulator experiment. This survey let participants evaluate multiple types of greenery, parking height and statements with regard to road design. This survey is presented in Appendix B: Survey on road designs. In this survey, more than 90% of respondents mentioned that increased road width would lead them to drive faster.

To explore this finding, road width will be varied at two levels in the experiment: a narrow configuration with a lane width of 3 meters and a wide configuration with a lane width of 3.5 meters. Based on the guidelines developed by CROW (2023a), the minimum road width for a road with a segregated bicycle path and two-way motor vehicle traffic is 9.2 meters, without central axis marking. This road type furthermore comprises two cycling paths of at least 1.7 meters width and a lane width for motor traffic of at least 5.8 meters. However, this lane width is considered too narrow if the road is a public transport route, as it may not allow for the safe passing of vehicles. If this road is a public transport route and falls in the ETW30 category, the preferred minimum lane width is 6.5 meters. If the road falls in the GOW50 category, it is 7 meters. Careful consideration is needed when choosing road widths, as wider roads can undermine the credibility of a 30 km/h speed limit. Therefore, it is recommended to adopt the road width standards for ETW30 to maintain speed limit credibility.

In the experiment, these findings leads to a road width of 6 meters for narrow roads and a road width of 7 meters for a wide road. The chosen road widths are thus representative, since GOW30 applies to roads that are either ETW30 and GOW50. Parking spaces have standardized sizes regardless of the road category: approximately 2 meters in width and 5.5 meters in length (TU Delft OCW, 2024).

Other variables of interest are traffic signs: the traffic sign A1-30 has to be repeated after each crossing. The road sign A1-30zb could be posted along the roads as well, but only upon entering a zone with a 30-km/h speed limit (CROW, 2023a). This way, a clear distinction between ETW30 and GOW30 can be made by road users. However, to ensure consistency in each scenario, the former option is chosen.

Figure 7: A1-30 From: TrafficSupply (2024).

Figure 8: A1-30zb. From Traffic Safety Systems. (2024)

3.3.4 Greenery types in the experiment

To determine the appropriate greenery types for the road environment, insights were gathered through interviews with three road designers from Witteveen + Bos and two mobility specialists from the municipality of Rotterdam. These insights were incorporated in the survey on road designs as well.

According to the interviews with the road designers and mobility specialists, greenery options include grass, hedges, marram grass, or trees with a maximum height of 4 meters for the Zaagmolenstraat. This is practically relevant, since tram catenaries are present. The experts also revealed that several criteria must be considered when selecting the appropriate type of greenery for urban roads. Firstly, the greenery should be aesthetically pleasing and well-suited for the built environment, taking into account factors such as size and whether the leaves have the potential to bleed color, which can create spots on the road. Additionally, the placement of trees should not obstruct visibility around (pedestrian) crossings, to ensure that road users can anticipate other traffic effectively. In a dense urban environment, only trees that grow vertically both above and below ground can be selected. Suitable examples include Populus, Conifers, and Cypress trees. In areas where there are no parking spaces, green strips with varying grass heights can also be incorporated to enhance the road environment.

Potential redesigns that focus on durability for the Zaagmolenstraat might include elevated parking spaces that are alternated with trees. This corresponds to the concept of shared space, since pedestrians share space with parked cars. This approach would create the optical effect of a wider sidewalk for pedestrians while simultaneously narrowing the visual appearance of Zaagmolenstraat. In the next paragraph, the chosen configurations are explained together with findings from the survey that evaluated preferences of 42 participants.

3.3.5 Experimental design

The beforementioned survey evaluated 32 developed designs, which can be found in Appendix B: Survey on road designs. All specific insights from this survey can be found in Appendix C: Survey results.

First, when asked on differences in driving speeds between roads with level and elevated parking, 39% of participants did not perceive any significant differences between the two road configurations. Meanwhile, 24.4% (10 respondents) observed a difference but indicated that it would not affect their driving speed. Conversely, 14.6% (6 respondents) reported a perceived difference and stated that they would drive faster, while 22% (9 respondents) reported that they would reduce their speed. To clearly see what the general effect is of elevated parking on driving speeds, this elevated parking is combined with two levels of road width.

Regarding greenery placement on the right side of the road, both greenery height and planter size were tested. Short green strips adjacent to the road were perceived as chaotic, particularly when participants drove at higher speeds. In contrast, continuous long green strips along the entire road were well-received because they acted as a barrier between the road and the sidewalk, limiting pedestrian crossings. However, this approach was deemed impractical due to the need to provide informal crossing points for pedestrians. As a result, planters measuring 5 meters in length and 1.5 meters in width, spaced 5.5 meters apart, were chosen to balance aesthetics and practicality. These planters housed greenery with varying heights (grass, marram grass and Populus trees).

For bilateral greenery, low or medium-height greenery between parking spaces was excluded, as this almost was invisible in the driving simulator experiment between parked cars. Consequently, only high greenery was tested between parking spaces. The planters for this greenery type measured 1.5 meters in length and 1.5 meters in width. Variations in the width of the greenery were also examined, as thicker greenery reduced visibility of the sidewalk. Survey results indicated that 92.7% of participants agreed that reduced visibility due to greenery resulted in slower driving speeds.

These insights led to the configurations from table 2: Road segment configurations. This table illustrates that the designs vary across five main factors: road width (narrow and wide), parking space height (elevated and level), greenery placement (none, right side of the road and both side of the road) and greenery height (low, medium, and high). High greenery between cars was also tested at two width levels. The wider option, labeled “high+”, featured trees that were twice as thick as the standard configuration. In each scenario, the greenery is placed in dedicated planters to ensure consistency in offset to the road and spacing between the greenery to be able to compare the impact of greenery to one another.

All participants drove through a circuit, in which the order of segments was randomly determined by ChatGPT with the following prompt: “I have a few road configurations all named differently, please randomize the order: NE, NL, NLRL, NLRM, NLRH, NLBH, NLBH+, WE, WL, WLRL, WLRM, WLRH, WLBH and WLBH+. Start with two segments that start with “W”, then follow by 7 configurations starting with “N”, followed by the remaining segments starting with “W”. This prompt resulted in the circuit with the following order, as seen in table 2: column ‘Segment order in circuit’. Here, each segment was 500 meters in length, similar to the Zaagmolenstraat. For reference, images of all segments have been included in Appendix D: Road segments.

Table 2: Road segment configurations

Road width	Parking	Greenery placement	Greenery type	Coding	Segment order in circuit
Narrow (6 meters)	Elevated (+ 15cm)	None	None	NE	6
	Level	None	None	NL	5
		Right side of the road	Low (grass)	NLRL	3
			Medium (marram grass)	NLRM	8
			High (Populus tree)	NLRH	7
		Both sides of the road	High (Populus tree)	NLBH	9
			High+ (twice as thick Populus tree)	NLBH+	4
Wide (7 meters)	Elevated (+15cm)	None	None	WE	11
	Level	None	None	WL	13
		Right side of the road	Low (Grass)	WLRL	14
			Medium (Marram grass)	WLRM	1
			High (Populus tree)	WLRH	12
		Both sides of the road	High (Populus tree)	WLBH	2
			High+ (twice as thick Populus tree)	WLBH+	10

3.4 Experimental procedure

First, participants were asked to sign the informed consent form. This form explained the context and purpose of this research. It also assured participants that their results would remain anonymous and instructed them to drive as they would in real-life situations.

After signing the informed consent form, participants were seated in the driving simulator. They were asked to adjust their seating position and were given instructions on how to operate the simulator, including the use of the throttle, braking pedal, steering wheel, reverse gear and indicator lights.

Then, participants engaged in a preliminary training for 5 minutes to get acquainted with the simulator. In this training, the built-environment was similar to the built-environment of the experiment, however roadside vegetation was not similar to the final experiment, to minimize bias. Consecutively, participants were asked to turn left on a crossing, park a car in a parking space, exit this parking space, make a 360-degree turn and continue their ride with a constant driving speed. In this training, participants encountered oncoming traffic after 2 minutes, with a frequency of 1 car per minute. Upon finalization of this training, participants had a 2-minute break.

After the break, participants were once again instructed to drive as they normally would and to start the driving simulation experiment in which they drove through 14 road segments. At the beginning of each road segment, a 30 km/h sign was placed, in line with CROW's (2023a) recommendations for GOW30. On each segment, participants encountered oncoming traffic with a low-frequency of 2 cars per minute, along with pedestrians standing at random places in order to mimic reality. These pedestrians did not cross the street, to minimize influence on driving behaviour. A stop sign was positioned at the end of each segment, serving as a point for participants to come to a complete stop and reset. At the end of scenarios 4, 7 and 11, participants turned right. Midway through the experiment (at the end of scenario 7), participants had a break of 5-minutes again, to reduce potential fatigue before resuming the simulation and driving as they would in real-life.

3.5 Questionnaires

Upon completion of the simulation experiment, participants were asked to fill in a questionnaire which comprised of four parts. This survey can be found in Appendix H: Post-experiment questionnaire The first part obtained information on their demographics and driving experience. The target variables of this part were age, gender, nationality, educational degree and their driving frequency per week. It should be noted that all data was made anonymous, in correspondence to guidelines of the Human Research Ethics Committee from TU Delft.

The second part of the questionnaire was aimed at the experience with the driving simulation, such as the extent to which participants experienced discomfort such as eye strain, disorientation and nausea on a 4-point scale ("not" to "severe") based on the Simulation Sickness Questionnaire (Kennedy et al., 1993).

The third part of the questionnaire was aimed at estimating participants' presence during the drive. For this aim, items from the Presence Questionnaire by Witmer et al. (2005) were used that measured fidelity of the simulator, immersion in the experiment and the extent to which the experience felt similar to reality.

Then, the last part of the questionnaire examined respondents' relation to the sustainable measures with a mix of scaled, multiple choice and open questions. For example, to which extent drivers find greenery comfortable, which road designs have their preferences and the influence of greenery on their sense of safety. Furthermore, questions were asked on other variables such as the presence of cars along roads and how participants expect a centerlines to have an influence on their driving behaviour. Finally, respondents were given the opportunity to make final remarks and explain why certain roads were preferred.

3.6 Data collection

In the experiment, the driving simulators collected driving trajectories with a frequency of 1Hz. The following variables were collected for the trajectories: driving speed [m/s], acceleration [m/s^2] and car position in each direction (x, y and z). In order to filter out non-representative data as a result of colliding with other vehicles, collision times were also recorded.

3.7 Analysis approach

When analyzing the results of the driving experiment, several data analysis options are available such as an analysis of variance (ANOVA) and a Linear Mixed Model (LMM). Several criteria need to be considered when selecting a data analysis method. First, the appropriate method should account for the correlation between the results for each participant, since the road (environment) is varied 14 times throughout the experiment. Second, demographic variables are important to include in the model, since literature has shown multiple times that these variables influence driving behaviour. Third, the sample of this experiment is not random, since participants are recruited at specific locations.

Given these criteria and complexity of data, a Linear Mixed Model (LMM) was chosen for the analysis. The LMM allows for the inclusion of various effects, such as participant, age, gender, weekly driving frequency, nationality, and educational degree. In addition to this, the dependent variable can be explained by the factors that were varied in the experiment: road width, parking height and greenery type. Elaboration on the categorization of these factors is explained in subsection 4.5: Data analysis.

This approach allows for a more detailed analysis, capturing the complexities of the experimental design and the interrelated nature of the data. Furthermore, the method employed represents a state-of-the-art technique, previously utilized in the analysis of driving simulation tests (Rad et al., 2021). Since two driving simulators were used in this study, the results are analyzed in combination and separately. It is expected that this will lead to differences in outcomes, thus these outcomes are compared to each other.

4 Analysis and results

In this chapter, the demographic statistics of the experiment are presented in the following subsection. Then, the data filtering approach is explained in subsection 4.2, which is followed by the distribution of driving speeds and lateral position in subsections 4.3 and 4.4. In paragraph 4.5, linear mixed model analyses are performed for driving speeds and lateral position. Finally, the survey results are presented in subsection 4.6, which is of importance for the interpretation of the results from the linear mixed models.

4.1 Demographic statistics of the experiment

In this sub-section, the descriptive statistics with regards to demographics of the participants are presented. For the 44 participants in both simulators, the mean age was 30.87 years with a standard deviation of 8.48. It can be seen that most participants drive on average less than 2 hours per week. 30 of the participants identified as male and 14 as female. Furthermore, the majority of the sample is higher educated, no participants have a vocational education. Finally, two people in the sample have another nationality than Dutch. This is assumed to not influence the results of the LLM's, since all participants were recruited in the Netherlands.

Figure 9: Distribution among participants based on personal characteristics (including TU Delft simulator)

4.2 Data filtering

As mentioned in the previous chapter, participants drove through a circuit of 14 road segments with a length of 500 meters per segment. In this circuit, participants made a total of 4 right-turns and braked for zebra crossings. Also, each participant braked for a stopping sign at the end of each road segment. Since these handlings influence the average free-flow speed and average lateral position on the road, the data resulting from these actions need to be filtered from the dataset for the data to be reliable.

Since each participant's driving behaviour can vary widely, it is not feasible to establish concrete thresholds that would consistently identify and remove problematic data across all participants. Therefore, no fixed criteria are applied for data removal based on changes in speed or lateral position, recognizing the individual differences in driving patterns.

With regards to data filtering, a balance needs to be found between improving the reliability of data, without significant loss of information and introducing selective bias to favor the developed hypotheses in chapter 2. In order to ensure a balance between improving the reliability, without significant loss of information and introducing selective bias, the below rules were developed:

R1: For all scenarios, if a participant collides with another vehicle in the simulation, measurements from the collision up to the point where lateral positioning and driving speed stabilize are removed from the dataset.

R2: In scenarios 1, 5, 8 and 11, the initial measurements are excluded, since these scenarios are preceded by right turns, which affect lateral positioning in the beginning of the road.

R3: To eliminate braking patterns, any braking movement immediately before reaching a zebra crossing is assumed to be due to approaching the crossing. Data from this braking point until the passing of the crossing is removed.

R4: If the speed profile immediately after passing the zebra crossing shows a new minimum or maximum compared to the profile before the crossing, this measurement is considered an anomaly. Data is excluded until the speed returns to the level of minimum or maximum driving speed before the crossing.

R5: When data is removed based on either speed or lateral position, the corresponding data for the other measure is also removed to maintain consistency.

In the following paragraphs, representative data was used to generate boxplots. This same data was used to perform the linear mixed model analyses for the derived metrics.

4.3 Distribution of driving speed per segment

First, boxplots were generated for all segments of the combined datasets for the Witteveen + Bos simulator as well as the TU Delft simulator. As illustrated in the figure 7, the mean driving speeds in each scenario are consistently close to 30 km/h. Still, large outliers can be seen in almost all scenarios. The largest outlier can be seen in scenario WLRL, which is a scenario with a wide road and low greenery on the right side of the road. Notably, the lowest average driving speed occurs in segment NLBH+, which exhibits no outliers, suggesting a more uniform driving speed among participants. This scenario comprises a narrow road bordered by tall and dense greenery. This homogeneity is particularly relevant, as variations in driving speeds can influence road safety. Higher speed differentials between vehicles and high driving speeds are associated with higher accident risks, as found by research from Elvik (2014).

For the data that is based only on the simulator at Witteveen + Bos, driving speeds are also close to 30km/h. The largest bandwidth can be seen in scenario WLRL, which is a wide road with low greenery on the right side. This illustrates that the participants in this sample also have their own driving speed preferences and sensitivity towards a change in roadside.

In figure 8, which illustrates the boxplots for the Witteveen + Bos simulator, the mean driving speed in each scenario is consistently close to 30 km/h as well. The lowest average driving speed still occurs in segment NBLH+, suggesting again that thick Populus trees placed in between cars have a speed reducing effect. The second lowest average driving speed can be seen in scenario WLRM, which features a wide road flanked by medium-height greenery. Then, a smaller bandwidth can be seen in scenarios NLBH and WE, which suggests more homogeneous driving speeds in these scenarios. Finally, outliers are reduced for NLRL, WL and WLRL which are primarily scenarios with low greenery. To test whether these observations for driving speeds are significant, a linear mixed model is estimated, which can be found in paragraph 4.5.

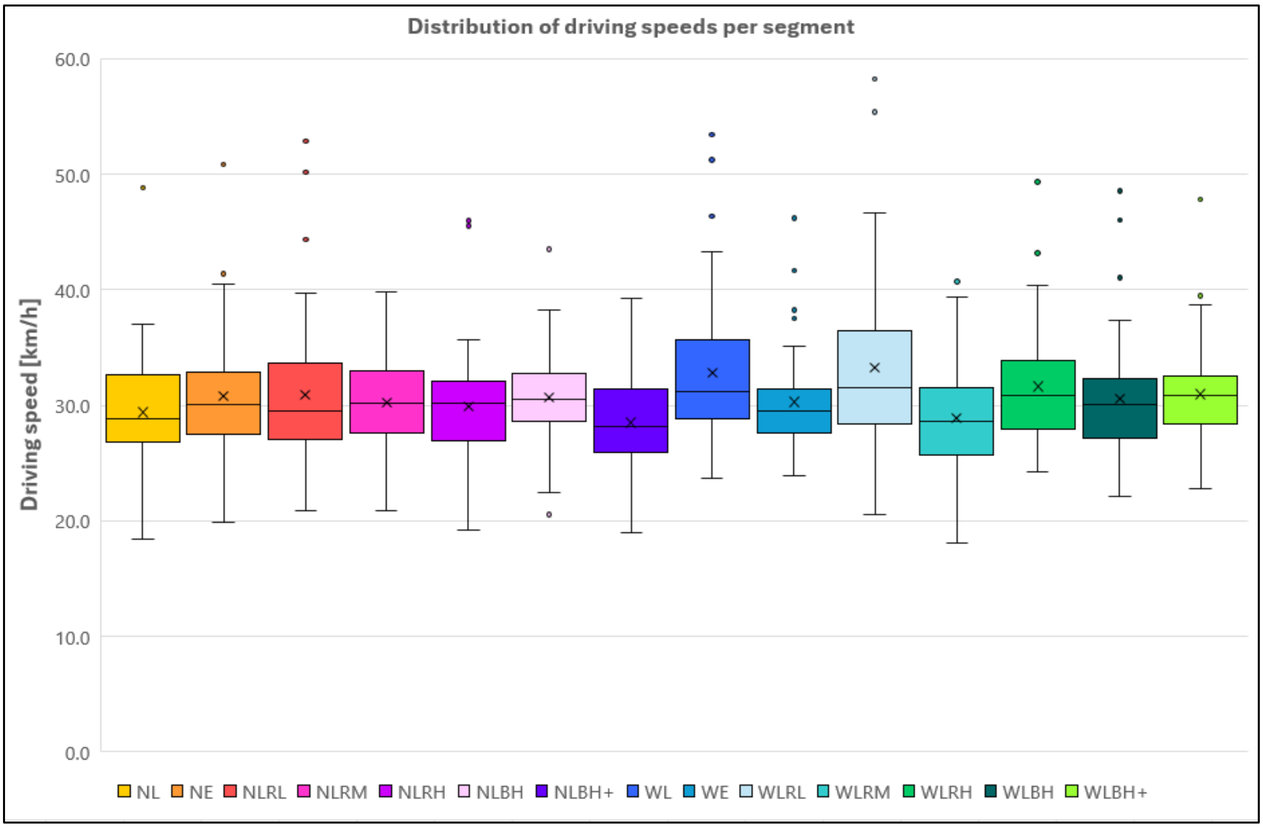

Figure 10: Distribution of driving speeds per segment (including TU Delft simulation data, total observations: 616)

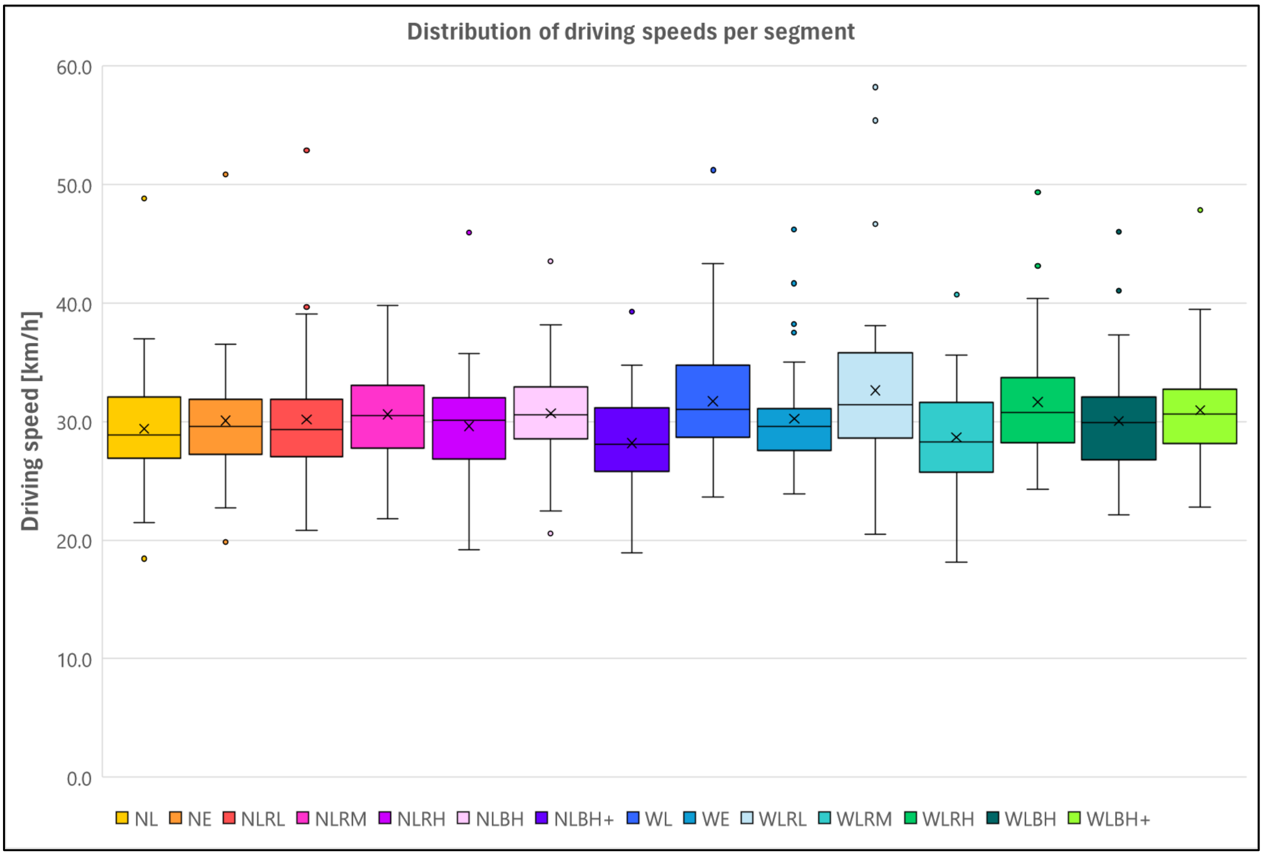

Figure 11: Distribution of driving speeds per segment: Witteveen + Bos simulation (total observations: 560)

4.4 Distribution of driving position

To get a clear insight into driving behaviour in general on the developed segments, boxplots have been generated to present the average driving position on the road for each segment. Here, a zero position indicates that car drivers position themselves in the center of their lane. Also, a positive lateral position indicates a right-position and a negative lateral position signifies a left-position.

As can be seen in the below figures, participants were mostly driving on the left side of the lane on road segments with parked cars on both sides: NL, NE & WL. The same can be seen in scenarios with parked cars and trees placed in between cars: NLBH, NLBH+, WLBH and WLBH+. The most right-oriented driving behaviour can be seen in segment WLRH, which is a wide road with level parking and high greenery on the right side.

Also, a high variety amongst participants in the metric can be seen in segments WLRM, NL, WLRL and WLRH, which could mean that participants each have a different sensitivity for objects along the road which influences their lateral positioning. In chapter 4.3, also a linear mixed effects model was estimated for lateral positioning on the road. Then, in chapter 5, these results will be discussed together with the findings of the linear mixed model for driving speeds, since it is likely that proximity to an object along a road segment and driving speed on that road segment influence each other. For the TU Delft driving simulator, narrow roads (e.g., NL, NE, NLRL) tend to have wider distributions with drivers positioning further from the centerlines. In contrast, wide roads (e.g., WL, WLRL, WLRM) display more centralized positioning, indicating that drivers are generally more centered or closer to the centerlines. The effect of greenery, especially high or dense greenery (e.g., "NLRH," "NLBH+"), also appears to influence lateral positioning, pushing drivers slightly further away from the centerlines compared to scenarios without greenery. The variance in lateral position across different road conditions suggests that road width, elevation, and greenery type all play significant roles in how drivers choose their position relative to the centerlines.

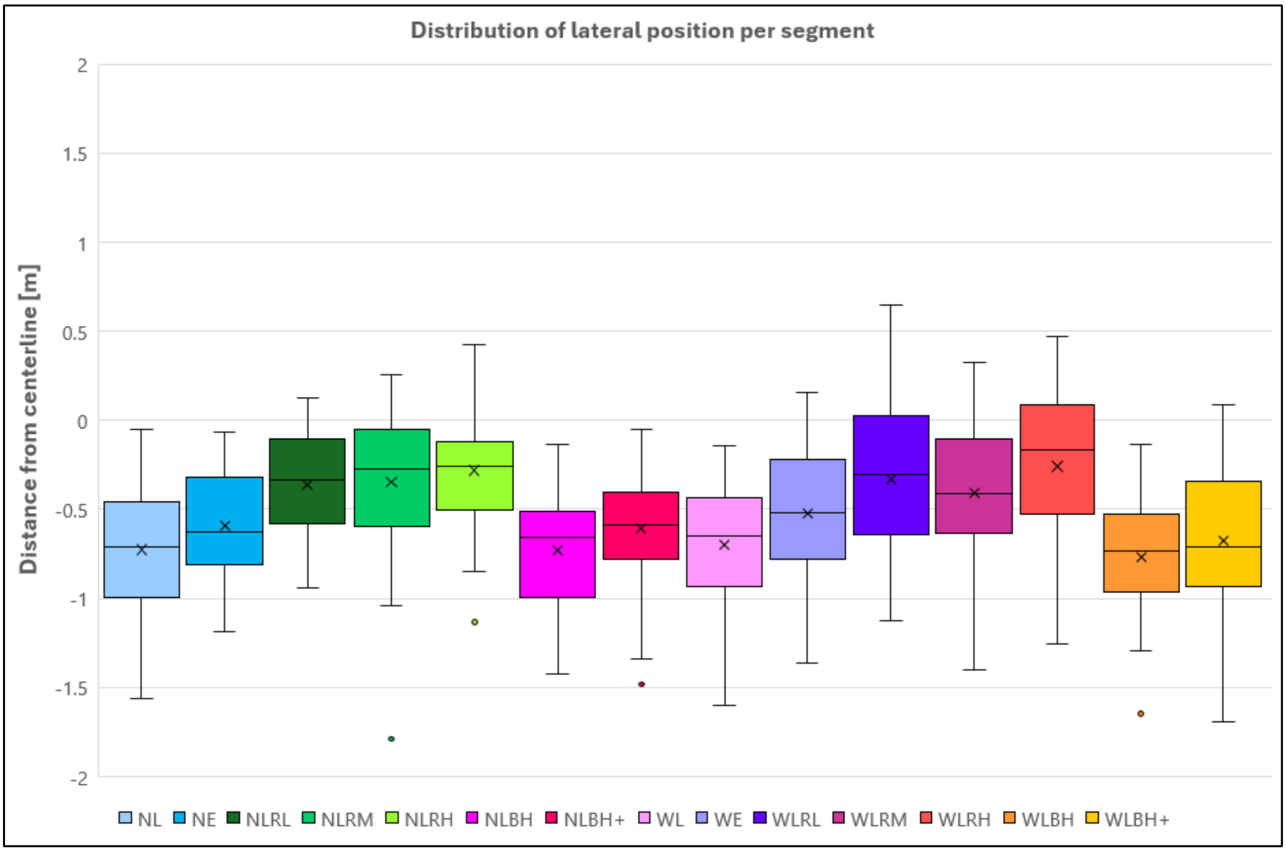

Figure 12: Distribution of driving position per segment (including TU Delt simulation data, total observations: 616)

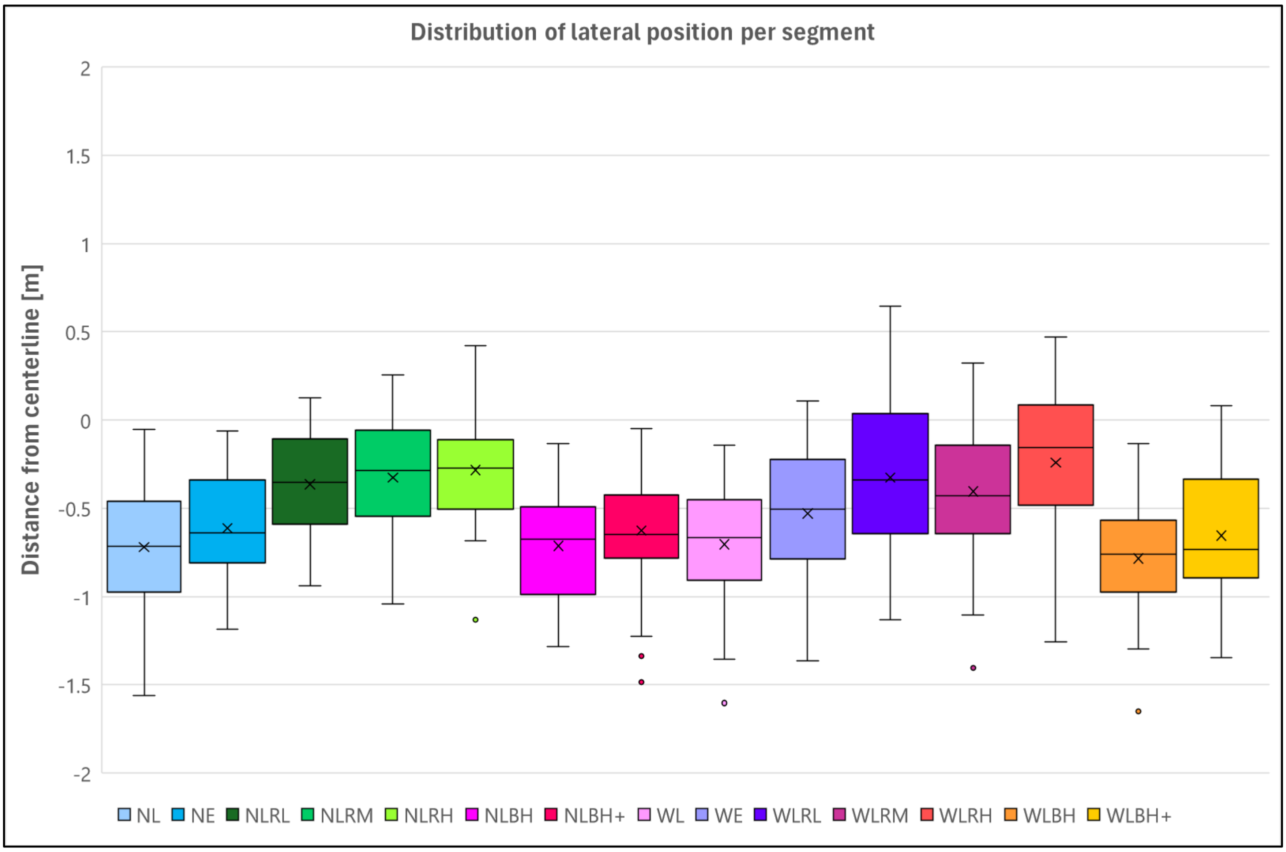

Figure 13: Distribution of driving position per segment: Witteveen + Bos simulation (total observations: 560)

4.5 Data-analysis

As indicated by the boxplots in paragraphs 4.3 and 4.4, driving speeds and lateral positioning vary across scenarios, exhibiting different bandwidths and averages. To determine whether these differences are statistically significant from the base scenario, Linear Mixed Effect Model analyses were performed with R. First, the estimated LMM's will be explained for average driving speeds per segment. Following up, the LMM's for average lateral positioning on the road.

In total, four LLMs were estimated: driving speed and lateral position are estimated for the combined dataset (including participants from TU Delft) and for the dataset excluding these participants. For all models, a random intercept was included for participants. A random intercept accounts for correlations between observations for each participant, varying by individual. In other words, some participants may naturally drive faster or prefer different positioning compared to others, even when road environment and other conditions are held constant. This random intercept estimated a difference for each participant based on the regression-line, providing a more accurate estimate of the effects of the experimental variables.

In addition to the random intercept, each model included a random slope per segment. This choice was made since it is expected that drivers each have a different sensitivity towards the change of road environments and the duration of the experiment. For example, while some participants may show a strong change in driving behaviour when encountering different road environments, others may exhibit a weaker response. With the inclusion of a random slope, the model accommodates this variability in sensitivity towards the different driving conditions.

As stated in the literature review, driving behaviour is different for various age groups. For these reasons, age in the analysis is categorized in very young adults (18-24), young adults (25-29) and older adults (30 and higher). The last category of users is expected to have many more years of driving experience.

In this study, gender is categorized into two groups: male and female. Weekly driving frequency is classified into three categories: less than 2 hours, between 2 and 5 hours, and more than 5 hours. Despite two participants not having the Dutch nationality, nationality is not a variable of interest in these analyses since all participants were recruited in the Netherlands. Educational degree is grouped into three categories: secondary education, a bachelor's degree (BSc), and a master's degree (MSc) or higher.

In this analysis, road width is categorized in two levels: narrow (0) and wide (1), while parking height is classified as level (0) or elevated (1). The primary objective of this research is to assess the impact of sustainable measures on driving behaviour. To investigate this, greenery type is varied across six conditions: no greenery (0), low greenery on the right side (grass(1)), medium greenery on the right side (marram grass(2)), high greenery on the right side (Populus trees(3)), high greenery on both sides between cars (Populus trees(4)), and high and dense greenery on both sides between cars (Populus trees, twice as thick(5)).

4.5.1 Linear Mixed Effect Models for driving speed

For driving speed, the models in table 3 and 4 were estimated to investigate the differences in driving speeds among the segments that differed in sustainable measures. These models were estimated in R with the following formula:

$$F1: DrivingSpeed \sim RoadWidth + ParkingHeight + GreeneryType + Age + Gender + Education + DrivingFrequency + RoadWidth * GreeneryType + RoadWidth * ParkingHeight + (1 + Segment \mid Participant)$$

This illustrates that personal characteristics were included such as age, gender, educational degree and driving frequency. Furthermore, interaction effects are included for road width with elevated parking and greenery type.

Table 4, which is the estimated model for both simulators shows a significant intercept of 34.050 km/h, which is the base driving speed on a narrow road with no greenery, for a male driver aged 18-24 with a BSc education and less than 2 hours of weekly driving.

Furthermore, road width solely is shown to significantly increase driving speeds with 3.229 km/h ($p < 0.001$). This results is consistent with previous literature, that stated that drivers increase speed when given more space. Similarly, the presence of elevated parking, while marginally significant (estimate = 1.267, p = 0.064), shows a slight increase in speed. Although this effect does not reach statistical significance, it suggests that elevated parking might slightly affect drivers' speed behaviour.

The analysis of the greenery types reveals that low greenery and high greenery on both sides of the road impact driving speeds significantly. Both greenery types have a positive effect on driving speed: low greenery increases driving speeds with 1.364 km/h (p = 0.047) and high greenery on both sides increases it with 1.405 km/h (p = 0.046).

Interestingly, high greenery on the right side results only in a slight, non-significant increase (estimate = 0.622, p = 0.035), and medium height greenery also in a non-significant increase in driving speeds of 1.059 km/h (p = 0.127). Conversely, the densest configuration (both sides with high and thick greenery) reduces speed insignificantly by -1.082 km/h (p = 0.113), suggesting that excessive greenery may hinder visibility or create a psychological barrier for drivers.

Exploring interactions between road width and other factors, wide roads combined with elevated parking significantly reduce speed (estimate = -3.568, $p<0.001$), indicating an interplay between road width and parking configurations. The interaction between wide roads and medium greenery also has a strong negative effect on speed (estimate = -4.714, $p<0.001$), suggesting that when wide roads are paired with medium greenery, drivers may perceive the environment as more constrained, leading to a significant reduction in speed. On narrow roads, driving speeds were shown to increase with high greenery. However, high greenery on both sides on wide roads is shown to decrease driving speeds with 3.447 km/h (p = 0.003).

Demographic factors also play a role. The age group of 25-29 years shows a significant decrease in speed compared to the reference group (18-24 years), with an estimate of -6.671 km/h (p = 0.007). Similar reductions are observed for the 30 years and higher group (estimate = -5.959, p = 0.016), reflecting that older drivers tend to adopt more cautious driving behaviour. Gender, educational degree and driving frequency did not influence driving speeds significantly.

Then, table 5 shows the results for the experiment without 4 participants from the TU Delft simulator. These 4 participants were in the age groups 18-24 and 30 and higher. All 4 participants drove less than 2 hours per week. This model shows a lower significant intercept of 32.946 km/h ($p<0.001$), which also is the base driving speed on a narrow road with no greenery, for a male driver aged 18-24 with a BSc education and less than 2 hours of weekly driving. However, this indicates that participants generally drove slower in the Witteveen + Bos simulation. Furthermore, almost all effects that were significant in the combined dataset are still significant, despite all estimates being lower.

One interesting finding is that now, high and thick greenery on both sides of the road reveals a significant speed reducing effect of 1.381 km/h ($p = 0.028$). This indicates that drivers in the driving simulator at TU Delft were generally less sensitive to an increase in greenery width of high greenery. Another finding is that now, grass does not have a significant speed increasing effect, despite it still indicating that it increases driving speeds with 0.670 km/h ($p = 0.286$).

In conclusion, both models highlight the significant impact of road design elements and driver age. Wide roads significantly increase driving speed, as well as high greenery on both sides on a narrow road. Findings also indicate that low greenery on narrow roads increase driving speeds and high and thick greenery decreases driving speeds. However, these effects are not clearly significant for all participants. When analyzing interaction effects with wide roads, elevated parking, marram grass and Populus trees on both sides have a speed reducing effect.

Table 3: Linear mixed model for driving speed (including simulation at TU Delft)

Dependent variable		**Model**				
		Estimate	**p-value**	**SE**	**df**	**t-value**
Intercept		34.050	**<0.001**	1.724	42.800	19.756
Measure	Wide road (7 meters wide)	3.229	**<0.001**	0.761	312.331	4.242
	Elevated parking	1.267	0.064	0.682	522.131	1.859
	Grass strips	1.364	**0.047**	0.686	537.920	1.990
	Marram grass strips	1.059	0.127	0.692	554.660	1.530
	Populus tree strips	0.622	0.365	0.686	537.920	0.907
	Populus trees on both sides	1.405	**0.046**	0.701	557.124	2.004
	Populus trees on both sides (twice as thick)	-1.082	0.113	0.682	522.131	-1.587
	Wide road * elevated parking	-3.568	**<0.001**	0.971	540.148	-3.677
	Wide road * grass strips	-0.610	0.530	0.971	540.148	-0.628
	Wide road * marram grass strips	-4.714	**<0.001**	1.156	170.914	-4.079
	Wide road * Populus tree strips	-1.529	0.116	0.971	540.148	-1.575
	Wide road * Populus trees on both sides	-3.447	**0.003**	1.156	170.914	-2.980
	Wide road * Populus trees on both sides (twice as thick)	-0.473	0.625	0.966	527.841	-0.489
Age (Reference group: 18 to 24)	25 to 29	-6.671	**0.007**	2.326	37.000	-2.868
	30 and higher	-5.959	**0.016**	2.351	37.000	-2.535
Gender (Reference group: Male)	Female	-1.959	0.137	1.289	37.000	-1.520
Education (Reference group: BSc)	MSc or higher	0.589	0.775	2.042	37.000	0.288
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	1.673	1.269	37.000	1.318	0.196
	More than 5 hours	4.159	0.161	2.908	37.000	1.430
Statistics						
Number of observations	616					
Number of groups	44					
REML criterion at convergence	3304.7					
Log-likelihood	-1652.336 (df=24)					
AIC	3352.672					
BIC	3458.83					

Table 4: Linear Mixed Model for Driving Speed: Witteveen + Bos simulation

Dependent variable		**Model**				
		Estimate	**p-value**	**Std. Error**	**df**	**t-value**
Intercept		32.946	**<0.001**	1.902	36.499	17.319
Measure	Wide road (7 meters wide)	2.321	**<0.001**	0.673	351.423	3.449
	Elevated parking	0.670	0.286	0.628	472.184	1.067
	Grass strips	0.775	0.219	0.630	483.469	1.230
	Marram grass strips	1.211	0.056	0.634	497.616	1.912
	Populus tree strips	0.215	0.733	0.630	483.469	0.342
	Populus trees on both sides	1.295	**0.043**	0.639	506.710	2.027
	Populus trees on both sides (twice as thick)	-1.381	**0.028**	0.628	472.184	-2.200
	Wide road * elevated parking	-2.129	**0.017**	0.891	485.155	-2.388
	Wide road * grass strips	0.125	0.889	0.891	485.155	0.140
	Wide road * marram grass strips	-4.241	**<0.001**	0.998	200.640	-4.249
	Wide road * Populus tree strips	-0.283	0.751	0.891	485.155	-0.318
	Wide road * Populus trees on both sides	-2.958	**0.003**	0.998	200.639	-2.963
	Wide road * Populus trees on both sides (twice as thick)	0.634	0.476	0.889	476.163	0.714
Age (Reference group: 18 to 24)	25 to 29	-5.975	**0.016**	2.359	33.000	-2.532
	30 and higher	-4.975	**0.047**	2.412	33.000	-2.063
Gender (Reference group: Male)	Female	-1.853	0.191	1.387	33.000	-1.336
Education (Reference group: BSc)	MSc or higher	0.809	0.692	2.025	33.000	0.399
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	2.194	0.095	1.278	33.000	1.720
	More than 5 hours	4.412	0.136	2.884	33.000	1.530
Statistics						
Number of observations	560					
Number of groups	40					
REML criterion at convergence	2854.9					
Log-likelihood	-1427.441 (df=24)					
AIC	2902.881					
BIC	3006.752					

4.5.2 Linear Mixed Effect Models for lateral position

To fully understand the driving dynamics for the simulated environment, lateral positioning on the roads should also be evaluated. In table 5, the estimates for lateral position of the combined dataset are presented. In table 6, the estimates for lateral position without the participants from the TU Delft simulation are shown.

Similarly to the estimations for driving speed, a model was estimated that took into account all demographic variables. This model was formulated as follows:

$$F2: PositionNormalized \sim RoadWidth + ParkingHeight + GreeneryType + Age + Gender + Education + DrivingFrequency + RoadWidth * GreeneryType + RoadWidth * ParkingHeight + (1 + Segment \mid Participant)$$

A random intercept was included in this model to account for correlations between observations for each participant, which can vary by individual. This is a logical approach, given that each driver may have a different baseline lateral position on the road. The baseline condition is defined as a narrow road devoid of greenery. All baseline conditions were similar to those for the estimated models for driving speed.

First, table 6 reveals an intercept of -0.637 with a significant p-value of <0.001. This suggests that in the base scenario, drivers were driving more on the left side of their lane rather than central in their lane. Also elevated parking shows a significant effect, with an estimate of 0.130 meters and a p-value of 0.008.

Then, all types of greenery except for high greenery on both sides show a significant difference compared to base. The biggest change in lateral position can be seen if high greenery is placed on the right side of the road. This measure has an estimate of 0.441 (p-value: <0.001), followed by medium height greenery (Marram grass) with an estimate of 0.387 (p-value: <0.001) and lastly by low greenery with an estimate of 0.371 (p-value <0.001). High and thick greenery on both sides of the road also lets drivers drive more centrally in their lane, as it increases lateral positioning with 0.116 meters (p = 0.017). None of the interactions of elevated parking and greenery types with road width show a significant difference compared to base, suggesting that the combined effects do not differ from the main effects and that lateral positioning is not influenced by greenery if road width is increased with 1 meter.

In table 7, the intercept estimate of -0.612 (p<0.001) suggests that the baseline lateral position is significantly different from zero. Several factors show significant effects on lateral position. Elevated parking increases lateral position by 0.107m (p = 0.031), and grass also shows a significant increase of 0.355 m (p <0.001). High greenery also increases lateral positioning by 0.438 m (p <0.001), indicating that drivers position themselves closer to the road edge when high greenery is present. Contrary to the combined model, high and thick greenery on both sides shows a marginally significant positive impact on lateral position. Finally, combinations of wide roads and various measures have non-significant effects on lateral position. Age, gender, educational degree and driving frequency do not show a significant impact on lateral position in the experiment.

In conclusion, both models reveal significant intercepts and significant differences in lateral position on road with elevated parking, low greenery, medium height greenery and high greenery on the right side. In the model estimated solely for the Witteveen + Bos simulation participants, high and thick greenery on both sides of the road does not show a significant difference, whereas there is a significant impact on lateral positioning in the combined model.

Table 5: Linear Mixed Model for Lateral Position (including TU Delft simulation)

Dependent variable		**Model**				
		Estimate	**p-value**	**Std. Error**	**df**	**t-value**
Intercept		-0.637	**<0.001**	0.139	41.518	-4.589
Measure	Wide road (7 meters wide)	0.033	0.531	0.052	377.580	0.627
	Elevated parking	0.130	**0.008**	0.049	520.790	2.673
	Grass strips	0.371	**<0.001**	0.049	533.644	7.629
	Marram grass strips	0.387	**<0.001**	0.049	549.484	7.904
	Populus tree strips	0.441	**<0.001**	0.049	533.644	9.058
	Populus trees on both sides	0.008	0.866	0.049	558.887	0.169
	Populus trees on both sides (twice as thick)	0.116	0.017	0.049	520.790	2.389
	Wide road * elevated parking	0.044	0.526	0.069	535.551	0.635
	Wide road * grass strips	-0.008	0.907	0.069	535.552	-0.117
	Wide road * marram grass strips	-0.094	0.226	0.078	213.762	-1.215
	Wide road * Populus tree strips	0.003	0.963	0.069	535.552	0.046
	Wide road * Populus trees on both sides	-0.082	0.291	0.078	213.762	-1.059
	Wide road * Populus trees on both sides (twice as thick)	-0.093	0.178	0.069	525.335	-1.350
Age (Reference group: 18 to 24)	25 to 29	-0.005	0.979	0.189	37.000	-0.026
	30 and higher	0.015	0.936	0.191	37.000	0.081
Gender (Reference group: Male)	Female	-0.136	0.201	0.105	37.000	-1.301
Education (Reference group: BSc)	MSc or higher	-0.004	0.979	0.166	37.000	-0.026
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	-0.098	0.350	0.103	37.000	-0.947
	More than 5 hours	-0.267	0.266	0.236	37.000	-1.130
Statistics						
Number of observations	616					
Number of groups	44					
REML criterion at convergence	153.5					
Log-likelihood	-76.751 (df=24)					
AIC	201.502					
BIC	307.660					

Table 6: Linear Mixed Model for Lateral Position: Witteveen + Bos simulation

Dependent variable		**Model**				
		Estimate	**p-value**	**Std. Error**	**df**	**t-value**
Intercept		-0.612	**<0.001**	0.149	36.571	-4.112
Measure	Wide road (7 meters wide)	0.017	0.754	0.054	336.537	0.313
	Elevated parking	0.107	**0.031**	0.050	472.454	2.159
	Grass strips	0.355	**<0.001**	0.050	484.361	7.139
	Marram grass strips	0.394	**<0.001**	0.050	498.861	7.867
	Populus tree strips	0.438	**<0.001**	0.050	484.361	8.793
	Populus trees on both sides	0.007	0.891	0.051	506.970	0.137
	Populus trees on both sides (twice as thick)	0.095	0.055	0.050	472.454	1.926
	Wide road * elevated parking	0.068	0.335	0.070	486.121	0.966
	Wide road * grass strips	0.021	0.763	0.070	486.121	0.301
	Wide road * marram grass strips	-0.096	0.232	0.080	189.561	-1.198
	Wide road * Populus tree strips	0.024	0.727	0.070	486.121	0.350
	Wide road * Populus trees on both sides	-0.088	0.269	0.080	189.561	-1.107
	Wide road * Populus trees on both sides (twice as thick)	-0.047	0.502	0.070	476.671	-0.672
Age (Reference group: 18 to 24)	25 to 29	0.027	0.883	0.185	33.000	0.148
	30 and higher	-0.031	0.870	0.188	33.000	-0.165
Gender (Reference group: Male)	Female	-0.166	0.136	0.108	33.000	-1.530
Education (Reference group: BSc)	MSc or higher	-0.009	0.956	0.158	33.000	-0.056
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	-0.107	0.292	0.100	33.000	-1.071
	More than 5 hours	-0.233	0.309	0.226	33.000	-1.034
Statistics						
Number of observations	560					
Number of groups	40					
REML criterion at convergence	115					
Log-likelihood	-57.505 (df=24)					
AIC	163.011					
BIC	266.881					

4.6 Survey results

In this section, the findings from the follow-up survey are presented which will aid in interpreting the results from the Linear Mixed Model analyses. Also, immersion in the experiment will be discussed, which is of importance for the interpretation and discussion of the results. In the following subsections, the figures are presented for the combined sample. The responses for the sample that took part in the TU Delft simulator are presented in appendix I.

4.6.1 Simulation Sickness during the experiment

Using the Simulator Sickness Questionnaire by (Kennedy et al., 1993), participants were asked questions to assess the extent of nausea, disorientation (such as dizziness or motion sickness), and oculomotor discomfort (including eye strain and headaches) they experienced. They rated their symptoms on a 4-point Likert scale, ranging from 1 (no) to 4 (yes, severe). The results from these questions are primarily positive, with the majority of participants not experiencing any of these symptoms, and a minority experiencing these symptoms mildly. Of 44 participants, 36 did not experience nausea and 4 experienced this mildly. For disorientation, the number of participants experiencing this was slightly higher, with 7 participants experiencing mild disorientation. 33 participants did not experience disorientation. Oculomotor discomfort showed a different response pattern. Here, 32 participants did not experience oculomotor discomfort, 7 experienced this mildly and 1 noticeable.

Figure 14: Simulation Sickness Questionnaire results (combined sample)

4.6.2 Presence during the experiment

Then, to estimate presence during the experiment the Presence Questionnaire by Witmer et al. (2005) was used to measure immersion, control of the simulator and perceived realism. On a scale from 1 (Not at all) to 7 (Extremely immersed), the majority of respondents scored a 5 on visual immersion and a 4 on auditory immersion. Furthermore, the majority of respondents scored a 5 on a scale from 1 (Not at all) to 7 (Extremely delayed) when asked on whether they experienced a delay in the simulation. The majority of participants was content with the simulation and the perceived realism of the simulation is almost equally distributed along the axis from 1 (Totally not similar) to 5 (Totally similar). Then, handling the accelerator pedal was primarily perceived as difficult, with respondents stating that this pedal was sensitive. Before conducting the experiment, this was mitigated by reducing the sensitivity of the pedal. However, if sensitivity was reduced this also increased delay of the pedal. Furthermore, the display quality during the experiment was primarily not interfering with the driving task.

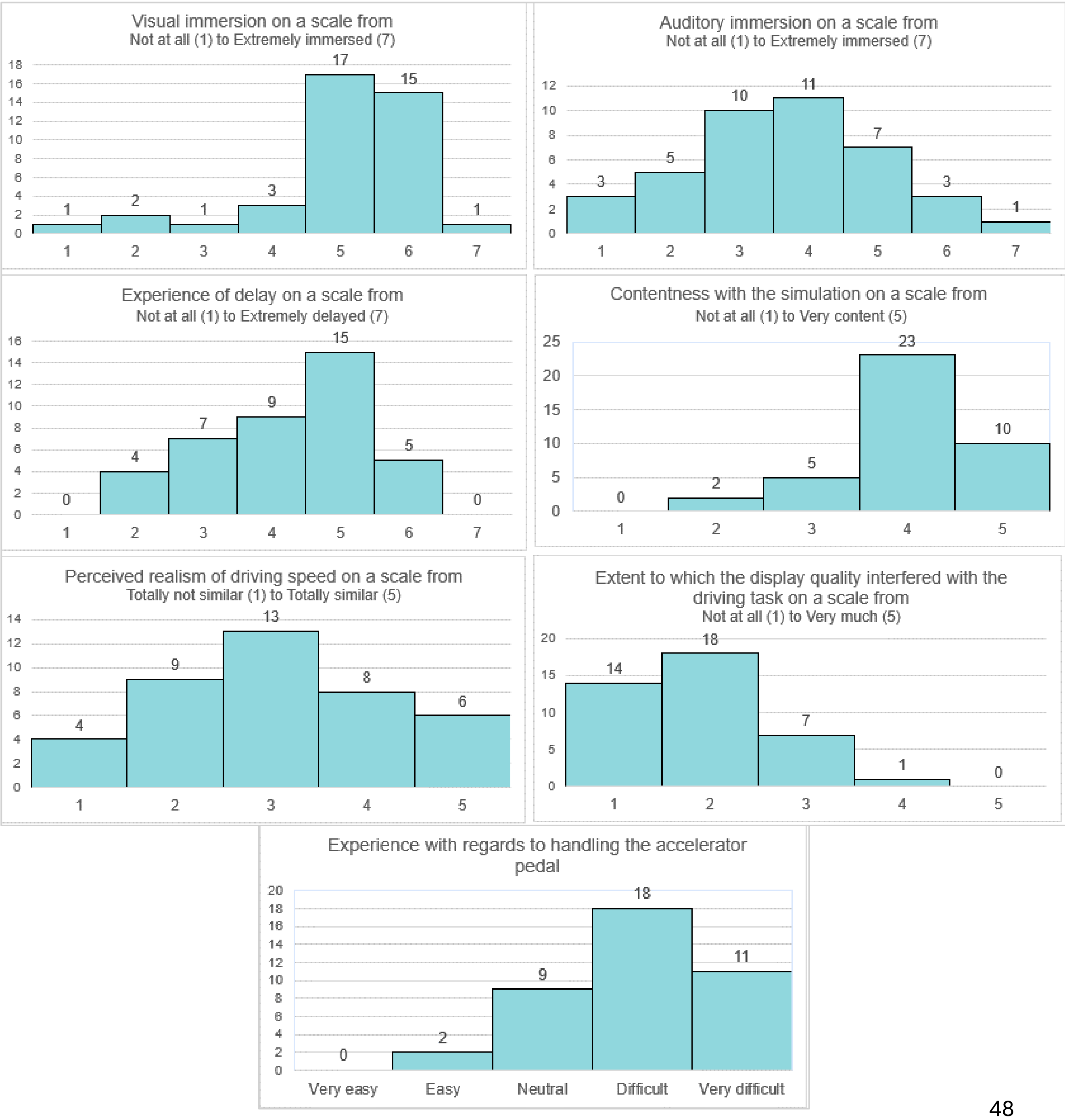

Figure 16: Presence Questionnaire results (combined sample)

4.6.3 Perception of greenery

Then, questions followed with statements that evaluated the presence of greenery and the influence of greenery on visibility. Similar to the findings of the survey used to select road designs, green strips influence sense of safety. 26 out of 45 participant state that green strips on the right side of the road compared to parked cars on the right side of the road make them drive faster. Furthermore, 11 participants stated that this change influences their safety perception, without making them drive faster. The remaining 4 participants state that this does not influence their safety perception, with half stating that they drive faster and half stating they do not drive faster. Furthermore, the majority of participants states that a green strip is perceived as a strong separation between the road and pedestrians. Most participants did not notice that trees were varied in thickness. However, thickness of greenery in this experiment did influence visibility for all participants except 5. When evaluating greenery in general, the majority of participants (19) state that greenery influences their driving behaviour much, followed by moderate (12), little to not (6) very much (5) and not much (3).

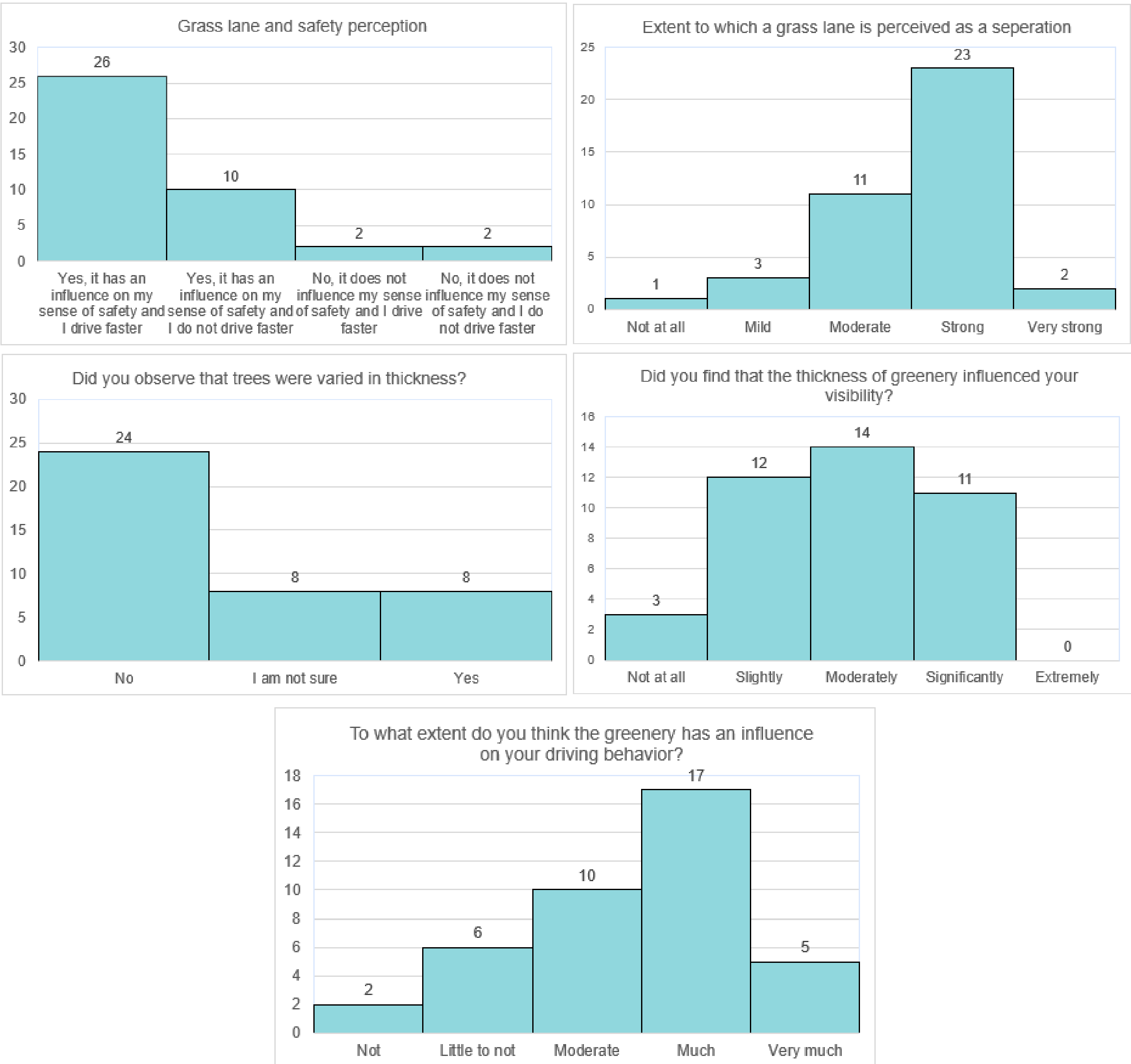

Figure 17: Perception of greenery results (combined sample)

4.6.4 Perception of other traffic and absence of centerlines

Finally, the questionnaire evaluated the influence of a centerlines in the experiment. If a centerlines were added, 24 participants state they would have driven slower and 19 participants state that they would have driven faster. Only 2 participants mention that a centerlines would not have had an influence on their driving speed. Also, 41 participants state that they would keep their lane more with a centerlines, whilst 2 participants state that this would not influence their lane keeping and 2 state that they would keep their lane less. When keeping oncoming traffic in mind, the majority of respondents (34) state they reduce their driving speed a bit with oncoming traffic and 9 state they reduce their speed a lot. Only 2 participants do not reduce their driving speed. All statements with regards to the experiment can be found in Appendix J: Post-experiment questionnaire statements. These statements can be summarized as follows: *The most comfortable road designs feature greenery such as grass or low vegetation on the right side, offering better visibility and a sense of openness. In contrast, narrow roads with parked cars on both sides feel restrictive and reduce visibility. Trees between cars can improve comfort, though dense trees are less comfortable than normal trees.*

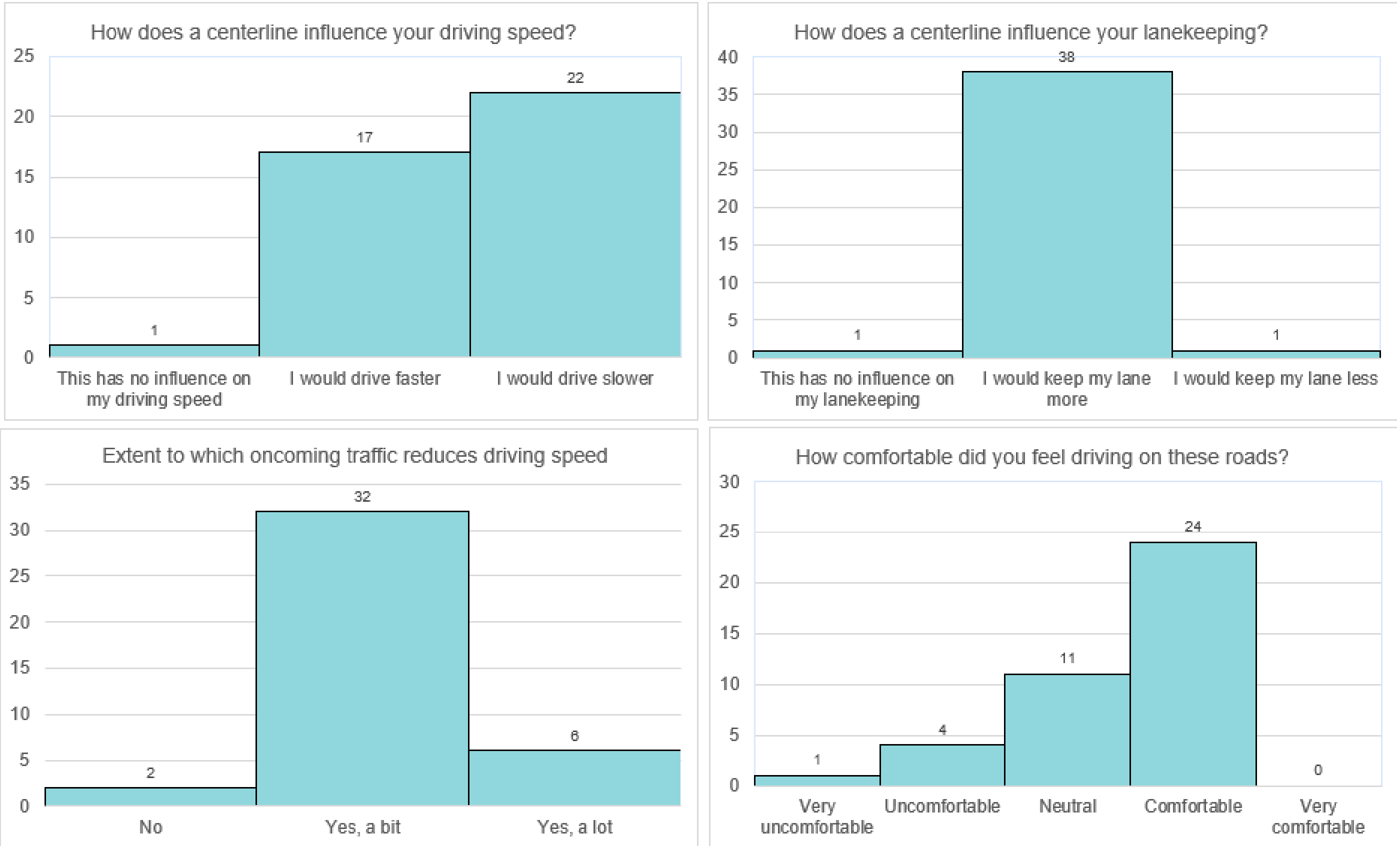

Figure 18: Perception of centreline and traffic (combined sample)

5 Discussion

In this chapter, the results of the study are discussed and interpreted in the context of existing research, highlighting both similarities and deviations. Then, limitations of the current study are considered that deal with the experimental design of this study, peripheral view and simulator fidelity. Finally, recommendations for future research are given.

5.1 Discussion of the results

In terms of sustainable measures, the data shows significant increases in driving speed under specific conditions. On wide roads devoid of greenery, the driving speed increases 2.3 km/h ($p < 0.001$ to 3.2 km/h ($p < 0.001$), depending on the analyzed sample. On narrow roads with Populus trees on both sides, driving speeds increase with 1.3 to 1.4km/h. Then, findings also indicate that low greenery (grass) and high and thick greenery on both sides of a road (thick Populus trees) influence driving speeds. However, these findings differ depending on the used sample for the analysis. In the combined sample which, includes participants from Witteveen + Bos and TU Delft, grass increases driving speeds with approximately 1.4 km/h ($p= 0.047$), but this effect is not significant in the sample that excludes participants from TU Delft. In the sample that excludes participants from the TU Delft driving simulator however, high and thick greenery placed on both sides in between cars decreases driving speeds with approximately 1.4km/h ($p = 0.028$).

Contrary to the initial expectations, significant decreases in speed were observed for interaction effects with road width and three measures: elevated parking, medium height greenery (marram grass) and high greenery (Populus trees) on both sides. Medium height greenery has the strongest speed reducing effect: around 4 to 5 km/h. Though, this finding should be interpreted with caution, since this was the first segment in the circuit that all participants drove through. Also, the second segment in the sample featured a wide road with Populus trees on both sides. This may indicate that despite initial training, participants might still have felt unsure in the first segments which could have influenced the results for these segments.

Then, the interaction effect of road width with elevated parking reduces driving speed with around 2.1 to 3.6km/h, with lower impacts for the dataset that only considers the Witteveen + Bos participants. To clearly understand driving behaviour, lateral position on the road should also be considered.

An intriguing aspect of the study is the impact of greenery on lateral positioning within the lane. If no cars are present on the right side of the road, high greenery leads drivers to position themselves further to the right of the lane, followed by medium-height and low greenery. Notably, high greenery on the right side shows the least significant change in driving speed relative to the baseline condition, with low and medium-height greenery having progressively larger impacts: medium-height greenery causes drivers to increase driving speed with 1.2 km/h compared to base, although this effect is marginally significant in the sample with only Witteveen + Bos participants.

In scenarios with elevated parking on narrow roads, drivers tend to steer closer to the elevated parking. This can be explained by the fact that elevated parking optically separates parked cars from the road. This corresponds to findings from the post-experiment questionnaire, where participants mentioned that elevated parking created a perceptual buffer from potential roadside obstacles, which increases driving speeds for the combined sample.

Conversely, on wide roads, drivers generally maintain a consistent lateral position due to the ample roadway width. While greenery and elevated obstacles can reduce driving speeds, their influence on lateral positioning is minor and not statistically significant on wider roads. The extra space allows for more consistent driving, regardless of roadside objects. Another factor could be that the greater variance in lateral positioning on wider roads complicates the estimation of significant effects in the linear mixed model.

Interestingly, the observed reduction in driving speed on wide roads with elevated parking is counterintuitive, given the increased space. This may be due to the presence of low-frequency oncoming traffic in the simulation, which heightens risk perception if drivers do not remain centered in their lane. Participants indicated that their sense of risk on GOW30 roads is influenced by the likelihood of a pedestrian emerging from behind roadside elements or potential collisions with other vehicles. Thus, driving behaviour can partly be attributed to risk avoidance. This aligns with the principles of the "woonerf" concept, where drivers reduce their speed in shared spaces with pedestrians and cyclists. Psychological insights into loss aversion reveal that individuals weigh potential losses more heavily than equivalent gains, influencing both risk perception and driving behavior (Raue & Schneider, 2019). This dynamic explains why drivers tend to respond more to perceived increases in risk than to safety improvements, which often leads to complex behavioral adjustments.

These findings underscore that proximity to obstacles typically correlates with a reduced tendency to increase driving speeds. Specifically, as drivers approach obstacles, they generally exhibit more conservative driving speeds and the presence of Populus trees positioned on the right side of the road appears to attract drivers more effectively. This phenomenon may be attributed to enhanced visual guidance provided by high objects, which could improve spatial awareness and navigation, thereby influencing driver behaviour. This is in correspondence with findings from Calvi (2015), who also found that obstacles along the road were used as visual guidance, but when these obstacles were placed closer led drivers to drive more cautiously.

To summarize, participants drove at an average lateral position of -0.6 meters and with a driving speed of approximately 33 km/h to 34 km/h in the baseline condition, which is a narrow road with parked cars on both sides and devoid of greenery. This indicates that, without a centerlines and low frequency of oncoming traffic, participants are positioned more to the center of the road rather than the center of their lane and exceed the 30km/h speed limit. Furthermore, the analysis demonstrates a significant correlation between age and driving speed: drivers older than 30 drove around 5 to 6 km/h slower than drivers in the age group 18-24. This observation corroborates findings from SWOV (2021), which also reported age-related variations in driving behaviour. Additionally, the study found that driving frequency, gender and educational degree did not reveal significant differences for driving speeds. In the following paragraphs, the limitations of this study are discussed.

5.2 Experimental design and learning effects

In this experiment, each participant drove through the same circuit, which introduces the potential for bias due to a learning effect, either from familiarization with the built environment or the handling of the driving simulator. It is assumed that any learning effect related to the simulator's handling was mitigated by the initial training session that familiarized participants before the experiment. Additionally, participants were instructed to drive as they normally would, both at the start of the experiment and again after the midway break, further reducing effects related to the duration of the experiment.

To account for unobserved variables, a random intercept was included in the linear mixed model, along with a random slope based on the sequence of segments. Regarding the built environment and the number of parked cars along the road, these variables were held constant across scenarios. However, since the focus of this research was on sustainable measures for GOW30 roads, the influence of the built environment and parked cars was excluded from the analysis. This limits the study's findings, as they may not be fully generalizable to suburban, rural, or other road environments.

Additionally, this study was conducted within the context of urban roads in the Netherlands, where local traffic laws and cultural driving habits may restrict the transferability of these findings to other regions. Therefore, caution is advised when applying these results to areas outside of dense urban environments or the Dutch road network. Further research across diverse settings is necessary to assess the broader applicability of these findings.

5.3 Peripheral vision in the experiment

Second, regarding the simulation setup, sideview mirrors on the vehicle were present, but did not provide view. There is a lack of literature specifically addressing the impact of side mirrors in driving simulator studies, although research on their impact in real driving conditions may exist. Despite this limitation, the absence of side mirrors in the simulation was consistent across all participants, allowing for direct comparisons. This uniformity may even enhance the consistency of results, as participants assess their lateral position based on a similar field of vision. For clarification: while some participants rely heavily on side mirrors, others rarely use them. A study on digital mirrors by Pampel et al. (2020) found that digital mirrors can increase driver view. However, this benefit is compromised when the mirrors fail. Research shows that failures such as degraded vision and mirror freezing increase cognitive workload, while a blank mirror has a less pronounced impact on workload. Additionally, variability in mirror usage is influenced by factors such as age and driving experience, with young and inexperienced drivers using mirrors less (Crundall & Underwood, 1998). Additionally, since this study does not involve lane-changing tasks, the side view is primarily relevant when approaching intersections. This data was not recorded, as the influence of driving behaviour near intersections with varying fields of view is beyond this study's scope.

5.4 Comparison of simulators and simulator fidelity

Third, when comparing metrics across the different simulators used in the study, differences can be seen in driving speeds and lateral positioning. The addition of data from the TU Delft simulator increases intercepts and generally leads to measures having a larger impacts. Given the fact that both simulators use different apparatus and provide a different field of view, the data was analysed in combination and separately, which illustrated minor differences in the results.

In general, participants' behaviour in a simulated environment may differ from real-life situations. Matviienko and Mühlhäuser (2023) found that individuals tend to be more confident and spend more time observing their surroundings after becoming acclimated to simulation conditions. Designing engaging scenarios is crucial to maintain participants' attention and ensuring task completion while simulating driving conditions, which is why pedestrians were placed at random locations throughout the experiment, as well as changing the colors of oncoming traffic. Evaluation by means of the Presence questionnaire by Witmer et al. (2005) allowed for insights to which extent the driving simulator experiment was similar to reality, with most participants answering a score of 3 on a scale from 1 (Totally not similar) to 5 (Totally similar). This underpins the need to interpret the results in the light of a driving simulator experiment, and not as if these were produced under real-life conditions. Although the nature of the experiment has its shortcomings, the results provide valuable insights into the relationship between driving speeds and lateral positioning on the road, specifically in the context of sustainable measures for GOW30 roads.

5.5 Future research recommendations

Given the limitations, future research could explore the long-term impact of sustainable road infrastructure on driving behaviour, considering variables like vegetation type, proximity to the road, and the presence of pedestrians and cyclists. Also, the diversity of the sample can be increased, since this sample only included higher educated people around the age of 30. When integrating sustainable measures into road infrastructure, various factors must be carefully evaluated. For instance, while adding trees can enhance the streetscape and provide environmental benefits, it also has potential drawbacks, such as increasing collision severity and water demand, potentially exacerbating water shortages (Stapel et al., 2021). When incorporating sustainable measures, these factors must be balanced against their potential benefits, such as reducing driving speed, influence on visibility on the road, improving air quality, and promoting public health through increased physical activity in green urban spaces. For this aim, an MCDA analysis can be performed for these variables, whilst also taking into account the extent to which various greenery types are speed reducing.

Furthermore, this research did not include road designs with cycling lanes. The interaction between greenery and cycling lanes is interesting to investigate since cycling lanes could be perceived as a buffer between driving cars and greenery placed along the road. Finally, since this research has a reduced validity compared to a real-life study, it is recommended that research is performed in real-life, under varying traffic and weather conditions. In this study, frequency of oncoming traffic was low in order to estimate driving behaviour of participants with minimal interference of other variables. Despite one participant not being able to finish the experiment, this participant did state that typically the absence of a centerlines reduces driving speed due to oncoming traffic, however in the experiment this participant found this effect negligible due to a low number of oncoming vehicles.

6 Conclusion

The objective of this study was to evaluate the effectiveness of sustainable infrastructural measures in enhancing driving behaviour compliance on GOW30 by means of a driving simulator experiment, guided by a series of research questions. In this conclusion, these research questions are answered consecutively.

First, the question needed to be answered on *which characteristics of sustainable measures were likely to influence driving behaviour*. These characteristics were identified through interviews with road designers, literature study and a survey involving 42 participants. Characteristics of interest were road width, parking height, greenery height and greenery width. Based on these insights, a driving simulator experiment was designed that tested multiple levels of these characteristics.

Road width was varied at two levels: narrow (6 meters) and wide (7 meters), with the expectation that wider roads would lead to higher driving speeds. Parking height was also manipulated at two levels: level and elevated, with both conditions tested on narrow and wide roads. Greenery was varied at three height levels: low, medium, and high placed on the right side of the road. Low greenery was represented by grass, medium-height greenery by marram grass, and high greenery by Populus trees, approximately 3.5 meters tall. Additionally, greenery density was considered an important variable; Populus trees placed between parked cars were varied in thickness. A thick Populus tree was defined as twice the thickness of a normal Populus tree, providing another layer of complexity in assessing the impact of greenery on driving behaviour. Similar to parking height, all greenery types were varied in combination with road width. In total, this led to a combination of 14 road segments.

To conduct the experiment, 4 participants were recruited on the Delft University of Technology, the Netherlands and 40 participants were recruited at Witteveen+Bos, an engineering consultancy company. All participants had a valid drivers' license and did not have a medical background that restricted them from participating in the experiment, such as epilepsy or being susceptible to migraines. Personal characteristics of these participants were collected. The characteristics of interest were age, gender, nationality and educational degree. Furthermore, driving frequency per week was also registered. The average age of the sample was 30.89 years, with a standard deviation of 8.57. The majority of the sample was male (30 participants) and the majority of participants had the Dutch nationality (42). Furthermore, all participants had an educational degree of BSc or higher and the majority drove a car less than 2 hours a week. After completion of the simulation experiment, simulation sickness and presence during the experiment were estimated by means of a survey. Then, preferences and opinions with regards to the road designs were asked and recorded anonymously.

With these findings, answers could be found with regards to *the impact of sustainable measures on driving speeds, lateral positioning and risk perception*. The results of this driving simulator experiment clearly demonstrate that wider roads lead to higher driving speeds, likely because drivers perceive these environments as safer or less restrictive, thereby reducing the credibility of the 30 km/h speed limit. This finding aligns with previous literature, which highlights road width as a critical factor influencing speed limit credibility and driving speeds. In the following sections, the impact of sustainable road design measures on driving speeds and lateral positioning is explored.

Similar to wide roads, narrow roads with low-height greenery also saw increased speeds, suggesting that certain types of greenery may not sufficiently reinforce speed limits for all drivers. Of the greenery types investigated, narrow roads with high and dense greenery between parked cars had the most significant speed-reducing effect, supporting the hypothesis that larger roadside objects increase perceived risk and encourage lower speeds or consistent driving behaviour.

An interesting observation is that on wide roads, roadside greenery does not have an influence on lateral positioning. Roadside objects do have an influence on lateral positioning for narrow roads however. Here, the suggest a pattern: when lateral positioning shifts toward the center of the road, driving speeds can decrease due to the perception of oncoming traffic. Lateral positioning shifts to the center of the road when parked cars are present. This suggests that drivers tend to veer away from roadside obstacles on the right, allowing them to maintain higher driving speeds again. The absence of a centerlines and low traffic volumes facilitate this behaviour, with almost all participants stating they would drive more in their lane if a centerlines were present.

To answer the research question on *which sustainable measures can enhance driving behaviour compliance on GOW30 and improve risk perception*, results demonstrate that sustainable infrastructural measures—particularly road width and the strategic placement of greenery can significantly influence driving behaviour on GOW30 roads. While wider roads tend to increase driving speeds, the presence of dense or high greenery has the potential to reduce speeds and promote safer lateral positioning due to the provided visual guidance. Incorporating low greenery, such as grass or marram grass may create a perceptual buffer for car drivers whilst providing more overview. This leads to increased comfort and potentially also to more (over-)confident driving behaviour.

Practical recommendations are to prioritize the incorporation of dense or high greenery to enhance speed limit credibility and to avoid low types of greenery that enhance sidewalk visibility, whilst keeping into account established guidelines for adequate visibility in traffic. These high types of greenery namely also have the potential to improve lateral positioning, which is important for GOW30 without centerlines since optical guidance on these roads is reduced.

It is important to note that these findings are derived from a driving simulation experiment, and as such, the results may not fully reflect real-world behaviour. The lack of perceived risk and the absence of physical forces, such as acceleration and lateral forces during turns, reduce the experiment's validity. To improve the accuracy of these findings, future research should include real-world studies or analyses of driving behaviour on GOW30 roads with different traffic and weather conditions.

Future research should also investigate additional factors, such as traffic density and the presence of cycling lanes, to deepen the understanding of driving behaviour in the built environment. Expanding the range of road segment types and including a more diverse sample of drivers could further refine insights into how sustainable infrastructure influences driving behaviour, potentially uncovering effects that were not significant in this study.

Appendix A: Scientific paper

The scientific paper starts at the next page.

Evaluating the effectiveness of sustainable measures in achieving driving behaviour compliance on GOW30 roads

A driving simulator experiment based on the Zaagmolenstraat in Rotterdam, the Netherlands

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Abstract

In order to increase traffic safety in the Netherlands, the government implemented the GOW30-policy. However, evaluation of this policy shows that drivers do not comply with this newly imposed speed limit sufficiently. For this reason, roads need to be designed in such a way that speed limits are perceived as credible. At the same time, the need for sustainable road designs arises, due to factors as increased urban heat stress and population growth. Thus, road designers need to make trade-offs between spatial quality and mobility. Incorporating greenery is a promising way to reduce urban heat stress, but the presence of greenery, particularly thick trees, can also increase the severity of traffic accidents. This study evaluated the impact of roadside greenery on driving behaviour, utilising a driving simulator experiment complemented by a post-experiment survey. Linear Mixed Model analyses (LLM's) together with survey insights revealed that perceived driving comfort leads to increased driving speeds. Comfort increases on wider roads and on roads with more overview. For this reason, it is not recommended to incorporate low greenery on GOW30 roads. Moreover, high and dense greenery is shown to reduce driving speeds while promoting better positioning on the road. It is furthermore recommended that research is performed in real-life, whilst evaluating roadside greenery in combination with cycling lanes under varying traffic and weather conditions.

Key words: driver behaviour, driving simulation, GOW30 policy, grey roads, sustainability, traffic safety, self-explaining roads, urban mobility, urban road design.

I. INTRODUCTION

In recent years, policies in the Netherlands with regards to road design in the built-up area have been focused on increasing traffic safety and sustainability. A policy that aims to improve traffic safety is the GOW30-policy, which targets *grey roads*. This term refers to roadways where intended function, design and actual use are not properly aligned. Think for example of a distributor road with a 50km/h speed limit, where cyclists do not have a separate lane. Reduced driving speeds on these roads are expected to lower the impact of collisions between cars and vulnerable road users. Rosén et al. (2021) found that fatality risk for pedestrians on roads with a 30km/h-speed limit is reduced by 10%, compared to roads with a 50km/h speed limit. Additionally, the Netherlands is seeing a rise in electric bicycle accidents among the elderly, which can be explained by factors such as increased cycling distances and age of the victims (Westerhuis et al., 2024). According to Davis (2001), the likelihood of a fatal accident in vehicle-pedestrian crashes at 50 km/h for pedestrians aged 60 and above is estimated at 65%, whereas at 30 km/h, this likelihood drops significantly to

4%. Thus, the GOW30-policy is a currently relevant policy that needs to be evaluated.

The policy is in line with the Dutch Sustainable Safety framework (SWOV, 2019), which is framed around three design principles and two organizational principles:

1. Functionality. This principle ensures that road segments and intersections are designed to fulfil a singular traffic function, either facilitating movement (flow) or enabling interaction (exchange) across all modes of transportation.

2. Biomechanics. This principle focuses on minimizing differences in speed, mass, direction, and size among road users to prevent severe accidents. It involves designing road environments and vehicles that are compatible with each other, providing necessary protections based on the characteristics of different road users.

3. Road designs should be intuitive, aligning with the expectations and competencies of road users, particularly older individuals. This principle emphasizes the importance of making road layouts and traffic signals self-explanatory and easily understandable, thereby encouraging predictable and safe behaviour.

4. Responsibility. All parties involved in road design and maintenance should have clearly defined tasks, so that accountability and safety considerations are well-maintained at every stage of road design.

5. Learning and innovation. Traffic incidents should regularly be assessed to identify areas for improvement.

In practice, urban designers make trade-offs between liveability, practicality and land use when roads need to be designed. For many years, scholars have mentioned that streets should serve the community and be walkable and liveable (Appleyard, 1981; Whyte, 1980). A principle that relates to this is shared space. This principle involves eliminating traffic control elements such as markings, encouraging road users to navigate and interact with each other more intuitively and cautiously (Moody & Melia, 2011). Ben-Joseph, E. (1995) found that shared paved space by multiple road users reduces traffic speed, which enhances predictability and improves safety. Additionally, pedestrian crossing rates increase due to the greater number of crossing points available compared to conventional roads (Tzouras et al., 2023).

An extension of the shared space principle is the woonerf concept. According to Kraay (1986), woonerfs are residential areas which must only carry vehicular traffic with an origin or destination within that particular woonerf. Also, there should be no continuous difference in cross sectional elements along the road, enough parking space accompanied with adequate lighting and vertical elements such as plant tubs and shrubs must not restrict visibility. Because drivers recognize the probability of sudden conflicts, driving speeds are lowered and attention is heightened. This is contradicting the principle of Sustainable Safety, which emphasizes clearly defined road layouts. The question therefore remains on how to seek a balance between road safety, mobility and sustainable road designs.

More specifically, this research aims to answer the main research question, which is formulated as follows: *Which sustainable measures are effective in improving driving behaviour compliance and risk perception of car drivers for GOW30?* This is done by providing answers to the following sub questions:

1. What are the most promising characteristics of sustainable measures that influence speed limit credibility?

2. What is the impact of these sustainable measures on driving speeds of car drivers on GOW30 roads?

3. What is the impact of these sustainable measures on the lateral position of car drivers on GOW30 roads, without the presence of a centerlines?

4. In what way do sustainable measures influence the risk perception of car drivers?

It is generally anticipated that vision-enhancing greenery and wide roads contribute to increased driving speeds. Conversely, larger greenery is expected to have a greater influence on lateral positioning, as it may be perceived as a more significant obstacle, heightening the driver's sense of risk and encouraging them to maintain a safer distance.

The basis of these research questions lies in findings by various scholars, illustrated in the conceptual model in figure 1. The conceptual model illustrates factors influencing driving behaviour, defined as the longitudinal and lateral movements of a driver, without estimating the relationship between driver capability and task demands. According to Fuller (2000), driving behaviour is constrained by human factor variables like fatigue, stress, and emotional state, which directly affect decisions and responses. Davidse et al. (2010) emphasize the importance of including physiological states, impacted by intoxication and tiredness, in understanding driving behaviour. Individual driving style preferences, including tendencies toward risky behaviour, are also vital. Additionally, other road users significantly influence driving behaviour; vehicles in proximity can affect each other's speed and positioning, creating a feedback loop between driving behaviour, road users, and driver decision and response. The model further builds on the premise that road design influences drivers' expectations, as discussed by Aarts & van Schagen et al. (2006). These expectations, shaped by experience, training and age, highlight that younger drivers are more prone to risky behaviour (SWOV, 2021; Abdel-Aty et al., 1998). Wickens et al. (2013) explain that human information processing relies on expectations formed from past experiences, which can lead to non-credible speed limits when road environments are changed, such as transitioning from GOW50 to GOW30. Theeuwes & Godthelp's (1995) concept of self-explaining roads supports this, suggesting that roads aligned with driver expectations promote safer, more predictable driving behaviour. Thus, the model posits that aligning road environments with user expectations is essential for speed compliance and overall safety.

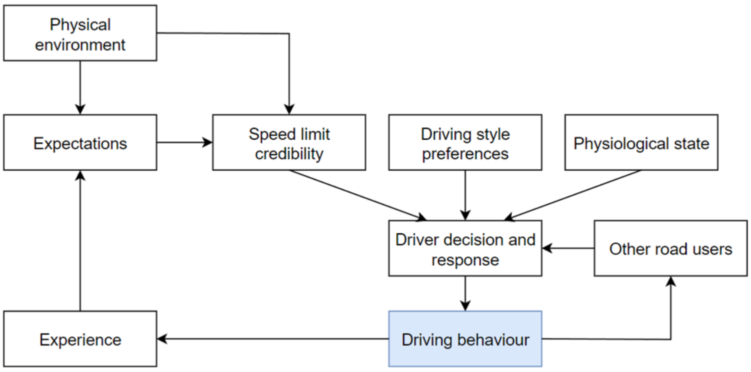

Figure 1: Conceptual model based on Davidse et al. (2010), Fuller (2000) & Wickens et al. (2013).

The remainder of this paper is structured as follows. Section 2 reviews the state-of-the-art in sustainable road design and its effects on driving behaviour, identifying key knowledge gaps. Section 3 outlines the methodology used to address these gaps, which is a driving simulator study. Section 4 presents the results from the simulation study. These are discussed and concluded in section 5.

II. LITERATURE REVIEW

The relationship between road design, roadside environment, and user compliance with speed limits is well-documented in literature. Yao et al. (2020) conducted a driving simulator study to examine how road layout and roadside environments impact driving speeds. Their research incorporated eight different scenarios with variations in road alignments (straight or curved), the presence of cycling lanes, and emergency lanes for rural highways. While this study yielded valuable insights, it leaves room for further investigation, particularly in urban settings where road complexity, congestion, and pedestrian activity are more prevalent. The research by Yao et al. (2020) is reinforced by the findings of Aarts & van Schagen (2006). Their study revealed that drivers tend to select higher speeds on wider roads with emergency lanes, fewer curves, smooth surfaces, and clear road markings. These factors, coupled with fewer surrounding buildings and less greenery, encourage drivers to maintain higher speeds. Additionally, personal attributes such as driver personality, vehicle characteristics, driving task complexity, and even trip purpose significantly influence driving behaviour. For instance, male drivers are more likely to drive faster than females, while older drivers and women tend to comply more closely with speed limits (Aarts & van Schagen, 2006).

Then, Silvano and Bang (2016) found that reducing the posted speed limit with varying road characteristics, such as carriageway width, the presence of on-street parking and sidewalks, influence free flow speeds. It was found that if posted speed limits are reduced from 50 km/h to 40 km/h, free-flow speed reduces 1.6 km/h. Increasing the posted speed limit from 50km/h to 60km/h led to an increase of 2.6km/h. So, drivers are generally more sensitive to an increase in posted speed limit than they are to a decrease. Goralzik and Vollrath (2017) further investigated speed compliance under varying traffic interventions. Their study on simulated German urban roads found that drivers responded differently to road narrowing and curves depending on the speed limit. On roads with a 50 km/h limit, drivers reduced speed in response to narrowing or curvature, but on 30 km/h roads, these road features did not trigger the same behavioural changes. This suggests that lower speed limits may create a behavioural "floor" that limits driver response to road geometry changes, emphasising the need for additional measures—such as enforcement or road redesigns—to influence speed on 30 km/h roads.

Either way, speeding behaviour on roads with a 30km/h speed limit is still common. In the Netherlands, between 55% and 60% of vehicles exceed the speed limit on roads with limits of 50, 60, and 70 km/h (SWOV, 2021). On 30 km/h roads, these numbers are even higher, ranging from 62% to 90% across Europe. One can easily assume that if roads are converged to a GOW30, without changing the road design and environment, speeding behaviour is encouraged. This is supported by Distefano and Leonardi (2019), who also point out that simply reducing speed limits from 50 km/h to 30 km/h may not achieve the desired effects without accompanying measures like information campaigns or police enforcement. Thus, a multi-faceted approach is necessary to enhance speed limit credibility and to promote safe driving behaviour. To assess whether speed limits are credible, the Dutch methodology "Veilige Snelheden, Geloofwaardige Snelheidslimieten" (VSGS) is used. Kint et al. (2022) tested the validity of this model and found that only road width and straight alignment consistently explain free-flow traffic speeds. Other factors in the model, such as surrounding road features, tend to correlate with one another, making it difficult to isolate their individual effects on free-flow speeds. Additionally, changing road width and curves are expensive and not very sustainable. How can sustainable measures, such as greenery, play a role in promoting safe driving behaviour?

To examine the relationship between sustainability measures and road safety, it's important to first clarify the concept of sustainability. As defined by the United Nations (1987), sustainability refers to *meeting the needs of the present without compromising the ability of future generations to meet theirs*. In urban environments, this often involves initiatives to reduce pollution and mitigate heat stress, promoting healthier living conditions. However, implementing sustainability measures does not always align with road safety objectives. For example, tree placement standards along roads are critical, as improper spacing can obstruct visibility and increase the likelihood of collisions. Cheng et al. (2020) found that wider spacing and smaller tree diameters significantly reduce injury risk in accidents for car drivers, emphasising the importance of such standards.

Research also highlights the influence of trees on driver perception and behaviour. Naderi et al. (2006) conducted a driving simulation involving urban and suburban settings with and without trees, finding that suburban streets with trees were perceived as safer, while urban streets without trees were seen as least safe. Additionally, the presence of curb side trees in suburban areas improved drivers' sense of spatial edge and reduced speeds by an average of 4.87 km/h. However, the sample size was small, and speed differences for other scenarios were not statistically significant.

Further studies by Fitzpatrick et al. (2014) demonstrated that dense vegetation and utility poles along highways reduced driving speeds by an average of 2 mph. In a follow-up simulation (Fitzpatrick et al., 2016), the width of the clear zone was found to influence driving behaviour, with narrower clear zones prompting drivers to position themselves closer to the center of the road. However, vegetation density did not significantly affect speed, but it did influence lateral positioning, especially on left curves.

Calvi (2015) extended these findings to two-lane rural roads, showing that the proximity of trees to the road significantly affects driving speeds. When trees were positioned at a 4-metre offset, drivers increased speed, using the trees as visual cues for direction. Conversely, when trees were placed closer (1.5-meter offset), drivers perceived them as hazards, leading to reduced speeds and more cautious driving. This phenomenon was linked to the concept of optical flow, where the speed of perceived visual patterns influences driving speed.

Recent research by Wu et al. (2023) supports these insights, showing that roadside vegetation and narrower lane widths are effective in reducing speeds during transitions from rural to small-town roads. Variations in tree height and spacing also contributed to speed reduction in these transition zones. Despite these findings, the effects of roadside greenery on driving behaviour in urban settings remain underexplored, indicating a gap in current research on how sustainable urban design can integrate road safety considerations.

In conclusion, while roadside greenery can enhance sustainability and improve road safety in specific contexts, such as rural and suburban environments, there is still much to learn about its effects in urban areas. For this reason, a driving simulator experiment will be conducted to investigate the effects of roadside greenery in an urban context. This way, the effect of sustainable measures can be tested in a controlled environment.

III. METHOD

A. Participants

A total of 40 participants were recruited through advertisements at the Rotterdam office of Witteveen + Bos, an engineering consultancy company located in the Netherlands. All participants were required to hold a valid driver’s licence and be free of any medical conditions that could pose a risk during the simulation experiment, such as epilepsy and susceptibility to migraines or motion sickness (Anses, 2021). These considerations were communicated to potential participants, before signing an informed consent form. This form, which received approval from the TU Delft Human Research Ethics Committee, made clear that participants agreed to participate in the study whilst taking into account the potential risks, as well as registration of age, gender, driving frequency per week and level of educational degree. The majority of participants fell in the age group of 25-29 years old. Also, the majority of participants drove a car less than 2 hours and were primarily male. More than 75% had a MSc-degree, the remainder a BSc-degree.

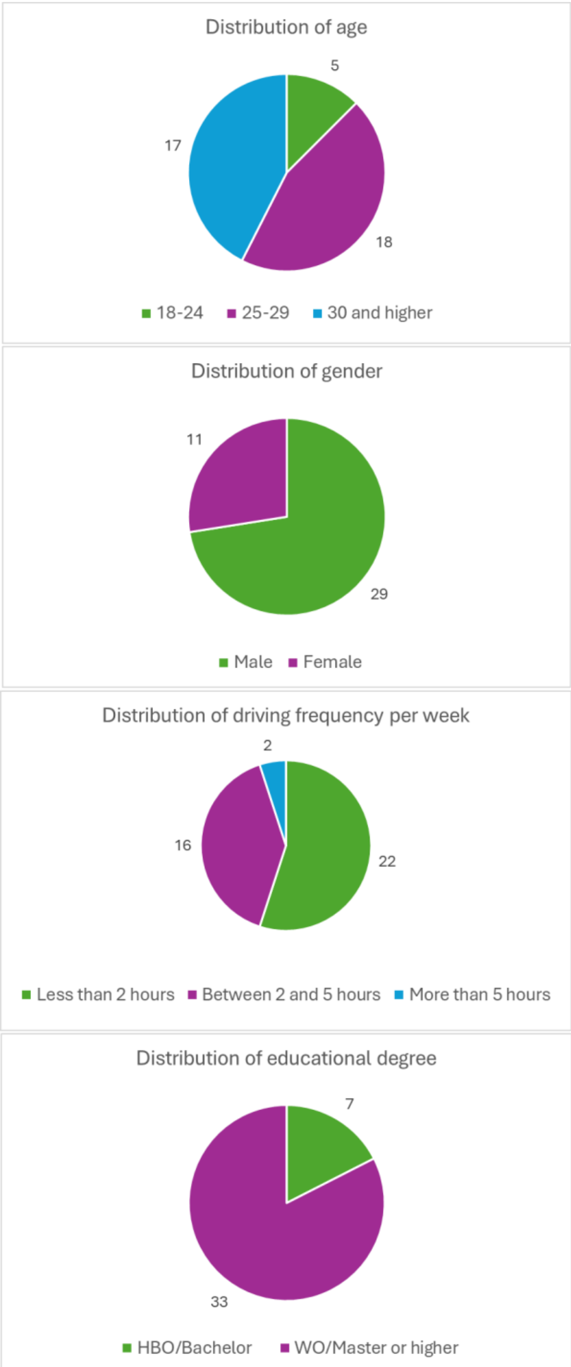

Figure 1: Distribution of personal characteristics

B. *Apparatus*

The apparatus used for this experiment was the CTOUCH Riva 4K 65” touchscreen, along with the fixed-based Playseat Evolution ActiFit and Logitech G920 Driving Force controllers. The screen provided approximately 120 degrees of view.

C. *Procedure*

Participants began the experiment by adjusting their seating position in the driving simulator and receiving instructions on how to operate the vehicle (accelerating, braking, steering, reversing and using indicator lights). They then completed a 5-minute training session to familiarise themselves with the controls, including tasks such as turning, parking, performing a 360-degree turn and driving at a steady speed. Oncoming traffic appeared after two minutes, which had a frequency of 1 car per minute. Upon completion of the training, participants took a 2-minute break.

After the break, they drove a standardised circuit consisting of 14 segments modelled after the Zaagmolenstraat in Rotterdam, a narrow two-lane road in a dense urban area shared by multiple modes of traffic, as seen in figure 2. This road was chosen since it will be converged to GOW30 in 2025 (Gemeente Rotterdam, 2024).

Figure 2: Zaagmolenstraat in Rotterdam, the Netherlands.

Each 500-metre segment varied in road width, parking setups, and greenery placement, as shown in Table 2: Experimental design. For each segment, images are included in Appendix A: Road segments.

Table 2: Experimental design

Road width	Parking	Greenery placement	Greenery type	Segment	Order
Narrow (6m)	Elevated (+ 15cm)	None	None	NE	6
	Level	None	None	NL (Base)	5
		Right side of the road	Grass strips	NLRL	3
			Marram grass strips	NLRM	8
			Populus tree strips	NLRH	7
		Both sides of the road	Populus trees	NLBH	9
			Populus trees (twice as thick)	NLBH+	4
Wide (7m)	Elevated (+15cm)	None	None	WE	11
	Level	None	None	WL	13
		Right side of the road	Grass strips	WLRL	14
			Marram grass strips	WLRM	1
			Populus tree strips	WLRH	12
		Both sides of the road	Populus trees	WLBH	2
			Populus trees (twice as thick)	WLBH+	10

To simulate real-life conditions, participants encountered a 30 km/h speed limit sign at the start of each segment, which complies to guidelines for road design in the Netherlands (CROW, 2023). They also encountered zebra crossing approximately midway the road segment and a stop sign at the end. This forced participants to come to a full stop, before entering a new segment. Oncoming traffic appeared at a frequency of 2 cars per minute, with pedestrians along the sidewalks. A 5-minute break was given midway to prevent fatigue before participants resumed driving. After this break, they were instructed to drive as they would normally. Finally, the participants filled in a survey on their experience.

D. Data collection

During the experiment, the driving simulator recorded driving trajectories at a frequency of 1 Hz. The following variables were collected: driving speed (m/s), acceleration (m/s²), and vehicle position along the x, y, and z axes. To account for potential data distortion caused by collisions, collision times were also recorded. Since participants made four right turns during the experiment and encountered zebra crossings, these events influenced their driving behaviour. As a result, initial driving trajectories following right turns were excluded from the analysis until the vehicle's movement had stabilised. Similarly, braking patterns prior to zebra crossings were omitted from the dataset to ensure a more accurate representation of typical driving behaviour.

E. Post-experiment survey

After the completion of the simulation experiment, participants filled in a survey which consisted of four parts. The first part obtained information on their demographics and driving experience. The target variables of this part were age, gender, nationality, education level and their driving frequency per week. All data was made anonymous, in correspondence to guidelines of the Human Research Ethics Committee from TU Delft. The second part of the questionnaire was aimed at the experience with the driving simulation, such as the extent to which participants experienced discomfort such as eye strain, disorientation and nausea on a 4-point scale ("not" to "severe") based on the Simulation Sickness Questionnaire (Kennedy et al., 1993). The third part of the questionnaire was aimed at estimating participants' presence during the drive. For this aim, items from the Presence Questionnaire by Witmer et al. (2005) were used that measured fidelity of the simulator, immersion in the experiment and the extent to which the experience felt similar to reality. This is critical to do, since driving simulator studies have a reduced validity due to the absence of real-life risk and different field of view (De Winter et al., 2012; Wynne et al., 2019).
Then, the last part of the questionnaire examined respondents' relation to the sustainable measures with a mix of scaled, multiple choice and open questions. For example, to which extent drivers find greenery comfortable, which road designs have their preferences and the influence of greenery on their sense of safety. Furthermore, questions were asked on other variables such as the presence of cars along roads and how participants expect a centerlines to have an influence on their driving behaviour. Finally, respondents were given the opportunity to make

final remarks and explain why certain road types were preferred.

IV. RESULTS

This section presents the results of the driving simulator experiment, together with the post-experiment survey. In the next subsection, the descriptive statistics of driving speed and lateral positioning are presented. These are followed in by the results of the Linear Mixed effects Models for driving speed in subsection B and lateral positioning in subsection C.

A. Descriptive statistics of driving behaviour

In below boxplots for driving speeds per segment, mean driving speeds are close to 30km/h. The lowest mean driving speed can be seen in scenario NLBH+, which is a narrow road with medium height greenery. The lowest average driving speed still occurs in segment NBLH+, suggesting that wide populus trees placed in between cars have a speed reducing effect. The second lowest driving speeds can be seen in scenario WLRM, which features a wide road flanked by medium-height greenery. Then, a smaller bandwidth can be seen in scenarios NLBH and WE, which suggests more homogeneous driving speeds in these scenarios. But also, wide road segments, starting with 'W' generally have more outliers. To test whether these observations for driving speeds are significant, a linear mixed model is estimated, which can be found in the next chapter. When looking at boxplots for lateral positioning, participants were mostly driving on the left side of the lane on road segments (negative estimate) with parked cars on both sides: NL, NE & WL. The same can be seen in scenarios with parked cars and trees placed in between cars: NLBH, NLBH+, WLBH and WLBH+. The most right-oriented driving behaviour can be seen in segment WLRH, which is a wide road with level parking and high greenery on the right side. Drivers tend to position themselves further to the right in their lane when there are no parked cars, especially if the greenery strips feature taller vegetation.

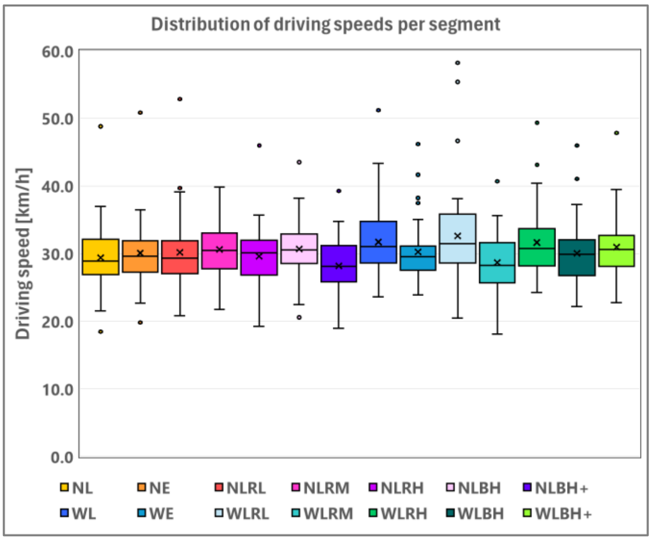

Figure 3: Distribution of driving speeds per segment

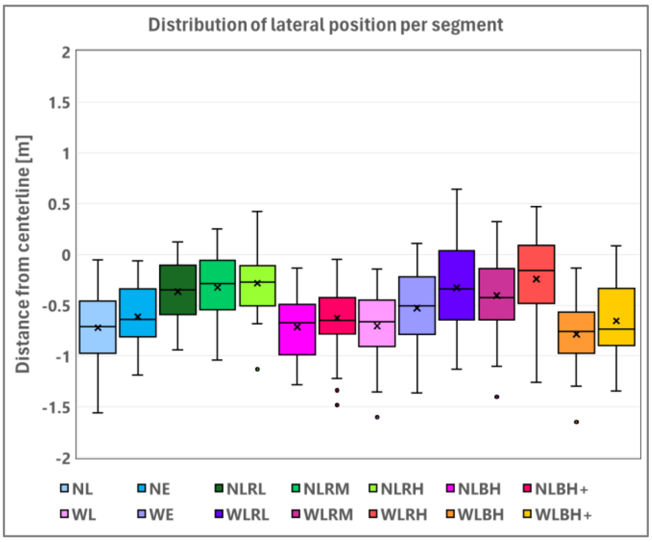

Figure 4: Distribution of lateral position per segment

B. Linear Mixed Effect Model for driving speed

To estimate whether the differences observed in the boxplots are statistically significant, Linear Mixed Effects Models (LMM) were conducted, accounting for participant characteristics. LLM is a robust analytical approach, especially suited for analysing unbalanced longitudinal data where the same individuals are measured at varying time points. Importantly, LLM's allow inclusion of random effects that cannot be controlled for in the experiment.

In the model analysing driving speed, two random effects were incorporated for each participant. First, a random intercept captures individual baseline driving speeds and the inherent correlation between multiple measurements from the same participant.

Table 3: Linear Mixed Model for driving speed [km/h]

Dependent variable		Model Estimate	p-value	t-value
Intercept		32.946	<0.001	17.319
Measure	Wide road (7 meters wide)	2.321	<0.001	3.449
	Elevated parking	0.670	0.286	1.067
	Grass strips	0.775	0.219	1.230
	Marram grass strips	1.211	0.056	1.912
	Populus tree strips	0.215	0.733	0.342
	Populus trees on both sides	1.295	0.043	2.027
	Populus trees on both sides (twice as thick)	-1.381	0.028	-2.200
	Wide road * elevated parking	-2.129	0.017	-2.388
	Wide road * grass	0.125	0.889	0.140
	Wide road * marram grass	-4.241	<0.001	-4.249
	Wide road * Populus trees	-0.283	0.751	-0.318
	Wide road * Populus trees on both sides	-2.958	0.003	-2.963
	Wide road * Populus trees on both sides (twice as thick)	0.634	0.476	0.714
Age (Reference group: 18 to 24)	25 to 29	-5.975	0.016	-2.532
	30 and higher	-4.975	0.047	-2.063
Gender (Reference group: Male)	Female	-1.853	0.191	-1.336
Education (Reference group: BSc)	WO/MSc or higher	0.809	0.692	0.399
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	2.194	0.095	1.720
	More than 5 hours	4.412	0.136	1.530
Statistics				
Number of observations	560			
Number of groups	40			
REML criterion at convergence	2854.900			
Log-likelihood	-1427.441 (df=24)			
AIC	2902.881			
BIC	3006.752			

Second, a random slope for each road segment was added, allowing the effects of the independent variables to vary for each participant based on the segment sequence. This is a critical adjustment given that all participants drove through the same circuit, and it accounts for potential within-subject variability across different road conditions

The model was estimated in R using the following formula: ***DrivingSpeed ~ RoadWidth + ParkingHeight + GreeneryType + Age + Gender + Education + DrivingFrequency + RoadWidth*GreeneryType + RoadWidth*ParkingHeight + (1+ Segment | Participant)***.

This formulation demonstrates that personal characteristics, such as age, gender, education level and driving frequency, were controlled for in the model. Moreover, interaction effects are included for road width with elevated parking and greenery type, capturing complex relationships between these variables and driving behaviour. This comprehensive model structure ensures a nuanced understanding of the factors influencing driving speeds, accounting for both fixed and random effects.

From the results in table 3, a significant intercept of 32.946 km/h ($p<0.001$) can be seen. This intercept represents the base driving speed on a narrow road with no greenery, for a male driver aged 18-24 with a BSc education and less than 2 hours of weekly driving.

Significant effects include Populus trees on both sides and Populus trees on both sides, which were made twice as thick. Populus trees on both sides between cars increase driving speed with approximately 1.3km/h (p-value = 0.043), whereas the same tree increased twice in width reduces driving speeds with approximately 1.4km/h (p-value = 0.028). If road width is increased, this leads to higher driving speeds of 2.321 km/h (p-value <0.001).

A contradicting finding is that wide roads interacted with elevated parking, medium height greenery and Populus trees on both sides of the road have a speed reducing effect that ranges from approximately 2.1km/h on wide roads interacted with elevated parking to 4.2km/h on wide roads interacted with Marram grass strips.

Finally, the model also reveals that participants aged 25 and higher drive faster than drivers aged 18 to 24. Gender, education and driving frequency do not reveal significant effects, but do indicate that females tend to drive slower, and participants who drive more than 5 hours per week tend to drive faster.

In conclusion, wide roads significantly increase driving speed, as well as high greenery on both sides on a narrow road. High and thick greenery decreases driving speeds. When analysing interaction effects with wide roads, elevated parking, marram grass and Populus trees on both sides have a speed reducing effect. To fully understand driving behaviour, lateral positioning also needs to be reviewed.

C. Linear Mixed Model for lateral position

Similar to the estimations for driving speed, a model was estimated that took into account all demographic variables with the following formula: ***PositionNormalized ~ RoadWidth + ParkingHeight + GreeneryType + Age + Gender + Education + DrivingFrequency + RoadWidth*GreeneryType + RoadWidth*ParkingHeight + (1+ Segment | Participant).*** A random intercept was included in this model to account for correlations between observations for each participant, which can vary by individual. This is a logical approach, given that each driver may have a different baseline lateral position on the road. The baseline condition is defined as a narrow road devoid of greenery. All reference categories for personal characteristics can be seen in table 4.

In this table, the intercept estimate of -0.612 (p<0.001) suggests that the baseline lateral position is significantly different from zero. Several factors show significant effects on lateral position. Elevated parking increases lateral position by 0.107m (p = 0.031), and grass also shows a significant increase of 0.355 m (p <0.001). High greenery (Populus trees) also increases lateral positioning by 0.438 m (p <0.001), indicating that drivers position themselves closer to the road edge when high greenery is present. Also, high and thick greenery on both sides shows a marginally significant positive impact on lateral position. Finally, combinations of wide roads and various measures, as well as the personal characteristics, have non-significant effects.

Table 4: Linear Mixed Effects Model for lateral position [m]

Dependent variable		**Model**		
		Estimate	**p-value**	**t-value**
Intercept		-0.612	<0.001	-4.112
Measure	Wide road (7 meters wide)	0.017	0.754	0.313
	Elevated parking	0.107	0.031	2.159
	Grass strips	0.355	<0.001	7.139
	Marram grass strips	0.394	<0.001	7.867
	Populus tree strips	0.438	<0.001	8.793
	Populus trees on both sides	0.007	0.891	0.137
	Populus trees on both sides (twice as thick)	0.095	0.055	1.926
	Wide road * elevated parking	0.068	0.335	0.966
	Wide road * grass strips	0.021	0.763	0.301
	Wide road * marram grass strips	-0.096	0.232	-1.198
	Wide road * Populus tree strips	0.024	0.727	0.350
	Wide road * Populus trees on both sides	-0.088	0.269	-1.107
	Wide road * Populus trees on both sides (twice as thick)	-0.047	0.502	-0.672
Age (Reference group: 18 to 24)	25 to 29	0.027	0.883	0.148
	30 and higher	-0.031	0.870	-0.165
Gender (Reference group: Male)	Female	-0.166	0.136	-1.530
Education (Reference group: BSc)	WO/MSc or higher	-0.009	0.956	-0.056
Driving frequency per week (Reference group: Less than 2 hours)	Between 2 and 5 hours	-0.107	0.292	-1.071
	More than 5 hours	-0.233	0.309	-1.034
Statistics				
Number of observations	560			
Number of groups	40			
REML criterion at convergence	115			
Log-likelihood	-57.505 (df=24)			
AIC	163.011			
BIC	266.881			

D. Questionnaire results

In this subsection, the findings from the post-experiment survey are presented which will aid in interpreting the results from the Linear Mixed Model analyses. Also, immersion in the experiment will be discussed, which is of importance to reflect on the validity of the experiment. All figures regarding these findings are presented in Appendix C: Questionnaire results.

Using items from the *Simulator Sickness Questionnaire* by (Kennedy et al., 1993), participants were asked questions to assess the extent of nausea, disorientation (such as dizziness or motion sickness), and oculomotor discomfort (including eye strain and headaches) they experienced. They rated their symptoms on a 4-point Likert scale, ranging from 1 (no) to 4 (yes, severe). The majority of participants did not report experiencing any of these symptoms, which is a reassuring outcome. Out of 40 participants, only 4 reported mild nausea. Regarding disorientation, 7 participants experienced it mildly, while the remaining 33 did not experience any disorientation at all. As for oculomotor discomfort, 32 participants did not report any symptoms, 7 experienced mild discomfort, and 1 participant noted noticeable discomfort.

Regarding items from the *Presence Questionnaire* by Witmer et al. (2005), results were more heterogeneous. The participant feedback provides a generally positive outlook on the simulation experience. The participant feedback reveals generally positive experiences across several areas of the simulation. For visual immersion, on a scale from 1 (not immersed) to 7 (extremely immersed), most participants rated their experience highly, with 17 giving it a 6. Similarly, auditory immersion, rated on the same 1-7 scale, showed moderate to high engagement, with 11 participants rating it a 5.

In terms of delay experience, where 1 means "not delayed at all" and 7 indicates "extremely delayed," participants showed moderate concern, with 15 rating it a 6. Despite this, satisfaction remained high. Contentment with the simulation was measured on a 1 (not content) to 5 (very content) scale, and 23 participants rated it a 5, indicating a largely positive reception.

Perceived realism of driving speed was assessed on a scale from 1 (not similar) to 5 (totally similar), with 13 participants scoring it a 4, indicating fairly realistic perception of driving speeds. Display interference was rated on a scale from 1 (not at all) to 5 (very much), with 18 participants giving it a 2, showing minimal interference. However, handling the accelerator pedal posed some difficulty for participants. On a scale from 1 (very easy) to 5 (very difficult), 11 participants rated it as "very difficult," while 18 found it "neutral," highlighting an area that could benefit from improvements.

In terms of perceptions regarding greenery, a notable 26 out of 40 participants indicated that the presence of grass lanes positively influences their sense of safety, resulting in increased driving speeds. Additionally, 23 participants recognized grass lanes as a significant visual barrier separating them from the sidewalk. Overall, 10 participants reported a moderate influence of greenery on their driving behaviour, while 17 participants acknowledged a substantial impact. Furthermore, 32 participants indicated that the presence of oncoming traffic tends to slightly reduce their driving speeds.

Regarding the presence of centerlines, 38 participants expressed that they would maintain their lane more effectively when a centerlines is present. Interestingly, nearly half of the participants (17) reported that they would drive faster due to the presence of a centerlines. In contrast, 22 participants indicated that they would drive more slowly with a centerlines, and only one participant claimed that it would have no effect on their driving behaviour.

V. DISCUSSION AND CONCLUSION

This study evaluated the effectiveness of sustainable measures in enhancing driving behaviour compliance within the GOW30 framework, utilising a driving simulator experiment. The findings indicate that specific characteristics of road design, particularly the presence of greenery and the use of centerlines, significantly influence driving speeds and perceptions of safety.

Baseline driving speeds observed on narrow roads devoid of greenery averaged between approximately 33km/h, exceeding the posted speed limit of 30 km/h. Age emerged as a significant factor, with drivers over 25 years of age exhibiting speeds that were 5 to 6 km/h lower than those of younger drivers, corroborating existing literature that identifies age-related variations in driving behaviour. The analysis demonstrated that increasing road width (7 metres) was associated with an increase in driving speeds of approximately 2.3km/h ($p < 0.001$). Then, the most promising characteristics of greenery were height and density: low greenery (grass), medium height greenery (marram grass), high greenery (Populus trees) and high and thick greenery (thick Populus trees) were varied and tested in the experiment. Regarding the impact of these sustainable measures on driving speed, a few findings became clear. Notably, narrow roads featuring high and dense greenery positioned between parked cars exhibited a marked speed-reducing effect of 1.4km/h ($p = 0.028$), supporting the hypothesis that larger roadside objects enhance perceived risk, thereby encouraging more cautious driving behaviours. Interestingly, while wide roads generally promote higher speeds, the presence of marram grass, elevated parking and trees significantly mitigated this effect. It should be noted that in the experiment, participants drove through a fixed circuit that was the same for each participant. In this circuit, a scenario with marram grass was the first scenario and one with trees on both sides the second scenario. For this reason, the validity of these findings are questionable. Another explanation for observed speed reductions on wide roads is the fact that lateral positioning compared to base was not changed. Thus, drivers drove more to center of the road, rather than centrally in their lane. Road positioning is associated with risk perception of car drivers. Here, the influence of centerlines was complex; although a majority of participants indicated that centerlines assisted in maintaining their lane, nearly half reported that they would drive faster when a centerlines was present. This finding suggests that the psychological effects of road design can yield unexpected outcomes, impacting driver behaviour in nuanced ways.

Overall, the study underscores that sustainable measures, such as the incorporation of greenery, significantly shape driving behaviour on GOW30 roads. While wider roads tend to encourage increased speeds, the integration of dense or high greenery has the potential to counteract this trend and promote safer driving practices. While this speed reducing effect was significant, the impact is relatively minor. It is important to acknowledge that these conclusions are derived from a driving simulation, which may not fully replicate real-world driving conditions. In this study, most participants experienced driving speeds as similar to reality and were generally content with the quality of the experiment. However, handling speed in the simulator was perceived as difficult. This was mitigated by a training that aimed to improve handling of the simulator. Because of this reduced validity, future research should extend to real-world studies and consider additional variables such as traffic density and the presence of cycling lanes, to deepen the understanding of how sustainable infrastructure impacts driving behaviour.

In conclusion, this study underscores the vital importance of intentional road design in urban planning, recommending the integration of greenery and other sustainable elements to create safer driving environments. The answer to the main research question, which aims to review *which sustainable measures are effective in improving driving behaviour compliance and risk perception of car drivers for GOW30*, is as follows: Roads with greenery, such as grass or trees, are generally associated with higher driving speeds and greater comfort, while roads lined with parked cars tend to restrict speed and are perceived as the least comfortable. Enhanced visibility and reduced obstructions on greener roads contribute to a more confident driving experience, allowing drivers to maintain speeds above posted limits. Practically this could mean that incorporating low greenery for GOW30 should be avoided to enhance speed limit credibility. Also, the absence of centerlines allows drivers to veer away from object and drive centrally on the road, which allows them to drive faster again. It is expected that on GOW30 with high traffic volume, this effect is reduced. However, future research should investigate the effects of different traffic volumes, with or without centerlines and interactions with cycling lanes. This preferably should be done in real-life conditions, which can vary by weather. This way, understanding of driving behaviour on GOW30 is heightened while addressing the limitations of this study.

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APPENDIX A: ROAD SEGMENTS

In the below table, images are included that present the 14 tested road segments. In the left column, all narrow segments can be seen. The wide road segments are presented in the right column, starting with "W".

Table 5: Road segments in the experiment

NL	**WL**
	
NE	**WE**
	
NLRL	**WLRL**
	

NLRM 	**WLRM** 
NLRH 	**WLRH** 
NLBH 	**WLBH** 
NLBH+ 	**WLBH+** 

APPENDIX B: POST-EXPERIMENT SURVEY

After the completion of the driving simulation experiment, participants were administered the below questionnaire to retrieve information on their demographics and the extent to which their wellbeing was influenced by the simulation setup. Furthermore, subjective information was gathered with regards to the presented road designs in relation to driving behaviour and safety perceptions. The results of this survey are presented in Appendix C: QUESTIONNAIRE RESULTS

Driving simulator experiment

Dear respondent,

Thank you for participating in the simulator experiment! Now a few questions regarding this simulation will follow. This will not take more than 5 minutes. Good luck!

Sign in to Google to save your progress. Learn more

* Required question

Please fill in your participant number *

Your answer

What is your nationality? *

Your answer

What is your age? *

Your answer

What is your gender? *

- Female
- Male
- Prefer not to say

What is your level of education? *

- ◯ VMBO
- ◯ HAVO/VWO
- ◯ MBO/Vocational education
- ◯ HBO/Bachelor
- ◯ WO/Master or PhD

Do you have a drivers' license? *

- ◯ Yes
- ◯ No

How many hours a week do you drive a car? *

- ◯ Less than 2 hours
- ◯ Between 2 and 5 hours
- ◯ More than 5 hours

Now, a few questions on your experience will follow

Did you experience any nausea, fatigue or sweating? *

- ◯ No
- ◯ Yes, mildly
- ◯ Yes, noticeable
- ◯ Yes, severe

Did you experience any oculomotor discomfort (e.g. headache, blurred vision or eye strain)? *

- ◯ Yes, severe
- ◯ Yes, noticeable
- ◯ Yes, mildly
- ◯ No

Did you experience any disorientation during the experiment (e.g. dizziness or motion sickness)? *

- ◯ No
- ◯ Yes, mild
- ◯ Yes, present
- ◯ Yes, severe

To what extent were you immersed in the simulation visually? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely immersed

To what extent were you immersed in the simulation auditorily? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely immersed

To what extent did you experience a delay in your actions versus the outcome? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely delayed

How content are you with the visual quality of the simulation?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very content

How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

To what extent did your driving speed feel similar to driving speeds in reality? *

	1	2	3	4	5	
Totally not similar	◯	◯	◯	◯	◯	Totally similar

How did you experience maintaining your driving speed in the simulation? *

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very difficult

Please elaborate *

Your answer

Now, a few questions on your perception will follow

To what extent does a grass lane serve as a separation between you and pedestrians? *

- ◯ It is a very strong seperation between me and other road users
- ◯ It is a strong seperation between me and other road users
- ◯ It is a moderate seperation between me and other road users
- ◯ It is a mild seperation between me and other road users
- ◯ It is not at all a seperation between me and other road users

Does a grass lane seperation influence your sense of safety, making you drive faster (compared to a situation with parked cars)? *

- ◯ Yes, it does influence my sense of safety and I drive faster
- ◯ Yes, it does influence my sense of safety and I do not drive faster
- ◯ No, it does not influence my sense of safety and I drive faster
- ◯ No, it does not influence my sense of safety and I do not drive faster

Did the oncoming traffic in the simulation make you driver slower?

- ◯ Yes, a lot (> 5km/h)
- ◯ Yes, a bit (<5km/h)
- ◯ I don't know
- ◯ No

In this experiment, did you observe that trees were varied in thickness? *

- ◯ Yes
- ◯ I am not sure
- ◯ No

Did you find that the thickness of greenery influenced your visibility? *

- ◯ Extremely
- ◯ Significantly
- ◯ Moderately
- ◯ Slightly
- ◯ Not at all

Suppose you were a pedestrian, do you see a tree as a protective barrier? And what if you are a car driver? *

Jouw antwoord

Do you think parked cars along a road make you drive slower? Please elaborate why (not)? *

Jouw antwoord

In what way would your driving style change if a centerline was added to the roads? Please check the boxes that apply. *

- [ ] I would drive faster
- [ ] I would drive slower
- [ ] This has no influence on my driving speed
- [ ] I would keep my lane more
- [ ] I would keep my lane less
- [ ] This has no influence on my lanekeeping

To what extent do you think that greenery in general influences your driving behavior? Think of your speed, steering movements and acceleration. *

○ Not

○ Little to not

○ Neutral

○ Much

○ Very much

Please explain briefly

Your answer

Now, the final 2 questions on your comfort!

Generally speaking, how comfortable did you feel driving on these roads? *

- ◯ Very comfortable
- ◯ Comfortable
- ◯ Neutral
- ◯ Uncomfortable
- ◯ Very uncomfortable

Generally speaking, which road(s) did you experience as the most comfortable and which one(s) the least? *

Your answer

APPENDIX C: QUESTIONNAIRE RESULTS

After the experiment, participants were asked to fill in a survey with regards to their experience. This survey asked personal characteristics of these participants, followed by questions on which extent they experienced simulation sickness, based on items from the Simulation Sickness questionnaire by Kennedy et al. (1995). Also, their presence during the experiment was evaluated based on items by the Presence Questionnaire from Witmer et al. (2005). Finally, preferences with regards to road design were evaluated.

As can be seen in the below figures, the majority of participants did not experience nausea, disorientation or oculomotor discomfort. Only one participant found their experienced oculomotor discomfort noticeable.

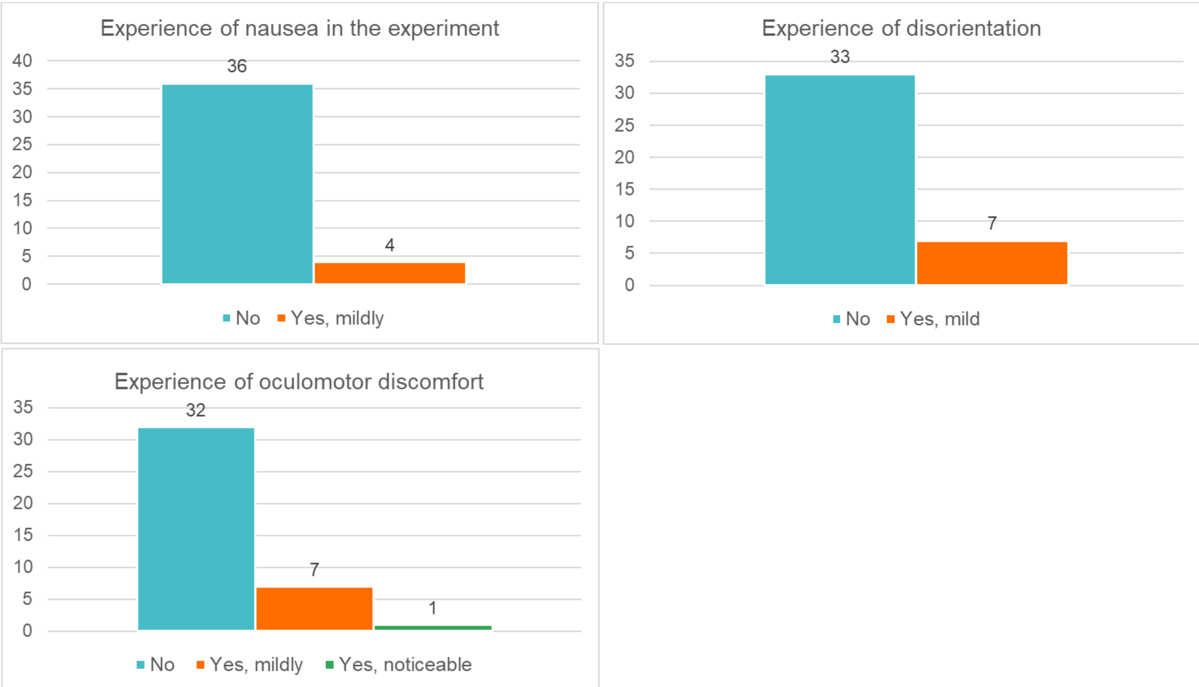

Figure 5: Simulation Sickness Questionnaire items results

Then, visual immersion scored primarily positively, with the most participants scoring a 5 on a scale from 1 (Not at all) to 7 (Extremely immersed). Auditory immersion was generally less, with most participants scoring a 4 on a scale from (Not at all) to 7 (Extremely immersed). Also, participants did experience a delay in the experiment, which can be explained by the fact that most participants found handling the accelerator pedal difficult. This was mitigated before the experiment, by increasing sensitivity. However, if sensitivity was too high, the simulator became too responsive and maintaining driving speeds constant was difficult. The participants primarily experienced driving speeds neutral, which is a limitation of a fixed-base driving simulator. Despite these findings, almost all participants were (very) content with the simulation and display quality did not interfere with the driving task.

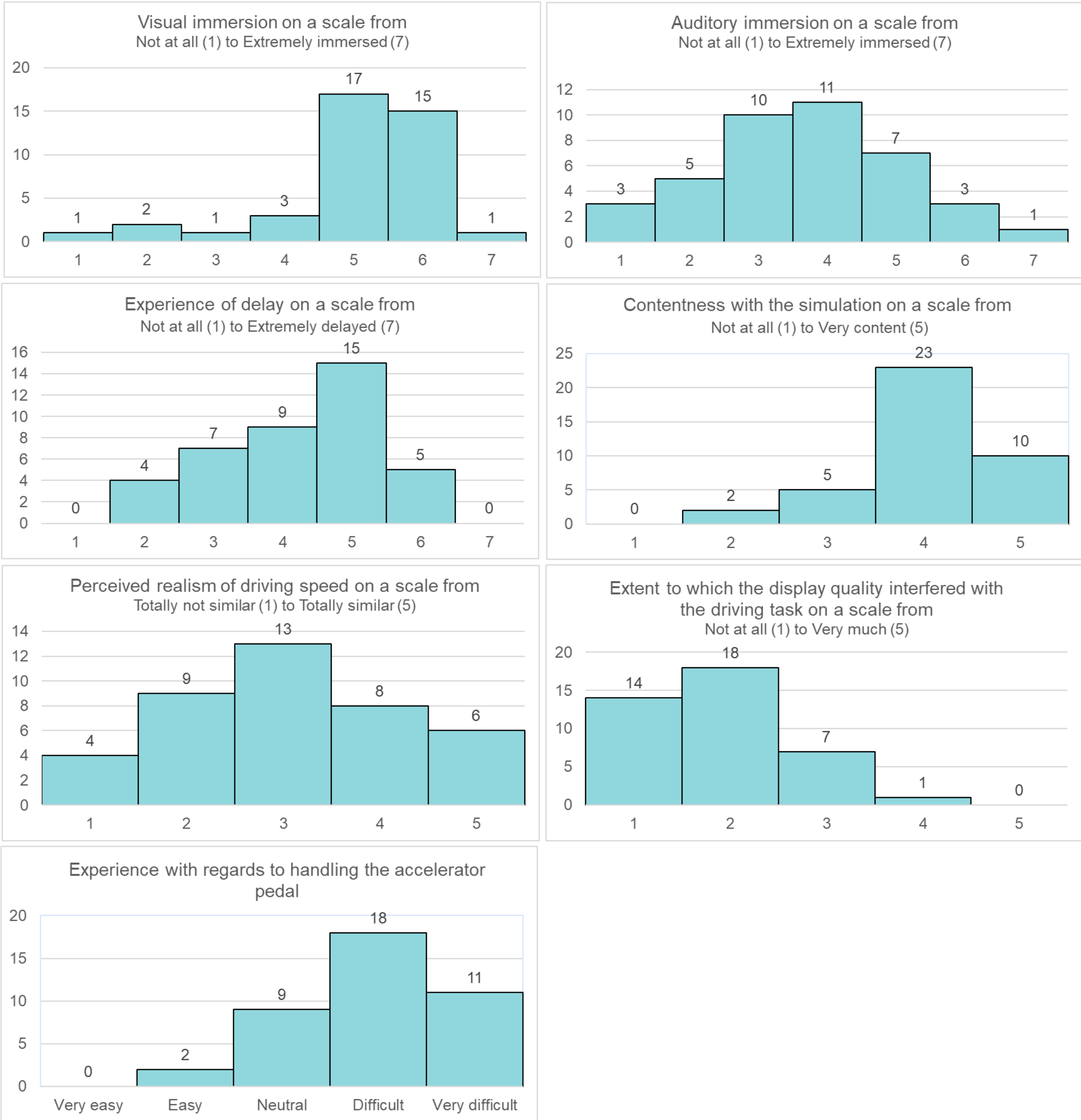

Figure 6: Presence Questionnaire items results

In addition to the previous findings, grass lanes were stated by the majority of participants to have an influence on their sense of safety in such a way that they drive faster. This can be explained by the fact that grass lanes are perceived as strong separations between the driver and the sidewalk. The majority of participants did not notice that trees were varied in thickness, however the Linear Mixed Model analysis for driving speed did indicate a speed reducing effect of high and thick greenery. Generally, greenery influences driving behaviour much and thickness of greenery does influence visibility for 37 out of 40 participants.

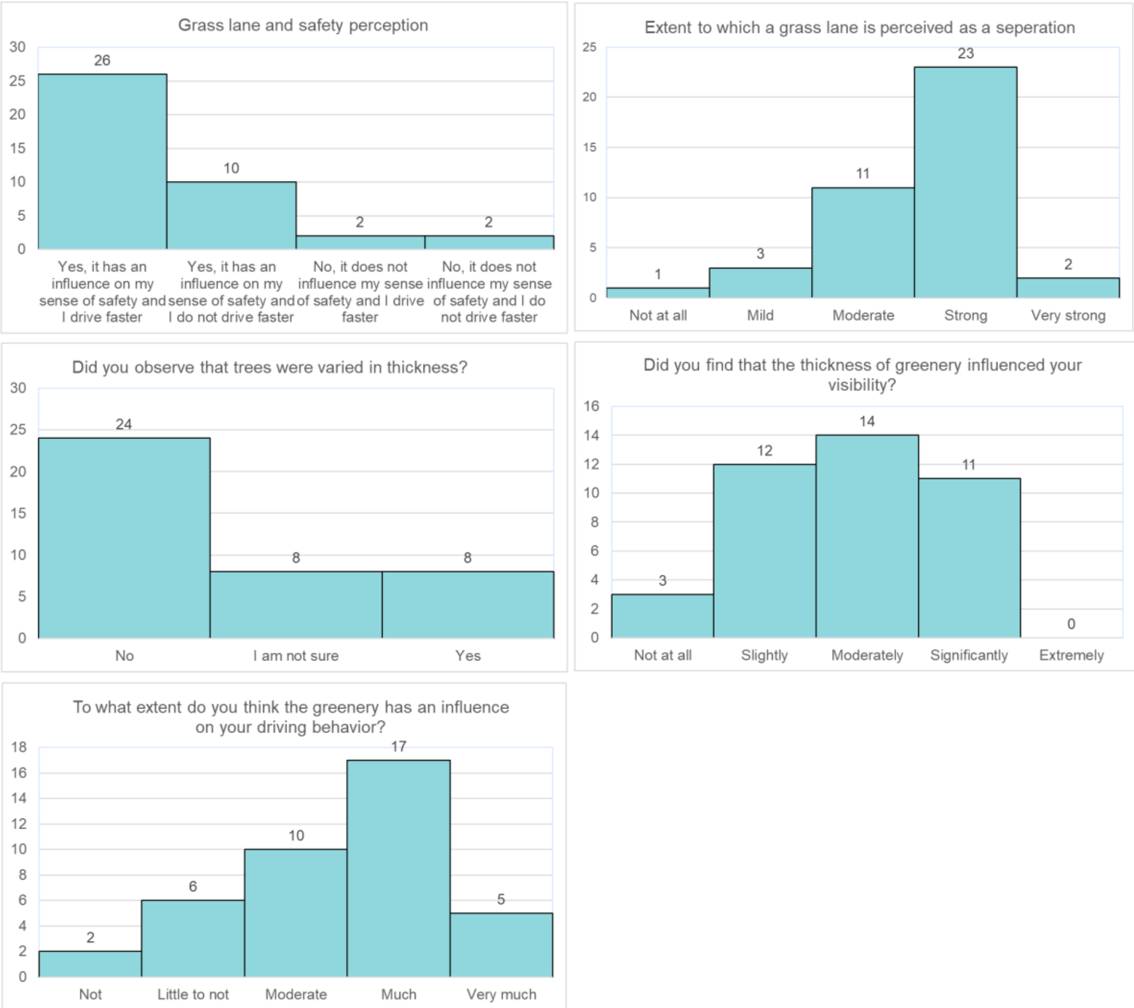

Figure 7: Perception of greenery results

Then, the effects of centerlines, oncoming traffic and perceived comfort are presented below.

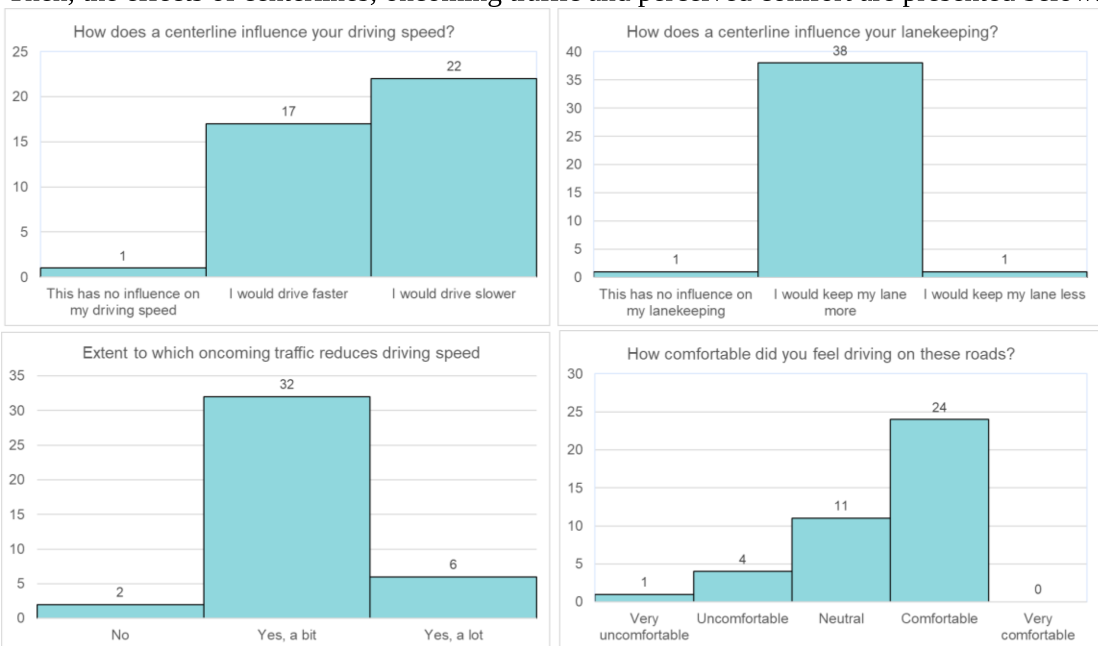

Figure 8: Perception of other traffic and centerlines

Finally, all participants provided insights with regards to their preferences for road design. These statements found that the driving experience is significantly influenced by road design, particularly through the presence of greenery and parked cars. Participants reported that roads with grass strips or low greenery on one side are the most comfortable, providing enhanced visibility and a sense of spaciousness. As one respondent noted, “The most comfortable setup is having grass on the right side, while the least comfortable is having cars and thick trees in between.” In contrast, roads with high and dense trees, especially when combined with parked cars, create discomfort by limiting visibility. One participant remarked, “The least comfortable situation was having cars parked on both sides,” emphasizing the restrictive feeling that such setups can provoke.

Visibility plays a crucial role in determining comfort levels, with many respondents indicating that increased visibility allows for faster driving while maintaining a sense of safety. As another participant stated, “The most comfortable setup is having grass or shrubs on the right side. The least comfortable is having cars parked on a level surface. A sloped curb adds some comfort. Thin trees are more pleasant than thick trees, but thick trees are still more comfortable than having cars parked on both sides.” These findings highlight the importance of thoughtful road design, which combines greenery with minimal obstructions to enhance both safety and driving enjoyment.

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Appendix C: Survey on road designs

With insights from literature and practice, a full factorial design was developed that varied road width in 2 levels (narrow and wide), placement of greenery in 2 levels (planters in between cars and on the right side of the road) and greenery in 3 levels (low, medium and high greenery). Furthermore, if parking was present on the road, this parking was varied in 2-levels (level and elevated) as well. This combination led to a full-factorial design of 32 road segments.

However, doubts were existing regarding the visibility of low and medium greenery if placed in between vehicles, as well as the difference between elevated parking and level parking. In order to reduce the number of scenarios of the full factorial design, a survey was conducted to estimate preferences or indifferences amongst car drivers.
This survey was first aimed at estimating driving speed regardless of a speed limit. This was done based on images from the Walenburgerweg and the Zaagmolenstraat (Google, 2024). The former has been transformed to a GOW30 road, and the Zaagmolenstraat is to be transformed to a GOW30 road in 2025 (Rotterdam, 2024). This furthermore ensured that respondents could relate the developed road designs to real-life cases. Then, questions were asked with regards to driving behaviour without a centerlines on the 2-lane bidirectional road and the visibility and effect that elevated parking had on driving behaviour, which were followed by questions that aimed at estimating preferences and the visibility of greenery.

Respondents were found via social media and sent to a team of mobility experts to ensure a variety of the sample. The majority of this sample did not take part in the driving simulation experiment. The software used for this survey is QualtricsXM and the survey was conducted in Dutch and English for the duration of 4 consecutive days, in which 32 respondents were found. In order to increase the number of respondents, the survey was set out for 7 consecutive days again which increases the number of respondents up to 52 respondents. However, 10 respondents who only engaged in three questions were filtered from the answers. The presented questions are presented on the following pages. The results together with the selected designs are presented in Appendix C: Selected road designs

Dear respondent,

For this short survey, I am interested in the preferences of car drivers for certain types of roads. To investigate these preferences, you will be shown images of roads that differ from each other.

Completing this survey takes approximately 7 minutes. Your participation in this survey is voluntary. You have the right to withdraw at any time. For this survey, your age and driving experience as a car driver will be recorded. Do not provide any other personal information, as this ensures anonymity.

Thank you for participating in this questionnaire and good luck!

- I have read the above text and give permission for the recording of my preferences
- ○ I have read the above text and do not give permission, I am now terminating the survey

Q1: What is your age?

Q2: How often a week do you drive a car?

- ○ Not
- ○ Less than 2 hours a week
- ○ 2 to 5 hours a week
- ○ More than 5 hours a week

Q3: The Walenburgerweg in Rotterdam was transformed to a road with a 30km/h (approximately 20 mph) speed limit. What would be your driving speed on this road as a car driver?

Q4: The Zaagmolenstraat is a through road within the built-up area of Rotterdam that is perceived as unpleasant. What driving speed would you maintain as a car driver on this road?

Q5: Suppose the centerlines is removed from this street. How would this affect your driving speed?

- This has no influence on my driving speed
- I now drive slower compared to a road with a center line
- I now drive faster compared to a road with a center line

Q6: Do you see a difference between these roads? Does this affect your driving speed and position on the road?

- I do not see a difference and do not drive differently
- I do see a difference and do not drive differently
- I do see a difference and drive slower in the upper image
- I do see a difference and drive faster in the upper image

Q7: Suppose trees are added to the Zaagmolenstraat, do you drive slower because of this?

- Yes
- Likely
- Unsure
- Unlikely
- No

Q8: Judge your speed difference between these two road segments

- No difference
- A small difference
- A large difference

Q9: Do you drive differently due to the addition of a green strip?

- No
- Yes, but my speed difference is minimal
- Yes, I clearly drive slower due to the addition of greenery
- Yes, I clearly drive faster due to the addition of greenery

Q10: Mark the street you find most pleasant

○ 

○ 

○ 

Q11: Why do you experience the other options as less pleasant?

Q12: On which road do you drive the slowest?

Q13: On which road do you drive the fastest?

Q14: Is there a speed difference between these two road segments? If so, where do you drive faster?

- I drive faster in the upper image
- No difference
- I drive faster in the lower image

Q15: Evaluate the following statement:'My speed difference between these two road segments is negligible'

- Disagree
- Disagree a little
- No idea
- Agree a little
- Agree

Q16: Evaluate the statement:'I drive slower if my visibility is reduced.'

- Agree
- Agree a little
- Do not agree, do not disagree
- Disagree a little
- Disagree

Q17: Would you like to see more greenery in cities?

- No
- Indifferent
- Yes

Q18: Is there a difference in your driving speed between these two road segments? If yes, where do you drive slower?

- No
- Yes, I drive slower in the lower image
- Yes, I drive slower in the upper image

Q19: Does your driving speed differ between these two roads?

- Yes
- Likely
- I don’t know
- Likely not
- No

Q20: Mark the road segment on which you drive the slowest

○ 

○ 

○ My driving speed on both segments is equal

Q21: Mark the road segment on which you drive the slowest now

○ 

○ 

○ 

Q22: Do you drive faster if the width of a road is increased?

- Yes
- A little
- No difference
- No

Q23: Which option has your preference?

○ 

○ 

○ 

Q24: Why?

Q25: Thank you for participating! Do you have any remarks or specific preferences for road segments?

Appendix D: Survey results

D.1Respondent demographics and driving patterns

First, it is important to analyze the characteristics of the survey respondents. A total of 42 individuals participated in the survey, which was conducted over four consecutive days. The average age of the respondents was 33 years. Among them, 85.7% drive a car, with driving patterns varying among the participants. Of these drivers, 14.4% does not drive weekly, 40.5% drives less than 2 hours per week, 26.2% drive between 2 to 5 hours per week and 19% drives more than 5 hours a week.

When asked what driving speeds participants would drive on the Zaagnolenstraat and Walenburgerweg, respondents mention a higher driving speed on the Walenburgerweg. The average stated driving speed on the Walenburgerweg is 37.3 km/h, even while mentioning that this is a 30km/h road. On the Zaagmolenstraat the average stated driving speed is 34.5km/h. If a centerlines is removed from the Zaagmolenstraat, 31.7% indicates no effect on driving speed. Then, the majority of 53.7% reports driving slower due to the absence of a centerlines. The remaining 14.6% reports driving faster on these roads.

All respondents indicate that they drive slower if their vision on roads is reduced. 92.7% agreed that they drive slower if their view is lessened, and 7.3% agreed slightly with this statement. Additionally, 90.3% of respondents mentioned that a larger road width increases their driving speed. Only 3 participants state that their driving speed will not increase and 1 participant was unsure on this matter. Furthermore, 85.4% of respondents expressed a desire for more greenery in Dutch cities, while 14.6% were indifferent. None of the participants had a negative stance towards greenery. These results illustrate the need to research driving behaviour in the context of GOW30, since stated driving speeds are higher than 30km/h.

D.2 Elevated parking

Regarding elevated parking, respondents had mixed views. A total of 39% (16 respondents) did not see a difference in the road segments, while 24.4% (10 respondents) observed a difference but would not change their driving speed. Additionally, 14.6% (6 respondents) noticed a difference and state to drive faster, whereas 22% (9 respondents) noticed a difference and stated to drive slower.

Specifically, for elevated parking on the left side of the road, 57.5% reported no change in their driving behaviour, 35% noted a small difference, and only 7.5% (3 respondents) reported a drastic difference. These findings suggest that the visibility of elevated elevated parking in the simulation expreiment needs to be improved. Furthermore, respondents are primarily insensitive to elevated parking if this is on the leftside of the road, which eliminates the need to further research this variable in the driving simulation experiment. Since uncertainty exists with respect to the visbility in the driving simulation experiment, this elevated parking is only varied for the base scenario of narrow road width and wide road width.

D.3 Righthandside greenery

Regarding greenery on only the right side of the road, respondents prefer green strips that provide a sense of calm and reduce pedestrian interaction. Short green strips are perceived as hectic, especially when driving fast, as these short planters quickly follow eachother up.

Of the green strip configurations, a continuous green strip was preferred by 53.7% (22 respondents), a long green strip by 39% (16 respondents) and a high-frequency green strip only by 7.3% (3 respondents). It was also found that respondents drive faster if low greenery is added to the environment, as it offers better visibility and forms a barrier between the pavement and the road, lowering the perception of risk. When comparing low greenery to no greenery, low greenery has a similar effect to an empty parking spot. This is stated to provide a sense of safety due to the absence of a potential obstacle. Longer green strips make drivers feel safer, thus increasing driving speed because there is no parked car to potentially crash into.

For righthandside greenery, the perception becomes more complex. When comparing low height greenery to medium height greenery, medium height greenery offers less view on the roadside, which makes drivers unsure. However, medium height greenery is a larger optical barrier between the sidewalk and the road. For this comparison, 61% (25 respondents) disagreed with the statement that their speed difference between low and medium height greenery on the right side of the road is negigible. 34.1% (14 respondents) agreed that their speed difference is negligible and 4.9% (2 respondents) were unsure. In the final part of the survey, some participants mentioned that low greenery offers the possibility to anticipate earlier on a pedestrian behind the greenery, which makes them feel more secure.

For scenarios with planted trees alongside the right side of the road, respondents mention that having a continuous row of trees drastically reduces view on the pavement. Furthermore, car drivers want more greenery, however in such a way that this does not increase optical flow too much and still providing a clear view of the pavement. The option with long planters and three trees is preferred by 66.7% (26) of respondents. 30.8% (12) preferred low frequency trees alongside the road and only 2.5% (1 respondent) preferred high frequency trees.

Figure 19:Populus tree at the Jonker Fransstraat in Rotterdam

Figure 20: Three trees in planter at the Van Waerschutstraat in Rotterdam

D.4 Bi-lateral greenery

For bi-lateral greenery, comparisons were made between no, low, medium and high greenery. When comparing where participants drive the slowest, the results varied. 21 respondents mentioned that they drive the slowest when they can see bushes between cars, while 10 respondents mentioned that they drive the slowest when there are trees along the road. 6 respondents reported driving the slowest in the normal situation and 2 respondents indicated they drive the slowest with grass between the cars.

When comparing greenery in combination with elevated parking on both sides, 22 respondents mentioned that they drive the fastest on roads with short green strips and 10 respondents indicated they drive the fastest under normal conditions without any added greenery. 5 mentioned driving the fastest with trees and 3 respondents reported driving the fastest when bushes are present.

When comparing medium height greenery versus low height greenery alternated between cars on both sides of the road, about 56.1% (23 respondents) mentioned that their driving speed is not different in the two scenarios. 31.7% (13 respondents) mentions driving slower with bushes in between cars and 12.2% of respondents (5 respondents) mentions driving slower with grass in between cars. However, the majority still does not state a difference.

Also, if grass strips in between cars are compared to a scenario with a lower number of parked cars, 51.2% of respondents mention that the addition of grass strips would not lead to a difference in driving speed. This means that a grass strip is similar in perception to an empty parking spot for the majority of the participants. The remaining 36.6% mentions driving faster if green strips are placed in between cars and the final 12.2% mentions going faster with lower number of parked cars. Thus, it is therefore clear that the addition of low level greenery has either has the same effect as medium level greenery or even has a speed increasing effect since low level greenery offers ectra overview and acts a barrier between obstacles parked alongside a road or pedestrians.

Finally, when comparing high greenery with medium height greenery, 45% (18 respondents) states that their driving speed is equal in both scenarios. 35% (14 respondents) mentions driving slower with bushes in between cars and 20% (8 respondents) mentions driving slower if trees are planted in between cars. However, this share changed when the width of the high greenery is increased further. As this width of high greenery doubled, 55% of particpants (22) stated that they drive slower in a scenario with a high greenery with double the thickness of the tree and only 22.5% (9) of the particpants stating that their driving speed is equal in all scenarios. Still, 20% mentions driving slower with bushes in between cars. This means that thickness is a relevant variable to vary, since if respondents compare a bush to a small tree, the bush is most speed reducing. When comparing the bush to a dense tree, the dense tree is more speed reducing.

In conclusion, low greenery is stated to have no effect or a speed increasing effect for most participants. Compared to low greenery, medium height greenery has either no speed reducing effect or a speed reducing effect since this offers less overview in between cars. The effect of medium height greenery is the strongest when a low number of cars is parked. The more the number of parked cars increases, the less strong the speed reducing effect of bushes, since cars block view on the sidewalk more and are an overpowering obstacle that drivers do not want to crash into. Finally, the speed reducing effect from bushes is in general stronger than a speed reducing effect from trees, unless the trees are doubled in thickness. For this reason, relevant variables to research are high greenery, combined with varying width of high greenery.

Appendix E: Road segments

Based on the survey results, the road segments chosen for simulation were selected to represent various roadway conditions. Elevated parking was specifically tested in scenarios with parking on both sides of the road, as it introduces an additional vertical element. Testing the combination of elevated parking with varying greenery heights was deemed unnecessary, given that both elements independently contribute vertical effects. Survey responses indicated that a large proportion of participants did not perceive any significant difference between elevated and level parking. However, for those who did notice a distinction, the impact on driving speed was inconsistent, with some reporting increased speeds and others reporting decreases. This variability is reflected in segments NL, WL, NE and WE, where segment NL represents the current conditions on Zaagmolenstraat, which serves as the baseline for further analysis.

Segments NLBH, NLBH+, WLBH and WLBH+ focus on the effects of greenery placed between parked cars, specifically examining variations in the density of tall greenery. Segments NLRL to WLRH explore the influence of low, medium, and high greenery situated in long planters on the right side of the road. To isolate the effect of greenery height on driving behaviour, the planter size was kept constant, ensuring that optical flow, as described by Niehorster (2021) and object distance are constant. Varying the greenery on the left side was expected to have a minimal effect, informed by participant feedback. These findings are consistent with Calvi (2015), who observed that participants in driving simulation experiments were more responsive to greenery positioned closer to the ego-vehicle.

To accurately simulate GOW30 road conditions, several factors need to be considered, including the length of the road section. The road must be sufficiently long to allow for representative measurements, while also preventing participant fatigue from skewing the results. Simulation sickness, which tends to increase with longer exposure, particularly after one hour (Kennedy et al., 2000), was also taken into account.

Consistency in driving behaviour during simulator experiments has been well-documented. Gemonet et al. (2021) noted that familiarization phases, lasting from two minutes to up to two days, are commonly used prior to simulation studies. They found that variability in driving speed, braking force, and engine revolutions per minute stabilized after six minutes, with no significant changes observed throughout a 40-minute experiment.

For this study, the length of Zaagmolenstraat, which extends 505 meters until a level crossing, serves as a useful reference. However, other roads in Rotterdam were also considered. In 2024, the municipality of Rotterdam published a list of 115 roads being reconfigured from 50 km/h to 30 km/h. Examples include Benthuizerstraat (315 meters), Eendrachtsweg (530 meters), Henegouwerlaan (380 meters), Gedempte Zalmhaven (290 meters), Glashaven (173 meters), Goudsesingel (670 meters), Witte de Withstraat (360 meters), and Zaagmolenstraat (816 meters), with an average road length of approximately 440 meters. For this simulation, road segments were set at 500 meters, comparable to the longer stretches of Zaagmolenstraat. At an expected driving speed of 30 km/h, this results in a driving duration of one minute per segment, excluding breaks, training, and special maneuvers such as turning. With 14 segments, the total effective driving time amounts to 14 minutes. Including a five-minute training phase, the entire experiment will last 20 minutes. This training phase will familiarize participants with vehicle handling and speed perception prior to the main driving experiment. A

Figure 21: NL (narrow road width and level parking)

Figure 22: WL (wide road width and level parking)

Figure 23: NE (narrow road width and elevated parking)

Figure 24: WE (wide road width and elevated parking)

Figure 25: NLBH (narrow road width and high greenery)

Figure 26: WLBH (wide road width and high greenery)

Figure 27: NLBH+ (narrow road width and high and thick greenery)

Figure 28: WLBH+ (wide road width and high and thick greenery)

Figure 29: NL (narrow road width and low height greenery)

Figure 30: WL (wide road width and low height greenery)

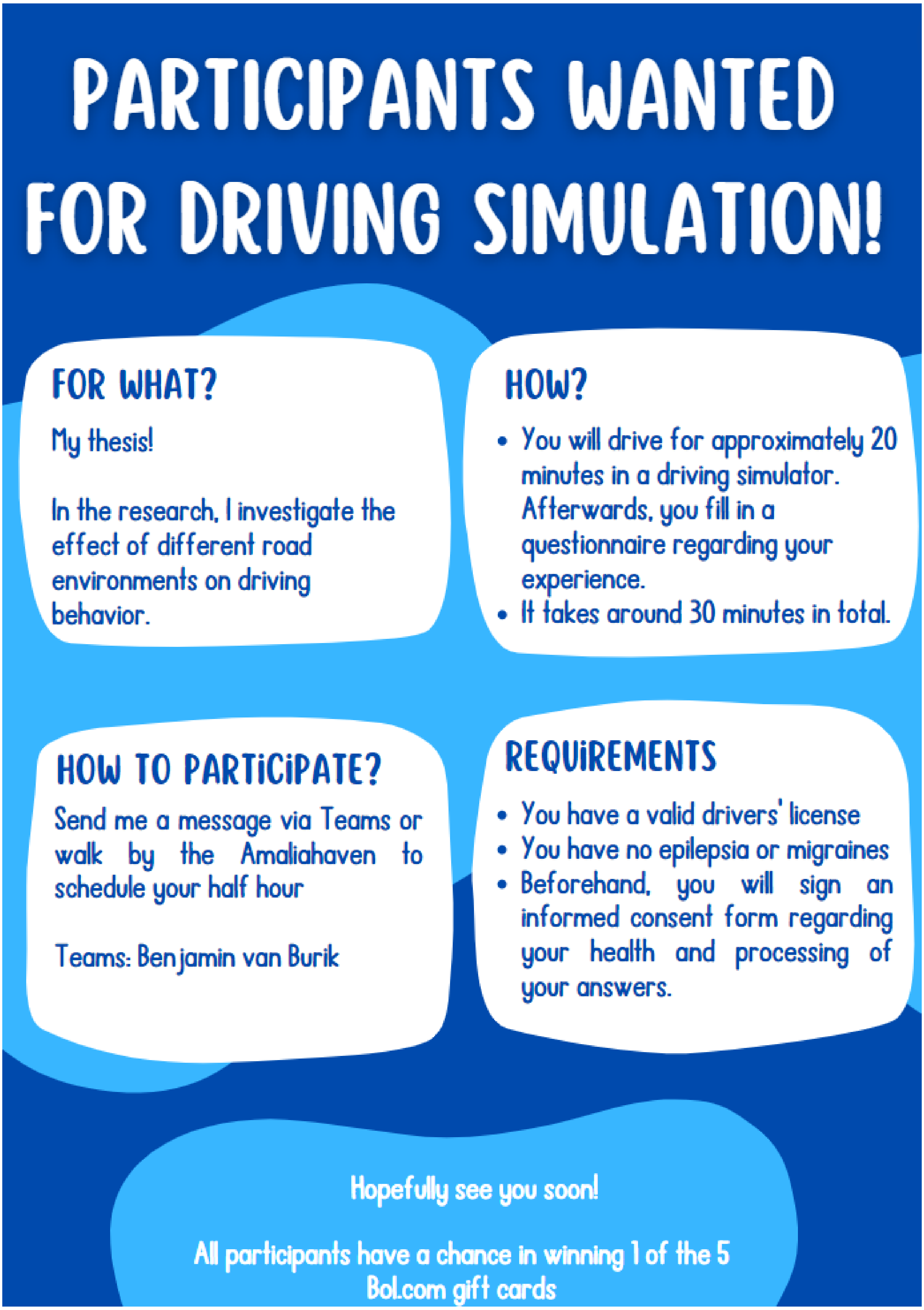
Figure 31: NLRM (narrow road width and medium height greenery)

Figure 32: WLRM (wide road width and medium height greenery)

Figure 33: NLRH (narrow road width and high greenery)

Figure 34: WLRH (wide road width and high greenery)

Appendix F: Recruitment advertisement



Appendix G: Instructions and informed consent form

Measuring the effectiveness of sustainable measures on urban roads

Informed Consent Form

You are being invited to participate in a research study titled ***Measuring the effectiveness of sustainable infrastructural measures for GOW30 roads***. This study is performed by Benjamin van Burik as a completion of the MSc Transport, Infrastructure and Logistics from Delft University of Technology.

The purpose of this research study is to measure the credibility and satisfaction of sustainable road designs. This simulation will take you approximately *30* minutes to complete. The data will be used for scientific purposes and made unretrievable to the individual. We will be asking you to drive in a driving simulator through a virtual environment based on the municipality of Rotterdam. Also, after the simulation you will be asked your age, gender, years of driving experience and educational degree. Furthermore, you are asked to give your opinion on the presented designs.

To the best of our ability your answers in this study will remain confidential. We will minimize any risks by ensuring anonymity of your personal information. In the experiment, your surname, e-mail and area of residence will not be recorded. Any personal information such as your age, gender, years of driving experience and educational degree will be assigned to a randomized number of your simulation experiment and deleted after the completion of the master's thesis.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any reasoning for doing so. Also, it is possible to ask for a deletion of data recorded on your personal number that is shared with you after the experiment.

Thank you for participating in this research,

Benjamin van Burik

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [...../...../..........], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. Name................................. Autograph..........................	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves:	☐	☐
Taking part in a driving simulator study that uses a fixed gaming seat and take part in a survey on the simulation afterwards. Answering the survey is aimed at evaluating my experience and opinion on the environment in the experiment. The survey records my age, gender, nationality, educational degree and driving experience.		
4. I understand that the study will end on the 26th of July 2024		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study involves the following risks. I understand that these will be mitigated by:	☐	☐
• *Potentially become dizzy or nauseous as a result from driving the simulation. Also, immersion in a virtual world potentially triggers migraines or epilepsy. I am not ill or have an underlying disease that limits my ability to take part in this simulation. I am not pregnant. Might it happen that I feel unwell, I can immediately stop the driving simulation.*		
6. I understand that taking part in the study also involves collecting personal information	☐	☐
• *My age, gender and years of driving experience will be recorded in the survey. For the application, my name and email address will be recorded for planning purposes.*		
7. I understand that the following steps will be taken to minimize the threat of a data breach, and protect my identity in the event of such a breach	☐	☐
Anonymous data collection, aggregation of the results and two-step verification measures with regards to the simulation ride and answers provided in the survey.		
8. I understand that personal information collected about me that can identify me, such as *my first name, e-mail address combined with my age, gender and driving experience* and will not be shared beyond the study team.	☐	☐
9. I understand that the personal data I provide will be destroyed after the 26th of July 2024.	☐	☐
Please add the anticipated timing or how the date will be determined		
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for publication in the TU Delft database for master's theses.	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
11. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐

Appendix H: Post-experiment questionnaire

After the completion of the driving simulation experiment, participants were administered the below questionnaire to retrieve information on their demographics and the extent to which their wellbeing was influenced by the simulation setup. Furthermore, subjective information was gathered with regards to the presented road designs in relation to driving behaviour and safety perceptions. The results of this survey are presented in Appendix G: Driving simulator survey results.

Driving simulator experiment

Dear respondent,

Thank you for participating in the simulator experiment! Now a few questions regarding this simulation will follow. This will not take more than 5 minutes. Good luck!

Sign in to Google to save your progress. Learn more

* Required question

Please fill in your participant number *

Your answer

What is your nationality? *

Your answer

What is your age? *

Your answer

What is your gender? *

◯ Female

◯ Male

◯ Prefer not to say

What is your level of education? *

- ◯ VMBO
- ◯ HAVO/VWO
- ◯ MBO/Vocational education
- ◯ HBO/Bachelor
- ◯ WO/Master or PhD

Do you have a drivers' license? *

- ◯ Yes
- ◯ No

How many hours a week do you drive a car? *

- ◯ Less than 2 hours
- ◯ Between 2 and 5 hours
- ◯ More than 5 hours

Now, a few questions on your experience will follow

Did you experience any nausea, fatigue or sweating? *

- ◯ No
- ◯ Yes, mildly
- ◯ Yes, noticeable
- ◯ Yes, severe

Did you experience any oculomotor discomfort (e.g. headache, blurred vision or eye strain)? *

- ◯ Yes, severe
- ◯ Yes, noticeable
- ◯ Yes, mildly
- ◯ No

Did you experience any disorientation during the experiment (e.g. dizziness or motion sickness)? *

- ◯ No
- ◯ Yes, mild
- ◯ Yes, present
- ◯ Yes, severe

To what extent were you immersed in the simulation visually? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely immersed

To what extent were you immersed in the simulation auditorily? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely immersed

To what extent did you experience a delay in your actions versus the outcome? *

	1	2	3	4	5	6	7	
Not at all	○	○	○	○	○	○	○	Extremely delayed

How content are you with the visual quality of the simulation?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very content

How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very much

To what extent did your driving speed feel similar to driving speeds in reality? *

	1	2	3	4	5	
Totally not similar	○	○	○	○	○	Totally similar

How did you experience maintaining your driving speed in the simulation? *

	1	2	3	4	5	
Very easy	○	○	○	○	○	Very difficult

Please elaborate *

Your answer

Now, a few questions on your perception will follow

To what extent does a grass lane serve as a separation between you and pedestrians? *

- ◯ It is a very strong seperation between me and other road users
- ◯ It is a strong seperation between me and other road users
- ◯ It is a moderate seperation between me and other road users
- ◯ It is a mild seperation between me and other road users
- ◯ It is not at all a seperation between me and other road users

Does a grass lane seperation influence your sense of safety, making you drive faster (compared to a situation with parked cars)? *

- ◯ Yes, it does influence my sense of safety and I drive faster
- ◯ Yes, it does influence my sense of safety and I do not drive faster
- ◯ No, it does not influence my sense of safety and I drive faster
- ◯ No, it does not influence my sense of safety and I do not drive faster

Did the oncoming traffic in the simulation make you driver slower?

- ◯ Yes, a lot (> 5km/h)
- ◯ Yes, a bit (<5km/h)
- ◯ I don't know
- ◯ No

In this experiment, did you observe that trees were varied in thickness? *

◯ Yes

◯ I am not sure

◯ No

Did you find that the thickness of greenery influenced your visibility? *

◯ Extremely

◯ Significantly

◯ Moderately

◯ Slightly

◯ Not at all

Suppose you were a pedestrian, do you see a tree as a protective barrier? And what if you are a car driver? *

Jouw antwoord

Do you think parked cars along a road make you drive slower? Please elaborate why (not)? *

Jouw antwoord

In what way would your driving style change if a centerline was added to the roads? Please check the boxes that apply. *

- ☐ I would drive faster
- ☐ I would drive slower
- ☐ This has no influence on my driving speed
- ☐ I would keep my lane more
- ☐ I would keep my lane less
- ☐ This has no influence on my lanekeeping

To what extent do you think that greenery in general influences your driving behavior? Think of your speed, steering movements and acceleration. *

- ○ Not
- ○ Little to not
- ○ Neutral
- ○ Much
- ○ Very much

Please explain briefly

Your answer

Now, the final 2 questions on your comfort!

Generally speaking, how comfortable did you feel driving on these roads? *

- ◯ Very comfortable
- ◯ Comfortable
- ◯ Neutral
- ◯ Uncomfortable
- ◯ Very uncomfortable

Generally speaking, which road(s) did you experience as the most comfortable and which one(s) the least? *

Your answer

Appendix I: Driving simulation survey results: TU Delft

I.1 Simulation Sickness evaluation

As can be seen in the below figures, participants that took part in the experiment with the TU Delft simulator, did not experience oculomotor discomfort. However, a feeling of disorientation was experienced more.

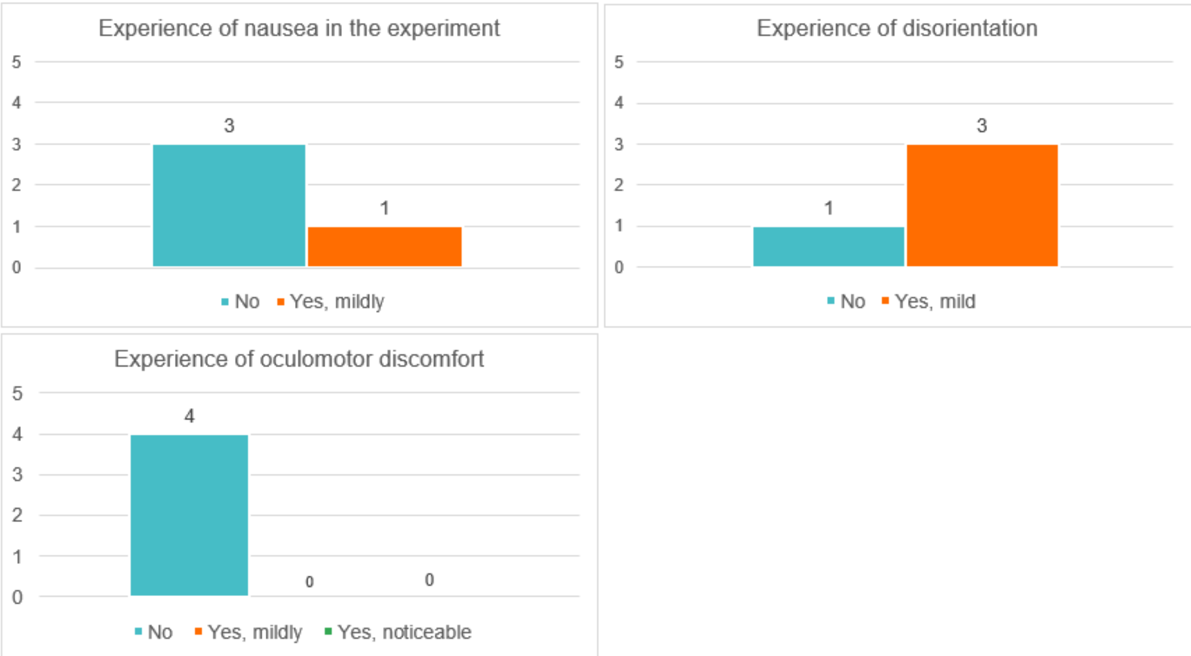


Figure 35: Simulation Sickness Questionnaire items results (TU Delft participants)

I.2 Presence during the experiment

Then, visual immersion scored primarily positively. Auditory immersion generally less. Also, the majority of the 4 participants experienced a delay in the simulation experiment. Also, the participants were generally content with the simulation, but realism of driving speed was experienced differently. This can partly be explained by the fact that handling the accelerator pedal was difficult.

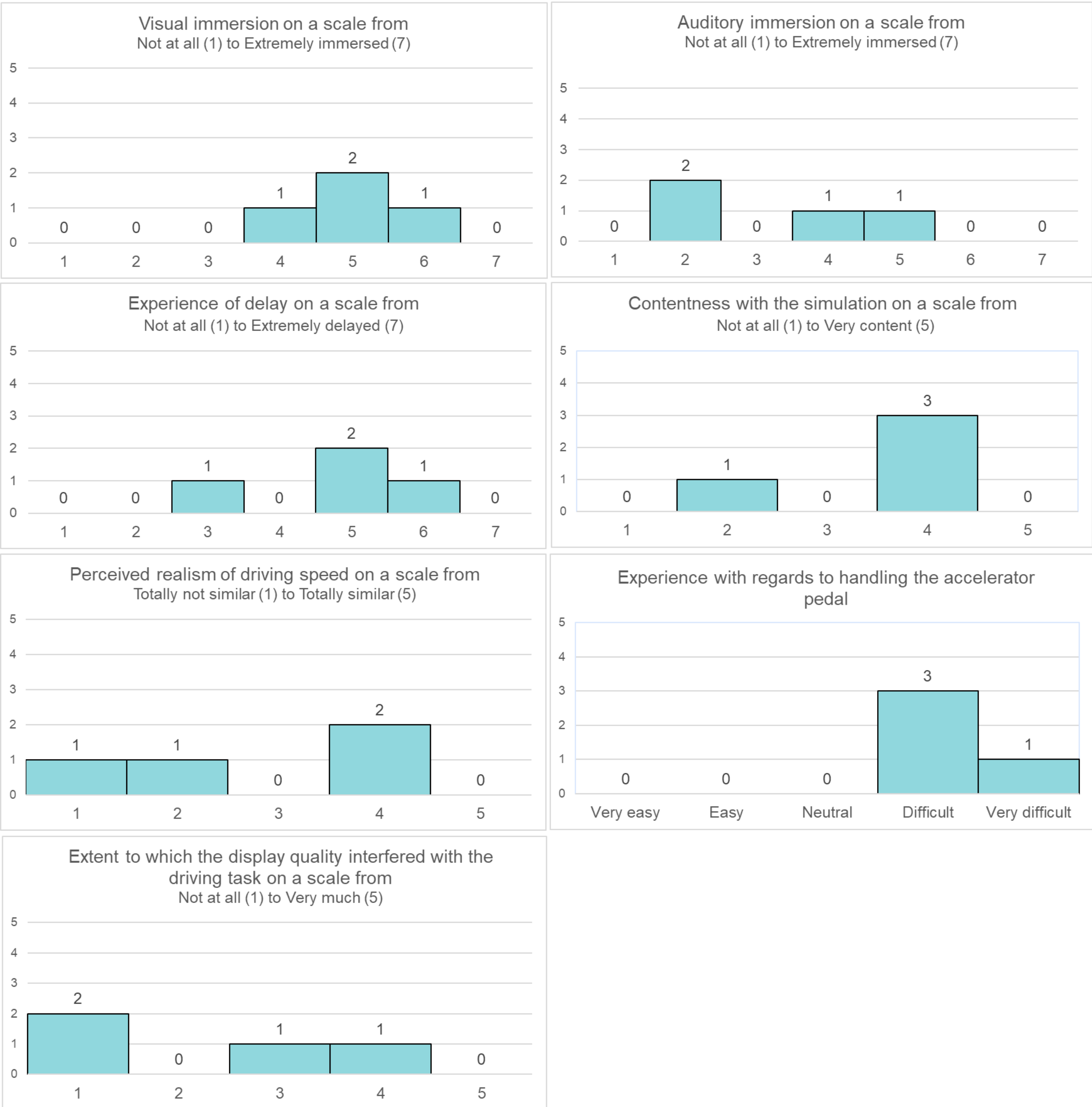


Figure 35: Presence Questionnaire items results (TU Delft participants)

I.3 Perception of greenery

From below tables, it becomes clear that grass lanes lead to drivers adapting higher driving speeds. Grass lanes are also perceived as strong separations between the road and the sidewalk. Generally, greenery has a moderate to strong influence on driving behaviour.

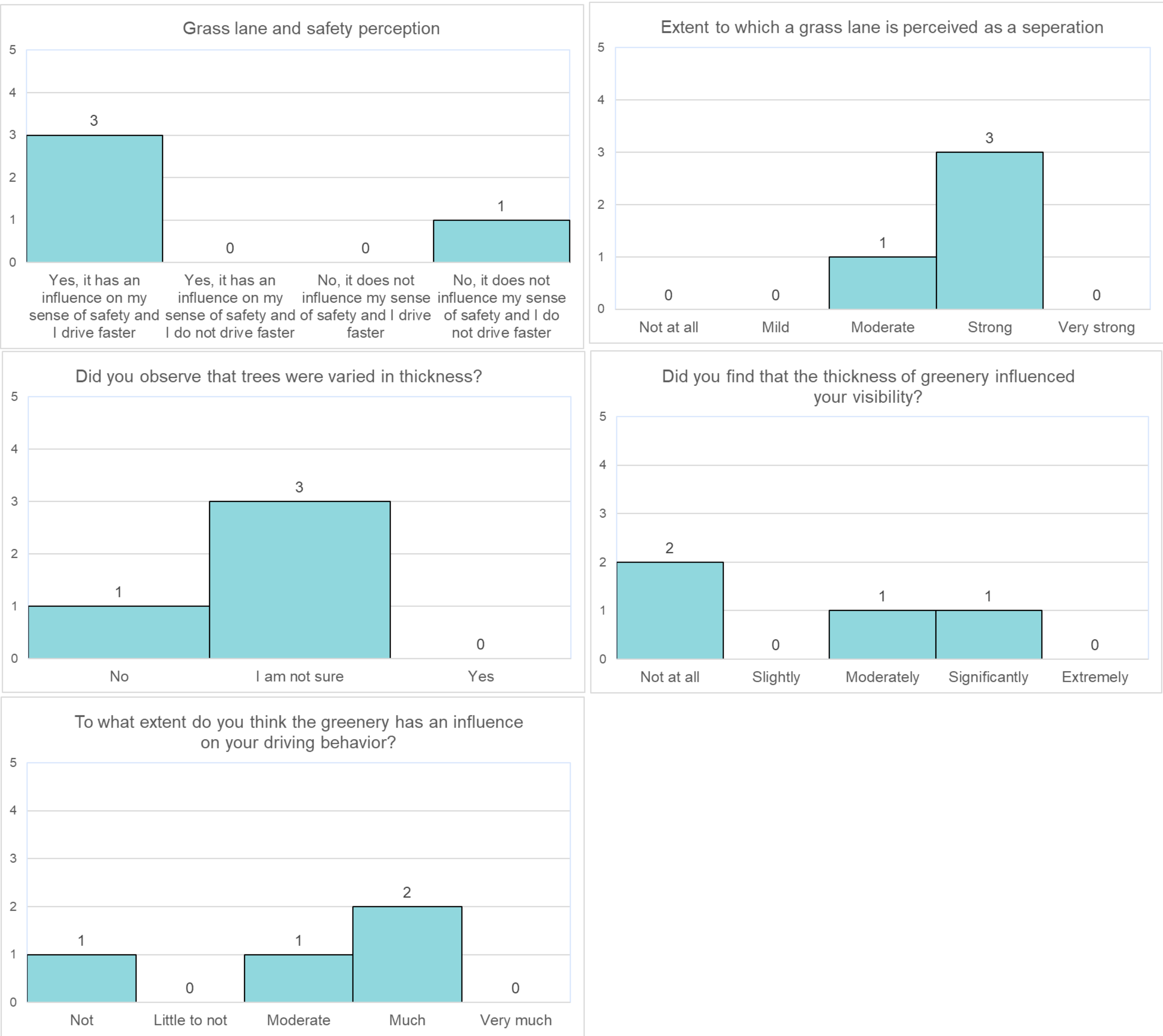


Figure 36: Perception of greenery results (TU Delft participants)

I.4 Perception of other traffic

Finally, the stated relations between centerlines, oncoming traffic and comfort on the presented roads differed. This can also be seen in below figures.

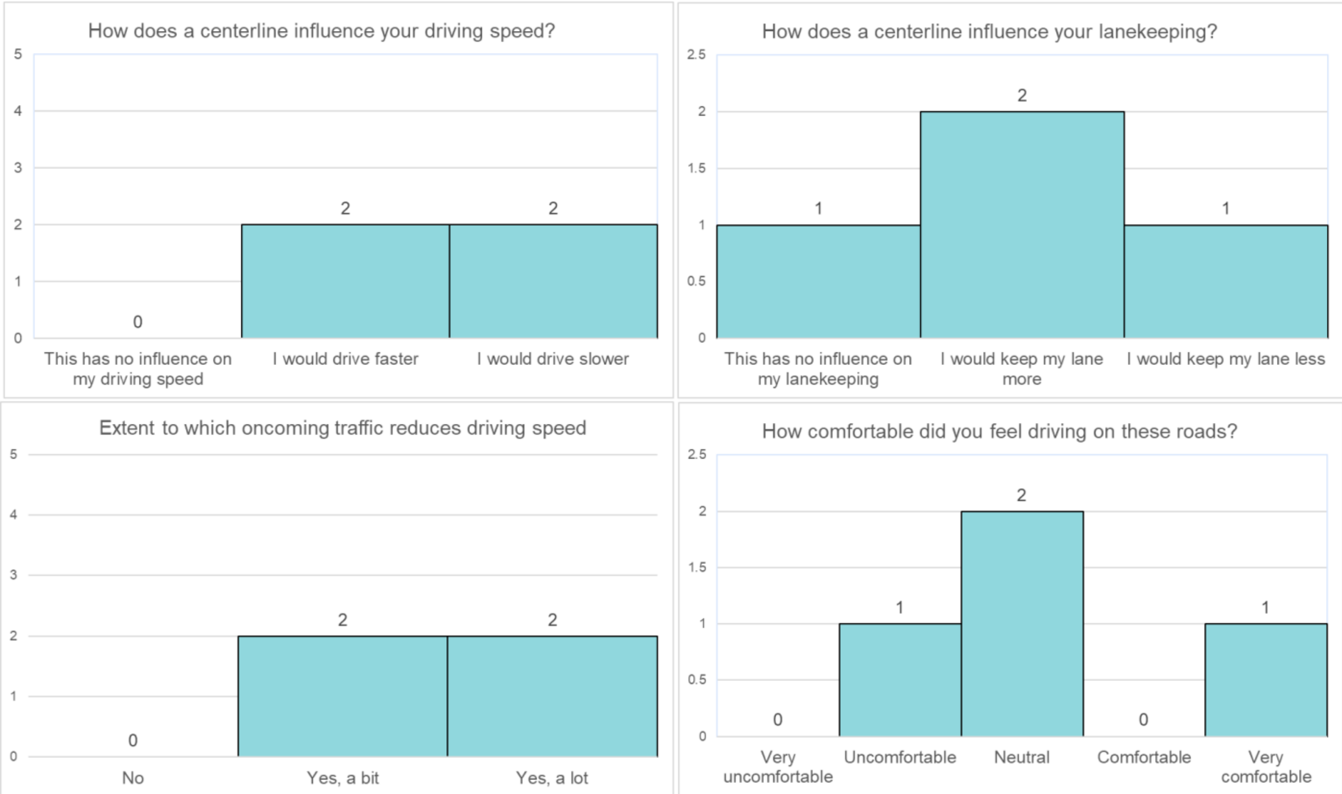


Figure 37: Perception of other traffic and centerlines (TU Delft participants)

Appendix J: Post-experiment questionnaire statements

Of the 44 participants taken into account for the analysis, 42 participants provided final remarks with regards to the experiment. All 42 statements are listed below.

S1: The least comfortable were roads with high and dense trees. If I find a road comfortable, I generally drive faster. The road does not invite to drive slow, it is a long straight segment.

S2: I do not drive faster or slower due to a centerlines, I would keep my lane more with a centerlines. I am not much influenced by greenery as a driver.

S3: Driving without obstructions, with green strips on both sides, is the most comfortable. Parked cars with trees are the least comfortable, as they limit visibility, causing you to drive more slowly.

S4: The least comfortable roads are those with parked cars; it feels like driving alongside a wall. Roads with grass strips are more pleasant to look at. I do prefer having something along the sides, as an empty road feels abandoned. Greenery enhances the driving experience, and trees do as well, although they can feel less safe. When there are trees in between, I find it more comfortable. I actually feel that parked cars pose a greater risk than trees. With a tree, you tend to be more cautious. I'd rather drive along roads lined with trees than with parked cars.

S5: It was very uncomfortable because I wanted to drive in the center, but due to oncoming traffic and other vehicles, it became uncomfortable. The least comfortable experience was on roads with high curbs. The most comfortable setup was having two parking spaces followed by a green strip. Grass sections were the least comfortable because I tend to drive faster on them.

S6: The most bothersome situation was having only cars or a sidewalk. Trees between parked cars made it better. Having grass on the right side was also quite pleasant because it prevents people from suddenly stepping onto the street.

S7: Green streets feel the most comfortable, partly because there are fewer parked cars. I have the best visibility on those roads.

S8: The most comfortable roads were those with low greenery between the cars. The least comfortable were the ones with tall trees.

S9: Lane narrowing is unpleasant for drivers, but better for pedestrians. The road with grass strips is the most pleasant. Trees in this setup are fine as long as they are small and spaced out, making it better than having parked cars.

S10: The least comfortable was having parked cars on both sides, while the most comfortable was having grass on the right side.

S11: Having nothing on the right side is similar to having a grass strip on the right, providing good visibility. Helmet grass is the same as regular grass. Trees have an impact, but bushes don't really make a difference. The least comfortable situation was having cars on both sides.

S12: I found the least comfortable situation to be having cars parked on both sides. The most comfortable setup was grass without trees, as it provides the best visibility.

S13: The least comfortable situation was having cars on both sides, with many crosswalks and high curbs. The most comfortable setup is a wide road with cars on the left and nothing on the right, or grass or helmet grass. Roads with trees and a straight curb tend to make you drive more slowly, as do roads with trees between parked cars.

S14: The best setup was having green strips with no trees, as it provides the best visibility. The least comfortable was having parked cars on both sides. With parked cars on the left, you have the best visibility, but with them on the right, you see better because you drive on the right side. Alternating trees is also more comfortable for me.

S15:Grass on the right side is the most comfortable. Having cars on both sides is less comfortable and very uncomfortable with oncoming traffic. Adding trees feels similar in terms of comfort. The road I found most believable was the one with cars on both sides; on the other types, I tend to drive at around 50 km/h.

S16: As a driver, having a grass strip on the right side was the most comfortable due to better sightlines. Cars on both sides were the least comfortable. There was no difference in experience with trees between parked cars, and no difference with elevated parking.

S17:The widest roads with green strips are the most comfortable, while having cars on both sides is the least comfortable. Elevated versus normal parking doesn't make a difference for you, and alternating trees with cars is better, provided there are enough trees.

S18: Greenery and grass strips, along with trees, make for the most comfortable setup, while parked cars are the least comfortable. The most believable setup involves cars, and more greenery often corresponds with driving at 50 km/h. Trees between parked cars are also believable. Grass strips are the least believable. Visibility on the sidewalk can be diminished by shrubs, making crossings without crosswalks potentially tricky.

S19: The most comfortable setup is having grass on the right side with occasional trees. The least comfortable is roads with many crosswalks and parked cars everywhere.

S20: Having any greenery is preferable. A high curb affects my driving, making me drive more slowly. With greenery, I can see further ahead, while low shrubs have a similar effect. Trees, on the other hand, obstruct my view more.

S21:The least comfortable setup was having cars on both sides, while the most comfortable was having grass on the right side. The lower the obstruction, the better. Alternating with trees is slightly better because it provides more visibility. Variations in tree thickness don’t make much difference. When I have more visibility, I tend to drive faster. Thin or thick trees don’t have a significant impact since there are already cars present.

S22: Generally, I prefer narrower roads. The more trees, the better, as I enjoy seeing them. Roads with cars on both sides are the dullest. It's more peaceful with just greenery on the right side. When there are cars everywhere, there's a higher risk of doors being opened.

S23: The most comfortable scenario is having only grass, as it provides the best visibility. The least visibility is with parked cars. Trees between parked cars still offer better visibility than just cars. Small shrubs or grass make no significant difference.

S24: It was uncomfortable because I felt like I was driving too far to the right, making it feel narrow. The most comfortable setup was having green strips with low or medium vegetation on the right side. The least comfortable was a narrow road with cars on both sides. A sloped curb is more comfortable because it provides separation between me and the parked cars.

S25: The least comfortable was a narrow street with closely parked cars, while the most comfortable was with low or medium-height greenery. Driving itself felt more challenging, but the roads were pleasant. The discomfort was more related to the driving experience rather than the road setup. The least pleasant was a narrow road with only cars, and the most pleasant was having green strips on the right side. Grass is better than shrubs, which are less certain in their effect.

S26: The most comfortable setup is asphalt without cars. Asphalt with many trees is less comfortable, and a wider road is better. Having no trees between cars is preferable. Helmet grass or regular grass makes no significant difference.

S27: The most comfortable setup is having grass on the right side, while the least comfortable is with cars and thick trees in between. Cars mainly create a sense that you need to be more alert.

S28: The least comfortable is a narrow road with cars. The most comfortable is having green strips on the right side, which feels more spacious. Roads with variety, such as greenery, are more pleasant to look at. Roads with cars parked on both sides and no greenery are less inviting.

S29: The most comfortable setup is having trees on the right side, rather than cars, because it provides greenery and a sort of barrier. I think I drove differently, but more unconsciously in this setup.

S30: A wide, easily passable road with minimal interaction with what's happening next to the road is most comfortable. Cars prevent interaction with pedestrians. Roads with cars and thick trees can be comfortable as they create a new perspective and encourage looking further ahead, which can lead to driving faster. It's not necessarily uncomfortable; a sloped curb allows for faster driving because the cars seem to be in a different position.

S31: The most comfortable setup is a wider road with either grass or helmet grass. The least comfortable is having cars on both sides and elevated parking, as it makes me feel like my tires might ride up, leading to a loss of control. Trees of varying heights, but still taller than people, can provide separation. It's important to see pedestrians coming up above something. Replacing grass with flowers could also be an option.

S32: The easiest and most manageable setup is having grass on one side and cars on the other, or having nothing at all, as it provides the best visibility. The least comfortable is having cars parked on both sides with oncoming traffic, as you see people walking behind the cars and it creates uncertainty. The least pleasant setup is having cars parked, especially with thick trees between them. A narrow tree makes it more pleasant by offering occasional visibility. A sloped curb feels narrower than normal parked cars but isn't necessarily less comfortable.

S33: The least comfortable is parked cars on both sides with level parking. The most pleasant is having grass on the right side. Trees between cars are also more pleasant than just cars, as they reduce car density. A sloped curb is also more comfortable than no slope, depending on the steepness.

S34: The most comfortable setup is having grass or shrubs on the right side. The least comfortable is having cars parked on a level surface. A sloped curb adds some comfort. Thin trees are more pleasant than thick trees, but thick trees are still more comfortable than having cars parked on both sides.

S35: The most comfortable setup is having two empty parking strips. The least comfortable is having cars on both sides. A sloped curb is less comfortable because you could potentially drive into it. Trees also make it less comfortable due to the added elevations.

S36: Thicker trees are less comfortable than thinner ones. There is little difference between grass and shrubs, but grass still feels better. With trees, there is a clear difference in comfort.

S37: Wider roads are the most comfortable. The least comfortable are the narrowest roads with parked cars on the sides. Trees between parked cars make it somewhat more comfortable, as it feels a bit more spacious and less constricting. A sloped curb is slightly more pleasant because it feels like a separation, similar to how a centerlines provides a visual reference point.

S38: If a centerlines were added, you drive slower but you can pass oncoming traffic more quickly. The most comfortable setup is having grass and trees on the right side, while the least comfortable is the existing road with cars parked on both sides, as it feels restrictive. A sloped curb helps in maintaining road position and makes elevated parking seem more organized. Trees between cars are also more pleasant, with thicker trees being slightly better than thinner ones because they enhance the road's appearance. High trees on the right are more pleasant than shrubs, and shrubs are better than grass on the right, which can look ‘empty’. You use mirrors to determine your road position, which wasn't possible in the test and made it more challenging.

S39: The most comfortable roads are roads with green strips, because this way I can see a large empty area. This makes me feel more free and if I hit grass, there are no financial consequences. The least comfortable roads had parked cars on both sides. This becomes more comfortable if trees are placed between cars. I think it also would be nice to have flowers or green plants along the road, but I am not sure on the influence on visibility of this.

S40: Generally speaking, highways are the most comfortable and narrow school zones the most uncomfortable.

S41: I find a lot of overview and few nearby vehicles comfortable. If many cars are nearby, this reduces overview and feels as if a lot is happening. The canting does not really matter, I drive faster with canting because there is more distance between me and the cars. If the road is a one-lane road, this would reduce my driving speeds because of the narrowing effect. There is not a large difference between my driving behaviour if grass or marram grass is placed along the road, but there is a bit with trees. Trees reduce my overview. I associate wider trees with wider roads, but if thin trees are placed in between cars this also does not really matter to me. I felt pretty uncomfortable because there is a lot of stimuli in this environment: it is very dense and I need to be alert.

S42: I found wide roads the least comfortable, because I had more trouble keeping the speed the same (I think) and I had more trouble focusing.