

# A new perspective on residential parking policy

**A multiple regression model to explain the visitor parking demand in Dutch urban residential areas**





# A new perspective on residential parking policy

A multiple regression analysis to explain the  
visitor parking demand in Dutch urban  
residential areas

by

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# Preface

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Delft, August 2021*

In front of you lies the thesis "A new perspective on residential parking policy" which sheds new light on visitor parking in urban residential areas. After six years of studying, this thesis is my final work to complete the master program Transport, Infrastructure and Logistics. During my bachelors, I became interested in multidisciplinary projects, and this continued during the master program. Especially during the second year of the masters, where I did a project on the interface of mobility and spatial planning. When starting my search for an exciting topic, Sweco provided the opportunity to combine these two topics in my final thesis.

Therefore, I want to thank Sweco for providing me with the opportunity to write my thesis on this interesting topic. I am grateful to my Sweco supervisor Jeroen Quee for your critical eye, our interesting meetings, and for keeping me on the right track. I also would like to thank my supervisors of the TU Delft, Gonçalo Correia and Jan Anne Annema. Your different perspectives on the topic were very valuable. Thank you for your quick responses on my emails, your feedback during the writing process and brainstorming about the results of my research. Besides, I want to thank Bert van Wee as the chair of my thesis committee. Your feedback during the official meetings was very valuable to improve my thesis.

Furthermore, I want to thank Diede Labots and Fleur Wouters for providing me insight into how parking policies are developed in practice. The interviews were very interesting and really showed the importance of my research for practice. I hope that my work can contribute to a better underpinning of reduced visitor parking standards in your municipalities.

Seven years ago, I could not imagine finishing a study at the TU Delft and become an engineer. I could not have done this without my parents. Thank you for supporting me throughout my study, but especially during the last six months. Having my own office at your place really helped me to get some distance from my thesis after a day of studying. Furthermore, a big thank you goes to my boyfriend Joost, who read many chapters repeatedly. Your supportive feedback gave me the trust and confidence to go on and finish my thesis in time. Finally, my friends and roommates have been a big support throughout my whole study time. You gave me distraction when needed but also were great 'study buddy's'.

I really enjoyed writing this thesis, and I hope you will enjoy reading it as well!

# Summary

The continuously increasing rates of urbanisation bring challenges in order to keep cities sustainable, liveable and accessible. In particular, one of the major challenges in The Netherlands is to build sufficient and affordable housing. Accessibility to these newly developed areas requires sufficient parking supply. However, determining the correct number of parking is challenging—insufficient parking capacity results in cruising cars, increased levels of congestion, and pollution in cities. In contrast, excessive parking supply supports car usage and car ownership. The number of parking is often based on pre-determined requirements that formulate the minimum number of parking spaces that have to be provided by urban developers. A problem with these requirements is that they are based on national averages and do not take local conditions into account. This results in an oversupply of parking places.

Parking demand in residential areas is determined by two types of demands, namely parking by residents and parking by visitors of these residents. To prevent an oversupply of parking while providing sufficient parking spaces, literature recommends considering context-specific factors. Nonetheless, these studies exclude the effect of context-specific factors on visitor parking standards. In addition, earlier research showed that the current visitor parking standards in The Netherlands exceed the visitor parking demand in Dutch residential areas. Consequently, this research aims to gain more insight into the demand for visitor parking and how this is affected by the local circumstances of their visiting area. This research will thereby contribute to the limited research about residential parking and provide more evidence for using context-specific parking standards. Furthermore, this research will help policymakers and developers to determine visitor parking standards in urban residential areas.

In The Netherlands, residential parking standards consist of a parking standard for residential parking and a standard for visitor parking. These standards are determined by the CROW and adjusted based on the local conditions in a specific area. For residents, the parking standards are differentiated based on the urban zone and housing type, while for visitors, the same standard applies in each neighbourhood without taking specific characteristics of an area into account. Interviews with municipalities and a review of policy documents revealed that, in general, the visitor parking standards suggested by the CROW are implemented. Furthermore, the interviewed municipalities stated that visitor parking standards are hard to reduce due to political infeasibility and lack of data about visitors' car ownership and car usage. However, a shift can be seen from municipalities that try to come up with more specific and underpinned visitor parking standards.

In order to identify factors that influence the visitor parking demand, a theoretical framework was developed. The resulted conceptual model shows that visitor parking is influenced by the visitor's car ownership and car usage. The former is influenced by the characteristics of the visitor, which include demographic characteristics and characteristics related to the residential area of the visitor (geographic and parking policy characteristics). The visitor car usage is influenced by both characteristics of the visitor and the characteristics at the parking area, the context-specific factors. The context-specific factors consist of the demographic, geographic and parking policy characteristics of the visited residential area. Due to missing data about the visitors, this study only considers the local conditions at the hosting resident's parking area. Furthermore, in practice, visitor parking standards can only be based on the conditions at the parking area; municipalities can not predict the characteristics of the potential visitors of the area. The final conceptual model thereby indicates that visitor parking demand is influenced by demographic characteristics and geographic and policy-related factors of the residential area of the host. Furthermore, car use is considered to be a proxy for the visitor parking demand. Consequently, the conceptual framework is shown in Figure 1.

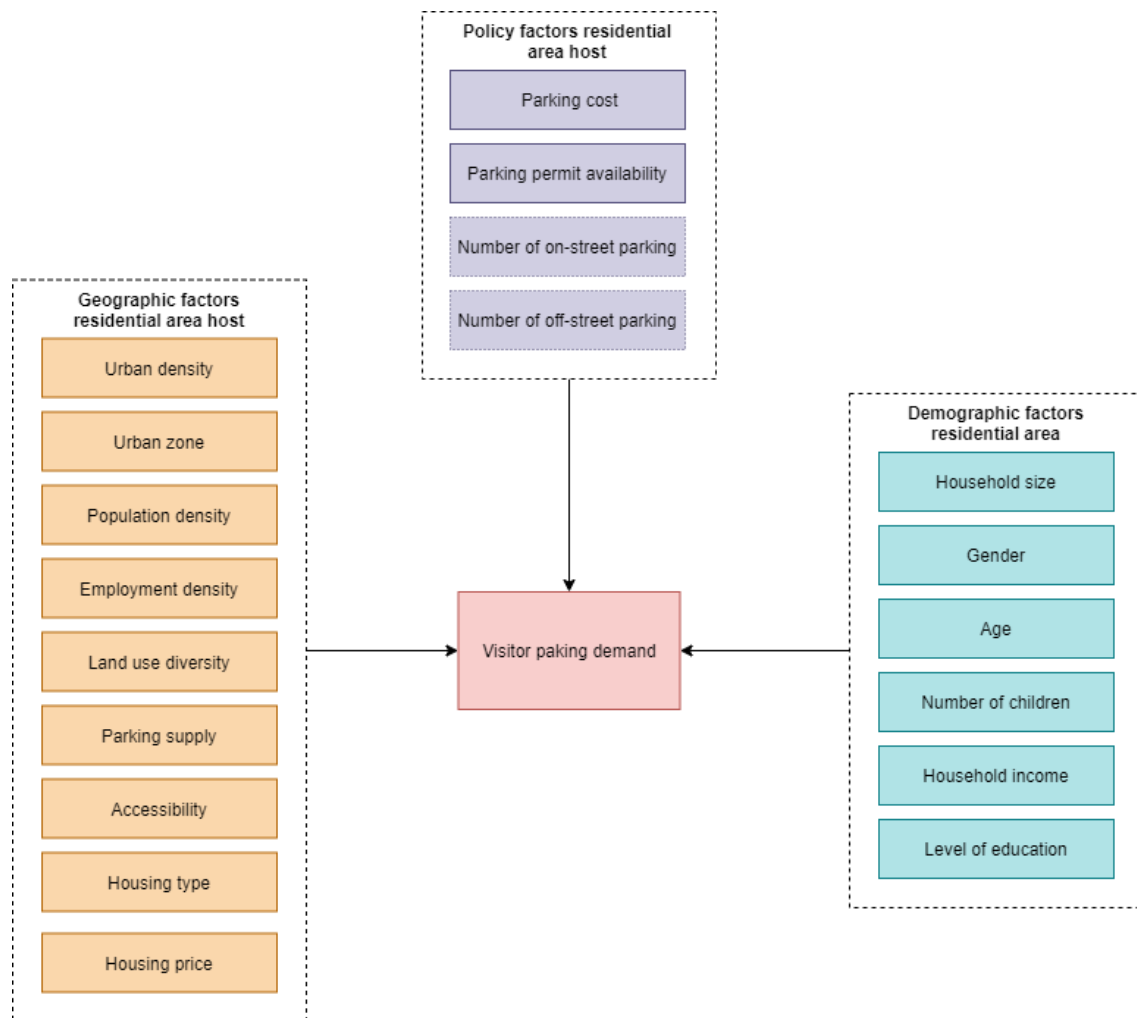


Figure 1: Factors influencing visitor parking demand

Data about the usage of visitor parking permits in Eindhoven was used as a proxy for the visitor parking demand. Eindhoven was chosen based on data availability. Furthermore, Eindhoven is the fifth-largest city in The Netherlands. The visitor parking permits allow residents of paid parking areas to let their visitors utilize parking spaces at a reduced price. The data contained information about the start and end date and time of the parking action, the parking zone and characteristics of the permit holder. The characteristics of the permit holder include the postcode, the date of birth and gender. The postcode of the permit holder was used to retrieve data about the demographic and geographic variables. The demographic variables include information about the demographic characteristics of the hosts at the parking area and were retrieved from the CBS. Geographic characteristics include information about the built environment of the parking area and were collected using Qgis.

Analysis of the parking data showed clear differences in the usage of these permits between different parking zones. In addition, the visitor parking actions differed during the days and between days. In general, most parking actions were registered at 7 p.m. However, the peak hour and spread of the parking demand over the day differed per parking zone. The differentiation of the demand indicates that during the day, the required number of parking places varies. From this, the conclusion can be drawn that most of the time, the required parking capacity will not be used. This allows policymakers to think about multiple usages of visitor parking places or reduction of visitor parking standards.

In order to determine the influence of context-specific factors on the parking demand, a multiple regression model was estimated. Multiple regression allows identifying how independent variables affect the dependent variable. Based on the conceptual model, the input variables of the regression model were determined. As

parking policy is a local policy that applies to a whole city and only the observed parking actions of Eindhoven were considered, policy factors could not be included in the model. The final model is shown in Table 1 and the coefficients are shown in Table 2. The resulting model explains approximately 40% of the variance of the visitor parking demand, in which both demographic and geographic factors influence the visitor parking demand significantly.

Table 1: Results final regression model

N	R	R Square	Adjusted R Square	Std. Error of the Estimates	F	Sig.
390	0.632	0.400	0.384	8.912	25.270	0.000

Table 2: Coefficients final regression model

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	13.403	4.898		2.736	0.007		
Young people and adults	0.130	0.052	0.130	2.480	0.014	0.576	1.736
Population density	0.001	0.000	0.122	2.876	0.004	0.881	1.135
Housing_100plus	0.186	0.061	0.154	3.045	0.002	0.622	1.608
Percentage housing sale	0.039	0.020	0.100	1.922	0.055	0.579	1.726
Housing old	0.070	0.032	0.097	2.175	0.030	0.798	1.253
Housing new	-0.052	0.024	-0.098	-2.214	0.027	0.805	1.242
Distance highway (km)	-2.554	1.253	-0.099	-2.038	0.042	0.671	1.490
Availability parking 250 meters (permit)	1.017	0.090	0.511	11.327	0.000	0.779	1.283
Bus stops within 400 meters	-0.974	0.427	-0.099	-2.278	0.023	0.839	1.192
Distance to city centre	-0.004	0.001	-0.179	-3.786	0.000	0.708	1.411

From the demographic factors, only age showed a significant relation with the visitor parking demand. People between the age of 15 and 44 years attract more visitors by car. Due to high correlations, other factors, such as the number of inhabitants, households, and household composition, could not be included in the model. Furthermore, single linear regression showed no significant relation between the number of inhabitants and households and the number of visitor parking actions in a specific area. This indicates that the number of inhabitants/households in a residential area does not influence the visitor parking demand. Since no significant relation could be found between the number of inhabitants and households and the visitor parking demand, visitor parking standards would preferably not be based on the number of residents or households in a particular area.

Regarding the geographic factors, different characteristics of the built environment showed to influence the visitor parking demand significantly. First, higher population densities show to attract more visitors than lower population densities. This finding is in line with the variable that indicates the distance to the city centre. Higher distances to the city centre reduces the visitor parking demand, which is consistent with the assumption of population density being higher in the city centre. Furthermore, different housing characteristics influence the number of visitor parking actions. The results showed that both bigger houses and owner-occupied houses generate more visitor parking while newly built houses reduce the visitor parking demand. In addition, the accessibility of the parking area by car and other modes of transportation have essential relations with the visitor parking demand. Increased parking supply and decreased distances to the highway increases the parking demand, while good accessibility to bus decreases the number of visitor parking actions.

The model points out that parking supply strongly impacts the visitor parking demand. This suggests that theories on residential parking supply also apply to visitor parking, whereby higher parking supplies will increase the visitor parking demand. Decreasing visitor parking standards, therefore, might result in lower usage of visitor parking permits. However, this measure could be accompanied by good accessibility to public transport and could take housing characteristics into account. Areas with bigger houses attract more visitors

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by car, while housing constructed after 1995 produce fewer visitor parking actions. This is related to new parking policies that reduced the parking standards and thereby offered less parking capacity. It is important to consider that this relation between supply and demand is measured in an urban area, and consequently, this conclusion might not be applicable to non-urban areas.

Based on the results of this study, it can be concluded that the visitor parking demand depends on context-specific factors at the residential area of the host. Consequently, determining visitor parking standards requires analysing the local conditions of the parking area. The results of this research show that visitor parking standards could consider the average age at the parking area, the urban zone (both the population density and the distance to the city centre), the housing characteristics of the houses in the parking area, the parking supply and the accessibility of the area by both car and public transport. Besides, could the variation of the demand during the day be used to implement lower parking standards or multiple usages of parking. In addition, the lacking relation between the number of inhabitants and the visitor parking demand suggests that visitor parking standards do not necessarily can be represented as a number of parking spaces per house. Visitor parking capacity thereby could be determined based on the local conditions rather than defining a single national standard that provides the number of parking spaces required per house. Taking context-specific factors into account requires analysing these local conditions in the residential area while determining the required number of visitor parking spaces and will contribute to a better estimation of the required parking capacity.

This research shed new light on residential parking policies. Policymakers can use the results of this study to come up with a better approach for visitor parking standards. Based on the results of this study, it is recommended that municipalities base their visitor parking standards on observed circumstances in their city. In addition, this research confirms that lowering parking standards will reduce the visitor parking demand. From a scientific perspective, this research is the first study that contributes to knowledge about residential visitor parking, enriching the literature on residential parking. However, the estimated model in this research does not explain the total variance in visitor parking demand. Therefore, follow up research is required to establish the effect of policy related factors and identify other factors that might influence the visitor parking demand. Furthermore, from a theoretical perspective, it is recommended to do further research on how visitor parking demand is related to the car use and car ownership levels of the visitors. However, in practice policymakers will only consider factors related to the parking area and thereby the insights gained by such a study will not be used. In addition, while this study did not compute a new visitor parking standard, further research is required to develop a method that combines the individual effects of different factors to determine the required visitor parking supply. Finally, future developments were not taken into account. Literature suggests that parking demand will change as a result of trends in mobility. Thereby, future research should focus on what these developments mean for the visitor parking demand.

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# Acronyms

**BAG** Basisregistratie Adressen en Gebouwen. 11, 38, 39

**CBS** Centraal Bureau voor de Statistiek. 11, 12, 32, 33, 38

**GIS** Geographic Information System. 11, 57

**ITE** Institute of Transportation Engineers. 5, 22

**OLS** Ordinary Least Squares. 9

**PC6** postcode with 6 digits (e.g. 1111 AA). 30, 32, 37, 57

**SEM** Structural Equation Modelling. 56, 59

**VIF** Variance Inflation Factor. 44, 48

# 1

## Introduction

### 1.1. General introduction

Urban areas are growing. In 2019, 75% of European citizens lived in cities (The World Bank, 2019) and it is expected that this will increase to approximately 84% by 2050 (European Commission, n.d.). Although urbanisation has advantages from an economic perspective (European Commission, n.d.), there are also some disadvantages of urbanisation. Disadvantages include topics as congestion, air pollution, sprawl and pressure on housing markets (Van Doorn et al., 2019, p.3). The increasing rate of urbanisation brings challenges to keep cities sustainable, live-able and accessible.

According to Van Doorn et al. (2019), housing is one of the most critical urban challenges in cities. Due to the urban population growth, demand for affordable housing increases. In The Netherlands, for example, 1 million houses have to be built before 2030 (Neprom, 2018). New housing also requires good accessibility to the newly developed residential areas. In Europe, passenger mobility is highly focused on personal car usage (Fiorello et al., 2016). Especially in urban areas, residents using cars experience congestion and parking difficulties (Fiorello et al., 2016). Furthermore, Shoup (1999) states that during their lifetime, cars are parked 95% of the time. For The Netherlands, this requires about 15 million parking spaces to provide parking to 8 million cars (Kansen et al., 2018). This makes the availability of parking an important and challenging subject in area development projects. On the one hand, insufficient parking availability results in cruising cars searching for a parking space, increasing the number of vehicle-kilometres driven and contribute to increased levels of congestion and pollution (Russo et al., 2019). On the other hand, excessive parking supply supports car usage and car-ownership (Li and Guo, 2014) (Russo et al., 2019). On top of that, a good parking policy is required.

In most European cities, the development of parking policy followed the same trend (de Wit, 2005) (Mingardo et al., 2015). European parking policy changed from accommodating the parking demand to regulated parking policies that balance the parking demand and the competing demand for urban space (Kodransky and Hermann, 2010). This is also acknowledged by Mingardo et al. (2015) who identified that there is a change from the absence of parking policy to regulated parking policy. Nowadays, parking policies are integrated into transport demand management (Mingardo et al., 2015).

In practice, the required number of parking spaces is often determined based on parking requirements (Mingardo et al., 2015). Municipalities use these parking requirements to indicate the minimum number of parking spaces developers need to take into account (Mingardo et al., 2015). More specifically, minimum standards set up the minimum level of parking developers have to provide in terms of the number of spaces per square feet or per housing unit (Guo, 2013a). Both in practice and in literature, problems with parking requirements are acknowledged. For example, Zuid-Holland (2017) observed that different projects in The Netherlands were hampered by the required parking capacity. Consequently, many development projects failed. This is mainly due to requirements being both physically and financially infeasible within the developing area. This is in line with the findings of Gabbe et al. (2020) who saw that real estate developers are constrained by the minimum parking requirements enforced by local authorities. Furthermore, projects with reduced requirements realised less parking, resulting in reduced costs for developers and lower housing

prices.

Besides the housing affordability, Zuid-Holland (2017) observed that many parking facilities are unoccupied. Literature relate these problems to how parking standards are determined. These methods differ per country. For example, in the U.S., two different methods are used. The first method determines the parking supply based on the observed demand and supply in nearby cities. The second method consults the so-called parking handbook of the Institute of Transportation Engineers (ITE). The parking generation is determined based on a survey for observed peak parking occupancy for different land uses in this handbook. In literature, these methods have been debated. Both Shoup (1999) and Willson (2000) argue that the standards are based on peak demand and reflect national averages and thereby are less applicable to the local conditions. Furthermore, the utilization studies are not able to capture different characteristics of the parking area. Consequently, the number of applied parking spaces in new development projects do not depend on the physical environment (Cuddy, 2007). This is also acknowledged by Litman (2016) who argues that current parking standards tend to be applied with little consideration of demographic, geographic and policy factors.

Conclusively, these national parking requirements are not able to determine the demand for parking accurately. This often results in an oversupply of parking, contributing to urban environments being unfriendly to pedestrians, cyclists and transit passengers (Li and Guo, 2014). Additionally, oversupply over parking will increase car use and car ownership (Guo, 2013b) (Christiansen et al., 2017).

## 1.2. Problem definition: visitor parking in Dutch urban areas

Residential parking standards consist of a number of parking spaces required for residents and a number of parking required for visitors of residents (De Gruyter et al., 2020). Visitor parking thereby can be defined by the parking generated by the visitors of residents in a particular residential area. The visitor parking demand then is the number of parking spaces needed in a specific area to accommodate the number of visitors at a specific time. In The Netherlands, the parking requirements are based on the standards determined by the CROW, 'the Platform for transport, infrastructure and public space' (Mingardo et al., 2015) (CROW, 2018a). Based on literature and experiences in the field, they determine standards for different land usage types, such as working, shopping and living. The parking standard for residents is defined based on different local conditions such as the urban zone and housing. For visitor parking, however, the parking standards do not deviate depending on the local circumstances (CROW, 2018a).

Taking local circumstances into account is in line with solutions provided by literature to decrease oversupply of parking due to minimum parking requirements. Johansson et al. (2019) showed that applying lower parking requirements resulted in lower parking demand and the results differed depending on local conditions. Additionally, Litman (2016) and Cuddy (2007) advocate for context-specific standards that account for factors at a certain location. However, none of the researches included visitor parking. Cuddy (2007) developed a method to define 'context-sensitive residential parking standards' (p.44). Due to insufficient data, visitor parking demand was not taken into account. However, he argues that in some areas, visitor parking standards have a significant share in the total residential parking standards and hence recommends doing further research into the usage of visitor parking (Cuddy, 2007, p.133). Moreover, earlier research showed remarkable levels of dissatisfaction among residents with visitor parking (Stubbs, 2002). In addition, in interviews held by Johansson et al. (2019) residents stressed the importance of visitor parking in residential areas.

The research of Spark (2018) showed that the visitor parking standards applied in The Netherlands often exceed the actual parking demand. They found that a visitor parking standard of 0.3 parking spaces per house is more than sufficient to meet the visitor parking demand and could be reduced to 0.1. This implies that also visitor parking standards result in an oversupply of parking. However, since this is based on data of a single city, they recommend conducting further research. Furthermore, also Mingardo (2016) suggests that the supply of visitor parking might exceed the demand. In his research, he showed that in The Hague, 20% of the visitor parking permits was not used. From the studies of Spark (2018), and Mingardo (2016) it can be concluded that also visitor parking has a share in the oversupply of parking. However, literature on this topic is still lacking.

Conclusively different problems regarding visitor parking can be identified. First of all, visitor parking is a highly under-researched topic. Studies focused on residential parking often neglect visitor parking, while various researchers showed that residents attach importance to visitor parking. Additionally, in some cities visitor parking standards have a high share in the total residential parking standard. Currently, in The Netherlands, a fixed parking standard is used without taking context-specific factors into account. This while there is pressure on space. Furthermore, literature shows that residential parking standards should be based on location-specific circumstances rather than on national averages. However, visitor parking is often neglected in these studies. Finally, earlier research showed that the visitor parking standards applied in The Netherlands often are much higher than the actual usage of visitor parking. However, there is a lack of studies that confirm this statement.

### 1.3. Research objective and scope

To build affordable housing and ensure efficient land use, literature recommends to apply context-specific parking requirements. However, literature did not consider this for visitor parking. This while visitor parking was emphasised to be important by residents. Moreover, visitor parking standards applied in The Netherlands showed to be excessive. This suggests that also visitor parking contributes to parking oversupply. Therefore, this research aims to gain more insight into the demand for visitor parking and how this might be affected by local circumstances. This will contribute to a better understanding of how visitor parking standards can be set based on context-specific factors in an area. Since spatial pressure arises in urbanised areas, this research will focus on Dutch urban residential areas.

### 1.4. Research questions

Following the aforementioned research objective and the scope of the research, the main research question is:

*What factors explain the visitor parking demand in Dutch urban residential areas?*

In order to answer the research question, multiple sub-questions are formulated:

1. What different parking policies for visitor parking are being applied in The Netherlands?
2. Which factors theoretically influence the visitor parking demand?
3. What is the parking occupancy in residential areas for visiting purposes?
4. To what extent do these factors influence the visitor parking demand?

To answer the main research question first requires insight into how visitor parking currently is included in parking policy. Furthermore, this requires insight into how visitor parking standards in The Netherlands are currently set. Second, a theoretical perspective on what factors influence the visitor parking demand is needed. Additionally, the occupancy of parking in residential areas and how this occupancy differs during the day has to be determined. Finally, it has to be determined to what extent the identified factors influence the visitor parking demand.

### 1.5. Scientific relevance

Currently, literature on residential parking is limited and the topic lacks research evidence (Guo, 2013a) (Li and Guo, 2014) (Marsden, 2006). Existing literature mainly focuses on the impact of lowering parking requirements on car use and car ownership. However, these researches only looked into household car usage and did not show any evidence on the usage of residential parking. Furthermore, most of the research on the effects of lowering parking requirements focused on the commercial end of journeys such as commercial areas and city centres. This research will contribute to more evidence-based knowledge on the usage of residential parking, especially on visitor parking. These insights can be useful in the development of context-specific parking requirements. This will contribute to a better understanding of how individuals respond to parking policy focused on visitor parking in residential areas. Finally, this research will contribute to a better understanding of the interaction between visitor parking demand and local circumstances.

### 1.6. Societal relevance

From a practical perspective, having insight into the usage of visitor parking in residential areas can help Dutch policymakers and developers. Furthermore, as was argued by Mingardo et al. (2015), strategic plan-

ning of parking becomes more critical and requires better integration of academic knowledge and practical experience. As this research is conducted in close cooperation with Sweco, the gap between the knowledge generated by academics and the knowledge needed by developers can be bridged. Furthermore, in practice, it has been suggested that the currently used CROW standard for visitor parking of 0.3 places per house is too high (Spark, 2018), resulting in excessive parking capacities. This research aims to provide a better indication of the factors that influence the visitor parking demand to help policymakers develop a better rationale of visitor parking standards. Finally, having a better approach towards the usage of visitor parking standards in residential areas will help developers and policymakers in the decision making for more efficient land use and the creation of affordable housing.

## 1.7. Thesis outline

The outline of this thesis is as follows. First, in chapter 2 the used methods will be discussed. Then, chapter 3 elaborates on Dutch parking policy and how these policies consider visitor parking. This will identify the first factors influencing the visitor parking demand. These factors are considered in the development of a conceptual framework, which will also be discussed in chapter 3. Based on this conceptual model, data preparation and data analysis will be conducted in chapter 4. Based on the data collection, preparation and analysis, in chapter 5 the results of a multiple regression model will be discussed. The conclusion of the research will be given in chapter 6. Finally, chapter 7 will reflect on the conceptual framework and discuss the limitations of this research. Furthermore, this chapter will discuss this research's implications for practice and provide recommendations for both practice and further research. Figure 1.1 presents the structure of this thesis and the related research questions that are answered in each chapter.

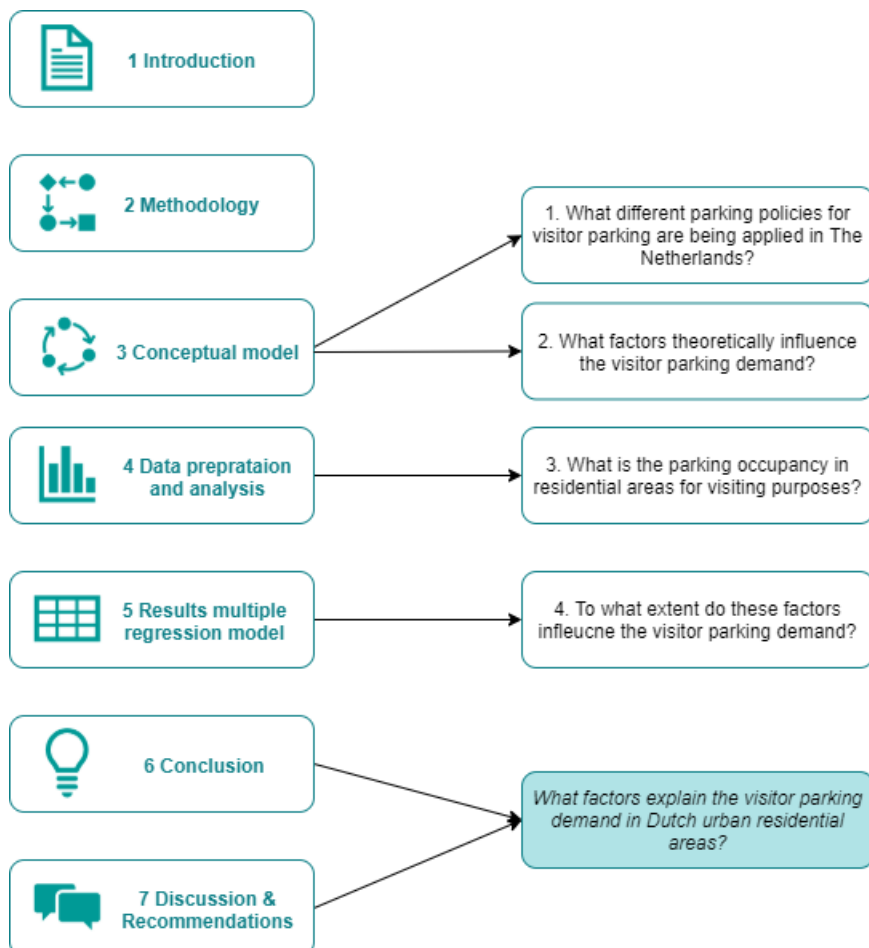


Figure 1.1: Thesis structure

# 2

## Methodology

In order to answer the research questions, different methods are used. This chapter describes the research methodology. Figure 2.1 provides an overview of the different methods that are used and how these help to answer the subquestions. The desk research aims at getting better insight into how visitor parking is based on local parking policies. Two interviews with municipalities test these findings. Furthermore, the desk research will identify the factors that might explain the usage of visitor parking. This is discussed in more detail in section 2.1. The primary method of this research is estimating a multiple linear regression model. This will be introduced in section 2.2. Before estimating a multiple regression model, data collection and analysis is required. The data collection will be discussed in section 2.3. Finally, the results of the study will be validated by case studies. This will be explained in section 2.4.

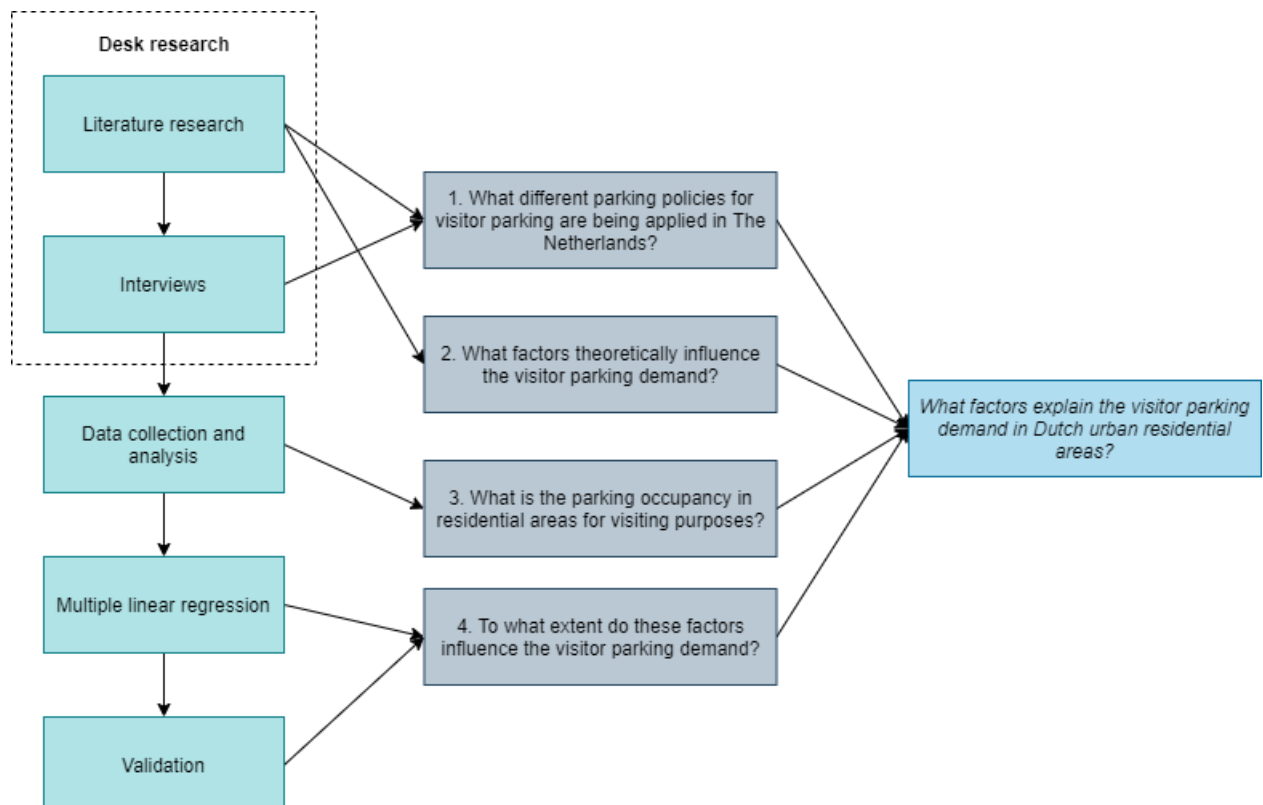


Figure 2.1: Overview methodology

## 2.1. Desk research

The first part of this research consists of desk research. This desk research aims to identify the factors that influence the visitor parking demand in residential areas. Finally, this will result in a conceptual framework indicating how visitor parking depends on different factors. First of all, this requires insight into how residential visitor parking is currently included in parking policies and how current parking standards are determined and applied in The Netherlands. As discussed in chapter 1, parking policy is a local policy, and therefore cities can select the instruments to achieve their policy objectives. Consequently, municipalities' policy documents and white papers will be studied to identify what different policies are used and how this results in different parking standards. These documents are found on websites of municipalities. In addition, this will reveal how visitor parking is included in the local parking policy. The first part of the desk research will be complemented by two interviews with the municipality of The Hague and Eindhoven. The results will provide more insight into how cities apply visitor parking in their parking policy. Consequently, the first part of the desk research will answer subquestion 1.

The second part of the desk research consists of a literature review. This review aims to identify the factors that influence the residential parking demand. Consequently, the literature review will answer subquestion 2. First, travel behaviour will be studied. Second, literature about residential parking demand will be studied. Relevant literature is found by different search engines such as 'Google Scholar', 'Scopus' and the TU Delft Library. Keywords that are used are 'travel behaviour', 'mode choice', 'travel demand', 'residential parking', 'parking demand', 'car ownership', 'car usage', 'built environment' and 'parking policy'. These keywords are combined using boolean operators. The relevance of the search is assessed based on the title, year of publication, number of citations and the publisher. In addition, forward and backwards snowballing is used.

The desk research will be used to develop a conceptual framework. This framework shows how visitor parking is expected to be influenced by different factors. This framework will set the hypotheses on how these factors will affect the usage of visitor parking in residential areas and will be used as the input of the multiple regression model (see section 2.2).

## 2.2. Linear regression models

To determine whether there indeed are relations between different factors and visitor parking usage, a statistical model will be estimated. A statistical model is a probability distribution that enables to draw inferences or make decisions from data (Davison, 2003). Such a model can be used to test or confirm theories (Davison, 2003). To test the identified relations of the conceptual framework, a multiple linear regression model is estimated.

### 2.2.1. Multiple linear regression

Multiple regression is a statistical model used to study the relationship between a single dependent variable and one or more independent variables (Allison, 1999). Multiple regression can be used to predict the dependent variable based on observed values of the independent variables. Furthermore, multiple regression can also be used in causal analysis. This method aims to determine whether a particular independent variable affects the dependent variable and estimate the magnitude of that effect (Allison, 1999). Furthermore, multiple regression allows identifying the individual contribution of each independent variable on the dependent variable (Allison, 1999). Since this research aims to identify how context-specific factors influence visitor parking demand, multiple regression is a suitable method.

Equation 2.1 represents the equation of a regression model. In this equation,  $Y_i$  represents the values of the dependent variable. In this research, this is the number of visitor parking actions in a certain area.  $X_i$  represent the values of the independent variables,  $n$  is the number of gathered observations, and  $e_i$  represents the model error. Finally,  $b_i$  represents the regression coefficient. These coefficients are estimated using the ordinary least squares method (OLS). This method aims to find the coefficients that minimize the sum of the squared deviations of observations (Berry et al., 1985). In other words, it aims to find the coefficients that minimize the difference from the predicted value of the regression model from the observed values.

$$Y_i = b_0 + b_1 X_1 + b_2 X_2 + \dots + e_i \quad \text{for } i=1,2,\dots,n \quad (2.1)$$

### 2.2.2. Assumptions of multiple regression

A regression model relies on several assumptions. Ignoring one of these assumptions might result in incorrect inferences (Aljandali, 2017). First of all, the independent variables should be uncorrelated. If two or more variables correlate, the effect of these variables on Y will be arbitrary, and might specify the regression coefficients wrongly in magnitude and sign (Aljandali, 2017). Second, the residuals in the population should have zero mean and a constant spread of variance about the regression line. This implicates that there is constant variance of the residuals about the regression line in the gathered sample. This is also referred to as homoscedasticity (Aljandali, 2017). Third, residuals should be normally distributed. If this assumption is violated, it might be that the model is more sensitive to a small subset of the data. Finally regression models assume that the residuals are independent and uncorrelated. Several methods exist to solve the violation of the assumptions on homoscedasticity or normality. One of the options is to transform the X and or Y variables by taking the logarithm or rootsquare of the variables (Osborne, 2002).

Graham (2003) provides several options to solve problems due to correlations between independent variables. He argues that multicollinearity can be ignored when the regression model aims to predict the dependent variable. However, this research aims to examine the effects of context-specific factors on the visitor parking demand. Consequently, in this research, multicollinearity is prevented by excluding highly correlated variables from the model. A disadvantage of this method is that it ignores the unique contribution of the omitted variable and thereby can result in a substantial loss of the explanatory power (Graham, 2003). When two variables are correlated, only one will be included. The variable with the strongest relationship with the dependent variable in single linear regression is included in the model.

The multiple regression model is estimated using SPSS. First, for each independent variable, a single linear regression model with the dependent variable is estimated. The results are used in case of high correlations between the independent variables. Second, a multiple regression model is estimated, including all independent variables using the enter method in SPSS. Third, a model is estimated that excludes variables with high correlations. This model is estimated by adding variables to the model one by one. A final model is estimated to determine the impact of outliers in the data.

As part of the data preparation, variables are analysed and outliers are identified. An outlier is an observation that is numerically distant from the rest of the sample in which it occurs (Grace-Martin, 2010). Literature research of Aguinis et al. (2013) show different definitions for outliers. Error outliers include outlying observations caused by not being part of the population of interest. Interesting outliers are valid data points that lie data distance from other data points and may contain valuable or unexpected knowledge. Model fit outliers influence the fit of the model, while prediction outliers affect the model's parameter estimates. Grace-Martin (2010) argues that removing outliers from the data results in a different model outcome. Therefore they recommend keeping outliers if they are not due to measurement errors or a special case isolated from a common phenomenon in the analysis. This is in line with Osborne and Overbay (2004) who suggests that the opinion on removing outliers differs between researchers. The data used in this research contains information about local circumstances. Therefore, the data may be more likely to be representative of the population as a whole if outliers are kept in the data (Osborne and Overbay, 2004). However, to identify whether regression model results will differ, a model that removes several outliers is estimated.

## 2.3. Data collection and analysis

Estimating the regression model requires sufficient data. First, data about the usage of visitor parking has to be collected. Second, since it is expected that the use of visitor parking depends on context-specific factors, data about the building environment and personal characteristics are needed.

### 2.3.1. Visitor parking data

The visitor parking demand is approached by measuring the usage of visitor parking permits. Many Dutch cities have paid parking zones. To make paid parking politically feasible, priority is often given to residents

by parking permits (De Groot et al., 2018). In addition to these permits, also visitor parking permits are provided. These permits offer the possibility for residents living in paid parking areas to buy several parking hours to be used for their visitors. This way, their visitors do not have to pay for on-street parking (Mingardo, 2016, p.76).

This study utilizes the data of the usage of the visitor parking permits in Eindhoven. Eindhoven is chosen since it is one of the bigger cities in The Netherlands. Furthermore, data about the usage of the license was available. Residents in Eindhoven can buy and use the visitor parking permit by an online application. In this app, residents can register the license plate of their visitors at their arrival and deregister the visitors after leaving. The application is provided by Desyde, a Dutch company that develops and hosts integrated parking applications for municipalities (Mobiliteitsplatform, n.d.). Consequently, they collect data about the usage of the visitor parking permit.

The data provided by Desyde contains information about the usage of parking permits in Eindhoven. In Eindhoven, residents living in paid parking zones can request a visitor parking permit. These areas are shown in blue in Figure 2.2 (Eindhoven, n.d.b). The visitor parking permit offers 200 parking hours per quarter and costs €40, equal to €0.20 per hour. The visitor parking permit only has to be used during the paid parking time window between 9 a.m. and 9 p.m. (Eindhoven, n.d.a).

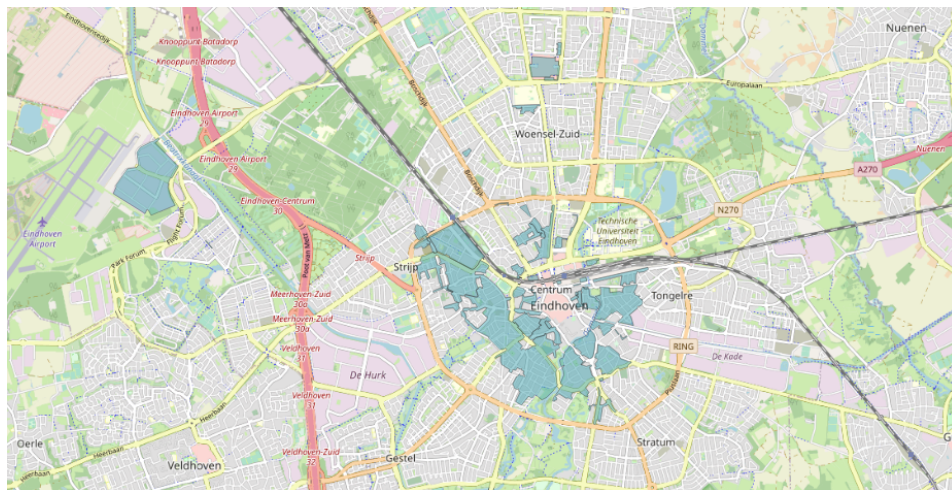


Figure 2.2: Parking zones with residential (visitor) parking permits in Eindhoven

The parking data are analysed by the parking characteristics defined by Parmar et al. (2020). These include the parking accumulation, volume, occupancy factor, average duration, and peak saturation. For each of the parking zones the parking accumulation is studied. The parking accumulation is the total number of vehicles parked at a particular interval of time. An accumulation curve generally represents this, showing the variation in the parking accumulation for a given parking facility over a specified period (Parmar et al., 2020). This will provide insight into how the parking demand in specific areas differ over the day and will reveal differences between regions. Subsequently, this will answer sub-question 3.

### 2.3.2. Context specific data

Besides data about the number of visitor parking, also data about the context are needed. Multiple sources will be used to collect this data. The literature research in chapter 3 will identify the factors that may influence the usage of visitor parking. Data representing these factors will be collected from the Centraal Bureau voor de Statistiek (CBS), the Basisadministratie Adressen en Gebouwen ('basic registration addresses and buildings')(BAG), the open data source of the municipality of Eindhoven and OpenStreetMap, and is supported by Qgis. Qgis is an open-source geographic information system (GIS) that enables to gather, manage and analyse data. GIS allows integrating different types of data and visualising data on a map (Esri, n.d.). Various applications are available to work with GIS systems. Qgis is chosen since it is an open-source application. OpenStreetMap is used as it is an open data source that is easily accessible. OpenStreetMap enables identifying bus stops, train stations, (underground) parking, bicycle lanes, bicycle storage, shared cars, and many

more. OpenStreetMap is an open data source aiming to provide open map data (OpenStreetMap, n.d.)

## **2.4. Validation of regression model**

Small case studies will be conducted to validate the results of the regression model. Validation of the results is a necessary step that is needed to confirm that the regression model produces the right results. Mayer and Butler (1993) argue that validations compare the model's predictions with real-world situations to determine whether the model is suitable for its intended purpose. Therefore, in this research, case studies compare the model results with the actual situation in real life. A case study is chosen since this allows to go beyond the quantitative statistical results and understand the behavioural conditions in real life (Zainal, 2007). Yin (2009) argues that case studies allow explaining, describe or explore phenomena in everyday contexts. Furthermore, Tellis (1997) states that case studies can help to explain the process and outcome of a phenomenon through comprehensive observation, reconstruction and analysis of the cases under investigation. To conduct a case study, often a small geographical area is selected as a subject of study (Zainal, 2007).

In this research, four different postcodes in Eindhoven will be analysed, which consists of analysing the local conditions at these postcodes. The postcodes are selected based on the number of parking actions. A case with a high number of parking actions, a low number of parking actions and two areas with about the same number of parking actions will be observed. The local conditions at these postcodes are observed by Google StreetView, and the demographic is analysed by the data that was collected from the CBS. By observing local conditions of different areas, the effects of the factors identified in the regression model can be put in perspective, and thereby the results of the regression model can be confirmed.

# 3

## Conceptual model

This chapter will develop a framework that indicates the factors that may influence visitor parking demand. First, this requires analysing how visitor parking is considered in Dutch parking policies and how visitor parking standards are currently set. This will identify the factors that are already considered when determining the parking standards. Second, a literature review will identify what factors impact residential parking demand. Finally, the results of this review will be used to construct a conceptual framework of the factors influencing visitor parking demand. Consequently, this chapter will answer subquestions 1 and 2.

### **3.1. Parking standards in The Netherlands**

This section provides insight into the development of Dutch parking policies and how municipalities deal with these policies. As will become clear, municipalities used to rely on the CROW parking requirements. These standards already consider different factors that influence the usage of parking. Finally, since this research is about visitor parking, visitor parking will be discussed. This will provide insight into how municipalities deal with visitor parking in their parking policies and how visitor parking standards are determined. The insights from this section can be used to develop the conceptual framework on visitor parking demand.

#### **3.1.1. Dutch parking policy**

As discussed in chapter 1, parking policy in Europe changed from demand-driven to integrated parking policy. This is also the case for The Netherlands, where four different parking evolution periods can be distinguished (Stienstra, 2011, p.7). Before the '60s, parking policies were focused on supplying sufficient parking to meet the demand. Increased car ownership, however, resulted in problems concerning the liveability of cities. This is when the first parking regulation shows up (Mingardo, 2016). First, this only included parking regulations on where can be parked and where this is prohibited. In addition, time restrictions were used to maximize the number of visitors in city centres by the usage of blue zones. Later, also paid parking was introduced (Mingardo et al., 2015) (Stienstra, 2011). From the '70s, municipalities were required to write a parking plan (Stienstra, 2011). This resulted in a balanced combination of different parking measures. Furthermore, in 1986 the first parking standards were set by the Ministry of Transport. These standards were part of the 'A-B-C planning policy' and attempt to create a national parking policy (Mingardo, 2016). However, the resistance against this national policy is high (Stienstra, 2011). Local authorities wanted to have more freedom to set their own parking standards. From 1994, the execution of the parking policy is therefore entirely in the hands of the municipality. Later, also the national parking standards were released. Nowadays, municipalities are entirely in charge of the parking policy (Stienstra, 2011) and can set their own parking standards (de Wit, 2005).

Parking supply is part of the mobility system and can influence the accessibility of a city (Kansen et al., 2018). Parking policies thereby can help to stimulate or discourage car usage. Following Kansen et al. (2018) municipalities often choose between the liveability of their city or the economic attractiveness of their city. Creating livable cities often result in less parking, while economic attractiveness puts more emphasis on the accessibility of the city, including sufficient parking (Kansen et al., 2018). The Hague, for example, wants to create a more livable city. Thereby, their new parking strategy focuses on the reduction of parking pressure (see

Appendix B). Eindhoven clarified that liveability and accessibility are a dilemma. To create liveable cities, parking standards should be reduced. However, the coalition also wants the city to be accessible. This makes it hard to reduce the parking standards. Especially visitor parking standards are hard to reduce (Appendix B). This clearly shows that there is a dilemma between the liveability and accessibility of the city.

Interviews with The Hague and Eindhoven confirmed the evolution from demand-driven to more steered policy (see Appendix B). Before 2011 the primary goal of The Hague was to satisfy the parking by applying the CROW parking requirements. In 2010 the municipality researched car ownership for different housing types and used the outcomes to develop a new parking policy in 2011. However, a new parking policy is currently developed to allow more flexibility and deviation from the parking standards. This allows developers to reduce the required parking when alternative modes are made accessible in newly developed areas. This change to more flexibility is also seen in Eindhoven. In 2013 they published a new parking policy document. Before this time, their parking policy was mainly demand-driven, which resulted in high parking standards. As a consequence of these high standards, many development projects failed. To solve this problem, parking standards were revised by introducing discounts on the parking standards when other mobility solutions are implemented. These mobility solutions include, among others, good accessibility to public transport, shared cars, and shared bikes. This flexibility is also seen in other municipalities such as Delft (Delft, 2018), Leiden (Leiden, 2020), Den Bosch (Berenschot & Sweco, 2021) and many other municipalities.

The introduction of reductions on the parking standards implies a relation between the accessibility of an area and parking demand. Furthermore, the interviews reveal that there is a relation between car ownership and parking demand. These relations will be dealt with in more detail in subsection 3.1.2 and section 3.2.

### 3.1.2. CROW parking standards

Parking policy is often part of the overall mobility policy (Kansen et al., 2018). After setting the parking policy, municipalities determine the parking standards (PublicSpaceInfo, 2013). The interviews revealed that the former parking policies used the CROW standards to determine the parking standards (see Appendix B). This section will explain how the CROW determines the parking requirements. It is important to note that the CROW recommends adapting the requirements based on the local conditions of the municipality since the CROW requirements are based on average cases (CROW, 2018a). In practice, however, municipalities often use the parking standards of the CROW without considering their own parking policy goals and required capacity (Kansen et al., 2018). Especially in areas suffering from a shortage of space, this can result in overcapacity of parking and therefore parking is unoccupied.

Based on literature and experiences of municipalities, the CROW defines parking requirements for multiple destinations and activities (CROW, 2018a). These include, among others, living, shopping, education, restaurants, sports facilities. However, this research will only discuss residential parking requirements. These consider four different factors that influence the parking generation and hence the parking demand in residential areas: the accessibility of the residential area, the specific characteristics of the residential area, the mobility characteristics of the residents and the parking policy.

#### Accessibility of the area

The CROW numbers assume that the location of the area determines the parking demand. In city centres, lower parking demand and parking generation are expected. In outer suburbs, parking demand and traffic generation are predicted to be higher. This can be explained by the fact that outer suburbs, in general, are less accessible by other transportation modes and car-oriented (CROW, 2018a). Hence, they distinguished three different zones in urban areas:

- Inner city
- Inner suburbs
- Outer suburbs

Furthermore, urban density influences the accessibility and service level of other transportation modes. Therefore, urban density impacts the parking demand indirectly. Consequently, the CROW describes the parking requirements based on five different density classes (CROW, 2018a).

- Extremely urbanised: more than 2.500 addresses per  $km^2$

- Strongly urbanised: between 1.500 and 2.500 addresses per  $km^2$
- Moderately urbanised: between 1.000 and 1.500 addresses per  $km^2$
- Hardly urbanised: between 500 and 1.000 addresses per  $km^2$
- Not urbanised: when there are less than 500 addresses per  $km^2$

#### **Area-specific characteristics**

'Area-specific characteristics' determine the number of traffic attracted by the area (CROW, 2018a). These factors thereby can determine the parking generation and hence the parking demand.

#### **Mobility characteristics of users/visitors**

CROW (2018a) argues that mobility characteristics of users impact the number of parking needed and the parking generation. They distinguish different motifs that will result in more or less car usage and consequently more or less parking generation. For example, since students have access to free public transport, student housing will generate lower parking demand.

#### **Parking policy**

As previously described, parking policy has a significant impact on the required number of parking spaces. In addition, the parking policy can contribute to achieving other goals. Local authorities determine these policies.

### **3.1.3. Determine required amount of parking for residential areas**

To determine the total required number of parking places in a certain area, one could take the following steps (CROW, 2018a):

1. Determine the function of the facility. In this research this is 'living'.
2. Determine the urban area. For example, the inner city.
3. Verify the degree of urbanisation.
4. Determine the size of the facility. For this research, this is the number of housing.
5. Find the key number that belongs to the project based on the earlier defined characteristics.

The parking requirements are defined for different housing types. These are categorised by rental housing and owner-occupied housing. For owner-occupied housing, low-price, average and expensive housing are used. For rental housing, a distinction is made between the private rental sector and public housing. Furthermore, housing prices are defined by expensive, middle, and cheap houses. These prices should be observed from a regional perspective. For example, an expensive house in one region can be classified as middle in another region.

Table 3.1 presents one of the numerous tables with parking standards determined by CROW (2018a). It shows the parking standards for owner-occupied, detached houses for multiple zones and degrees of urbanisation. This suggests that there are relations between different factors and the required number of parking. The CROW provides for every type of housing a table with parking standards, depending on the urban zone and urban density. The parking requirements differ for each of the housing types. Nonetheless, the parking requirement for visitors is 0.3 parking spaces per household except for student housing. Therefore in subsection 3.1.4 the consideration of visitor parking in parking policy will be discussed.

<i>Owner-occupied, detached house</i>								
<b>Parking standards</b>								
	Center		Inner suburbs		Outer suburbs		Buitengebied	
	min.	max.	min.	max.	min.	max.	min.	max.
Extremely urbanised	1,0	1,8	1,2	2	1,5	2,3	1,7	2,5
Strongly urbanised	1,1	1,9	1,3	2,1	1,6	2,4	1,8	2,6
Moderately urbanised	1,3	2,1	1,4	2,2	1,7	2,5	1,8	2,6
Hardly urbanised	1,3	2,1	1,6	2,4	1,8	2,6	1,8	2,6
Not urbanised	1,3	2,1	1,6	2,4	1,8	2,6	1,8	2,6

**Share of visitor parking: 0,3**

Table 3.1: Example parking standards defined by CROW for owner-occupied detached housing (parking standards are given as the number of parking space per house)

### 3.1.4. Visitor parking in Dutch municipalities

The residential visitor parking standards of the CROW (2018a) do not differ for different housing types, urban zones and urban densities. Interviews with the municipality of The Hague and Eindhoven were held to gain insight into how visitor parking is embedded in residential parking policies. A summary of these interviews is given in Appendix B. Furthermore, policy documents of other municipalities are studied.

Municipalities experience that visitor parking is hard to include in the general parking policy and to determine visitor parking standards in the same way as regular parking standards. First, because data about the visitors' car ownership and car use is lacking. Second, because of the political feasibility of reducing visitor parking standards. Furthermore, Eindhoven faces that there is sufficient space available in the zones outside the centre. This makes it hard to have a proper foundation to reduce visitor parking standards. Besides, there is no political support to lower the visitor parking standards, showing that the parking policy is strongly dependent on politics. The Hague also mentioned the political feasibility. They face problems with reducing visitor parking standards since politicians want to offer sufficient parking to residents. Therefore, residents also consider (visitor) parking permits as a prerogative good, which makes it harder to change the policy regarding these (visitor) parking permits.

Currently, The Hague is developing a new parking policy that includes revising the visitor parking policy. While the visitor residential parking standards used to be derived from the CROW parking standards, the new visitor parking standards are based on the publication of Spark (2018). Additionally, in line with the traditional residential parking standards, the visitor parking standards will be based on the location and housing size. The municipality states that the post-war zone is hard to access by public transport and therefore expects that this part of the city will be accessed by car, resulting in more visitor parking demand. The other zones, pre-war and centre, will have lower visitor parking standards. Furthermore, they consider that smaller apartments will have fewer visitors than big family houses (see Appendix B).

These considerations are in line with the visitor parking standards of other municipalities, which are provided in Table 3.2. It is important to note that since the new standards of The Hague are not yet publicly published, the number in the table represents the visitor parking standard determined in 2013. The table shows that many municipalities use the requirements provided by the CROW. The CROW suggests a parking standard of 0.3 parking spaces per household, except for student housing for which a standard of 0.2 is advised (CROW, 2018b). However, some municipalities also differentiate their parking standards based on the urban zone. For example, Zoetermeer distinguishes three different zones. These zones are based on the urban zone and the car dependency, which is dependent on the accessibility to high-quality public transport, the cycling facilities (dependent on the distance to the city centre) and the proximity of facilities such as shops (Gemeente Zoetermeer, 2019). This distinction is also seen in Almere, where zones are distinguished based on the number of facilities and the distance to train and bus stops (Gemeente Almere, 2020). However, they argue that it is hard to come up with a good standard since the car ownership of visitors can not be used as a proxy for the parking demand (Gemeente Almere, 2020). In Breda, visitor parking standards are based on the observed usage of the visitor parking permit in different areas. They found that the use of this permit differs in the

three different zones that they distinguished. This results in a standard of 0.1 parking spaces per house in the city centre, while in residential areas with a higher distance from the city centre, the standard is 0.3 parking spaces per house (Gemeente Breda, 2021). In contrast, Amsterdam established one visitor parking standard that applies in every zone of the city, while the regular standard differs in three different zones (Amsterdam, 2017). Den Bosch argues that although different projects might be in the same zone, local conditions can still differ (Berenschot & Sweco, 2021). Therefore, they introduced reduction factors that can be used when development projects are within a certain distance of the train station and a parking facility within a certain distance. Furthermore, their parking standards differ based on the housing characteristics, especially the surface of the housing (Berenschot & Sweco, 2021).

The interviews and policy documents reveal a change from using the CROW parking standards to determine the visitor parking standards based on local conditions. Some municipalities distinguish different zones and derive different standards based on the characteristics of these zones. This implies that municipalities expect visitor parking demand to depend on the urban zone and the accessibility of the zones by cars and other modes of transportation. Furthermore, since Den Bosch differs their visitor parking standards for different housing surfaces, this also might be a factor affecting the visitor parking demand. These factors can be used in the development of the conceptual framework in section 3.3.

Table 3.2: Visitor parking standards in Dutch cities

Municipality	Visitor parking standard	Explanation
Amsterdam (Amsterdam, 2017)	0.1 per house	Visitor parking standard same for each type of housing and every area. Only for new development projects. Regular standard based on car-ownership, household/housing size.
Delft (Delft, 2018)	<ul style="list-style-type: none"> <li>• 0.1 Within city center</li> <li>• 0.2 inner suburbs</li> <li>• 0.3 outer suburbs</li> </ul>	So different standards for visitor parking distinguished based on the urban zone. For normal residential parking the parking standards depend on the size of the housing and the urban zone.
Zuidplas (Zui)	<ul style="list-style-type: none"> <li>• 0.2 in 'Zone A'</li> <li>• 0.3 in 'Zone B' and 'Zone C'</li> </ul>	The visitor parking standard differs per zone. This is based on the accessibility of the zone by public transport and bike.
Utrecht (Gemeente Utrecht, 2020)		Reduced parking standards in paid parking zones. The parking areas are divided in three different zones; ABC. These zones are based on the accessibility of the zone by public transport and bike, the land-use mix and the usage of the public space?
Leiden (Leiden, 2020)	<ul style="list-style-type: none"> <li>• 0.1 Inner city</li> <li>• 0.1 Inner suburbs</li> <li>• 0.2/0.3 Outer suburbs</li> </ul>	The municipality of Leiden determines the parking standards based on the car dependency of the zone. This car dependency is based on the accessibility and service level of public transport, the accessibility and quality of the zone by bike, the proximity of other facilities and the characteristics of the residents and other people such as employees and visitors of the area.
Den Haag		The new standards are not published yet.
Almere (Gemeente Almere, 2020)	<ul style="list-style-type: none"> <li>• 0.15 in 'Zone A'</li> <li>• 0.20 in 'Zone B'</li> <li>• 0.30 in 'Zone C'</li> </ul>	The zones are based on the car dependency. This car dependency is based on the accessibility to public transport, the cycling facilities and the proximity of other facilities such as stores, schools, hospitals, etc.
Hilversum (Hilversum Mediastad)	0.3 or 0.2 depending on type of housing	Derived from standards of CROW.
Den Bosch (Berenschot & Sweco, 2021)	Differs between 0.1 and 0.3	Differentiates based on the floorspace and the urban zone.
Breda (Gemeente Breda, 2021)	<ul style="list-style-type: none"> <li>• 0.3 per 100m<sup>2</sup> floor space</li> <li>• 0.2 per 100m<sup>2</sup> floor space for studenthousing</li> </ul>	Parking standards are defined per zone, but not for visitor parking.
Tilburg (Swaans and Kypers, 2017)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Apeldoorn (Gemeente Apeldoorn, 2019)	0.25	They use the average of the min and max values of the CROW.
Haarlem (Gemeente Haarlem, 2015)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Enschede (Gemeente Enschede, 2017)	0.3 or 0.2 depending on type of housing	Their parking nota states that in some cases it is possible to ignore parking standards for visitor parking and therefore these are not considered in these areas.
Amersfoort (Gemeente Amersfoort, 2020)		
Zaanstad (Gemeente Zaanstad, 2016)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Zoetermeer (Gemeente Zoetermeer, 2019)	<ul style="list-style-type: none"> <li>• 0.15 in zone A</li> <li>• 0.2 in zone B</li> <li>• 0.3 in zone C</li> </ul>	Besides the differences between housing type, they also take specific target groups and their car dependency into account. They make a distinction between stacked and non-stacked housing.
Leeuwarden (Gemeente Leeuwarden, 2015)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Maastricht (Gemeente Maastricht, 2017)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Edo (Gemeente Ede, 2019)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Alphen aan den Rijn (Gemeente Alphen aan den Rijn, 2020)	0.3 or 0.2	Depends on floor surface and housing type.
Westland	0.3	Derived from standards defined by CROW. They deviate from this numbers by neglecting the attendance rate for residents and visitors. This rates is already corrected for in the parking standards. Furthermore they state that the visitors are dependent on the target group.
Alkmaar (Gemeente Alkmaar, 2017)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Venlo (Gemeente Venlo, 2007)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.
Deventer (Gemeente Deventer, 2013)	0.3 or 0.2 depending on type of housing	Derived from standards defined by CROW, they use minimum standards.

### 3.2. Factors influencing residential parking demand

In section 3.1 it was shown that the residential parking requirements consider different factors that influence the required number of parking. These include the urban zone, urban density and the type of housing. However, these factors were not considered for the visitor parking. Nonetheless, the interviews and policy documents showed that different municipalities base new visitor parking standards on various factors such as the urban zone and housing surface, although most municipalities still use the visitor parking requirements of the CROW. This section will identify the factors that influence residential parking demand, suggested by the literature. The results of this section will be used to define the factors that are expected to influence the visitor parking demand in section 3.3.

Mode choice is very important in relation to the residential parking demand. Only if people choose to travel by car they will generate parking demand. The mode choice depends on the individual characteristics of the traveller, the journey type, the perceived service performance for each mode and situational variables (Beirão and Cabral, 2007). These situational variables can be related to the built environment (Ding et al., 2017). They argue that travel mode choice behaviour is directly influenced by the built environment, car ownership, travel distance and socio-demographic factors. Dieleman et al. (2002) describe that travel behaviour is influenced by personal and household characteristics and the residential environment. They argue that car ownership is the most important personal characteristic that determines car use; 'if people own a car, they use it' (p.18). This is in line with Van Acker and Witlox (2010). In their research, they used car ownership as a mediating variable. They argue that ignoring car ownership as a mediating variable will likely overestimate car use. Therefore, they recommend not only focusing on policies that reduce car use but also on car ownership (Van Acker and Witlox, 2010). This is illustrated in Figure 3.1.

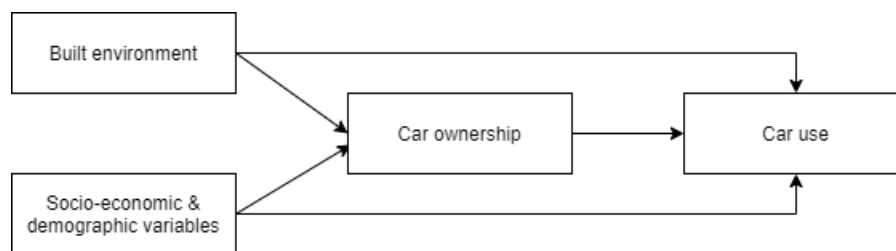


Figure 3.1: Relation car ownership and car use (source: Van Acker and Witlox (2010))

Car ownership generates parking demand as each car has to be parked before and after any activity. Ninety-five per cent of the time cars are parked, in most cases at home or work (Shoup, 2017). According to Silva et al. (2021) car ownership is even one of the most important aspects influencing parking demand. As the number of vehicles grows, the need for parking space and therefore parking demand increases as well (Parmar et al., 2020). Additionally, chapter 1 showed that more parking automatically results in increased car ownership and car usage. As parking demand is strongly dependent on the number of cars, and therefore car ownership, these relations can be used to determine the parking demand. This is in line with Van de Coevering et al. (2008), who argue that the car ownership of residents determines residential parking demand. Furthermore, in previous studies car ownership was often used as a proxy for parking demand (De Gruyter et al., 2020), (Kelly and Clinch, 2006) (Chaturvedi, 2012). This implicates that the overall parking demand is dependent on car ownership in an area.

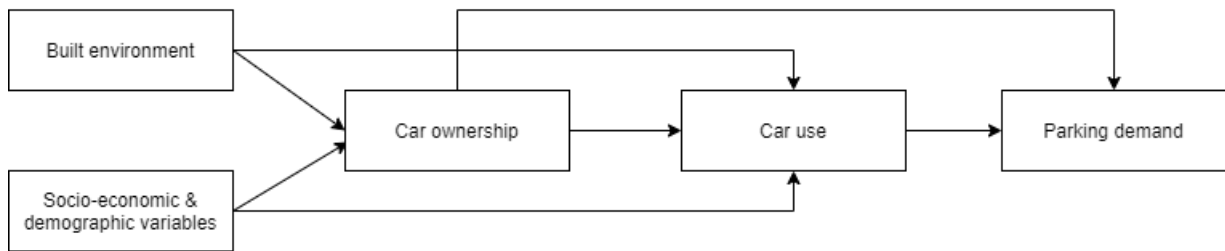


Figure 3.2: Relation between car ownership, car use and residential parking demand

Figure 3.2 shows how parking demand is influenced by car ownership and car use. This figure indicates that car ownership influences the visitor parking demand both directly and indirectly by car use. Since car ownership and car use are influenced by the built environment and socio-economic- and demographic factors parking demand is indirectly influenced by these factors. In addition, De Gruyter et al. (2020) argue that the so-called 7D's defined by Cervero and Kockelman (1997) and Ewing and Cervero (2010) impact the car ownership and the residential car parking demand. These factors can be described as follows:

- Density: Population density
- Diversity: Land use mix
- Design: The intersection density or the quality of walking/cycling environment
- Destination accessibility: The distance to the Central Business District and the job accessibility
- Distance to transit: Distance to nearest station/stop
- Demand management: Parking policies
- Demographics: Age, income

Other studies identified different factors which are related to these factors. Litman (1995) described three different categories of factors that influence car ownership and subsequently parking demand which include demographic factors, geographic factors and management factors. Parmar et al. (2020) consider that the parking demand also depends on the parking choice. The parking choice is influenced by social, economic and environmental factors (Parmar et al., 2020). This is in line with other studies. For example, Ruisong et al. (2009) studied the drivers' parking choice behaviour when choosing on-street or off-street parking. They suggest that the parking location choice depends on the characteristics at the parking location, the travellers' characteristics and the trip characteristics. The parking location characteristics include the parking fee, walking time and safety, while travellers' characteristics relate to age, gender and income. Besides, policy factors such as parking restrictions, parking costs, and parking permits are considered factors that influence parking demand. An overview of these studies is given in Appendix C.

Finally, in line with the earlier defined 3 D's, factors related to the built environment influence parking demand. These are referred to as geographic factors and include factors such as the urban zone, the land use mix, the accessibility to public transport, the population- and urban density and many other factors (see Appendix C). Schwanen et al. (2002) argues that for leisure activities, socio-demographic variables determine rather than residential context whether or not a person engages in leisure activities by car. Therefore, this might also apply to visiting residents.

Most of the identified factors are in line with the 7D's. In this research, the factors influencing residential parking demand are categorised into three categories: policy-related factors, geographic factors, and demographic factors. An overview of these factors is represented in Table C.1 in Appendix C. The following subsections will describe how these factors can be related to parking demand.

### 3.2.1. Socio-demographic factors

Different demographic factors influence car ownership, car use, and indirectly residential parking demand. Van Acker and Witlox (2010) consider four different socio-economic and demographic factors influencing car ownership and car use. These include age, gender, income and household size. This is in line with Ruisong et al. (2009), who identified age, gender, and income as influential factors. Ding et al. (2017) add the population density and the number of children within a household as factors influencing the residential parking

demand.

Parking demand is influenced by the number of inhabitants in the residential area. More inhabitants result in increased car ownership. In literature, this relation is described through the household size. Litman (1995) showed that car ownership increases with bigger household size. In addition, car use increases with increasing household size (Yao et al., 2016). Furthermore, Ding et al. (2017) proved that the number of children per household is significantly associated with less car ownership. The most important reason is that children cannot have driving licenses. Besides, they found that people in the middle-aged group have significantly higher car ownership than younger and elder people (Ding et al., 2017). This is in line with the findings of Harms (2008), who saw that in 2005 in The Netherlands car was most used by people older than 25, while the group of people older than 65 used cars less frequent. In addition, the car travel distance of the elderly in general is shorter compared to younger car users (Van Acker and Witlox, 2010). Men and women show different car ownership and car usage levels (Harms, 2008). Men use cars more often than women while women are more frequent users of public transport and bicycle (Harms, 2008). He also explains that women between 30 and 40 with children also use bicycles more often. Van Acker and Witlox (2010), however, debate that there are mixed findings on the relationship between gender and car ownership and usage. In general, they state that women commute more by public transit, bike, or foot while car usage for commuting tends to be higher among men. This is in line with the earlier studies. However, they also suggest that some studies explained that women use cars more often to fulfil household maintenance tasks. Furthermore, in literature, there is a contradiction in the presence of children. Schwanen et al. (2002) argue that households with children have higher car ownership levels while Ding et al. (2017) argue that children are associated with lower car ownership. This difference is due to how the presence of children is measured. The research of Ding et al. (2017) compared the car ownership among different age groups to determine car ownership, while Schwanen et al. (2002) looked into the car ownership of different households, with and without children. Subsequently, households with children are expected to have higher car ownership, while within the age group of children, car ownership is expected to be low.

Another relation found in literature is the effect of household income. Yao et al. (2016) found that the car purchasing demand in Beijing increased as a result of increasing incomes. This is also suggested in other studies. De Groote et al. (2018) argue that income is a perfect predictor of car ownership. Lower incomes are expected to have lower car ownership (Rowe et al., 2011) while higher incomes have a higher likelihood of purchasing cars (Li and Zhao, 2017). Furthermore, income is related to education and employment status (Van Acker and Witlox, 2010). Highly educated persons are more likely to obtain more specialized jobs, often involved in more long-distance commuting and more car use. As these variables are related, it will result in comparable results (Van Acker and Witlox, 2010).

Figure 3.3 visualizes the relations found in the literature. The red arrows represent direct relations between factors and the residential parking demand. Car ownership is influenced by household size, gender, age, number of children, household income, and the average level of education. Car use is influenced by household size, gender, age, and level of education. Furthermore, it has been argued in the literature that household income and education level are strongly related. This relation will result in the same levels of car ownership and car use. In addition, the number of children is related to the household size.

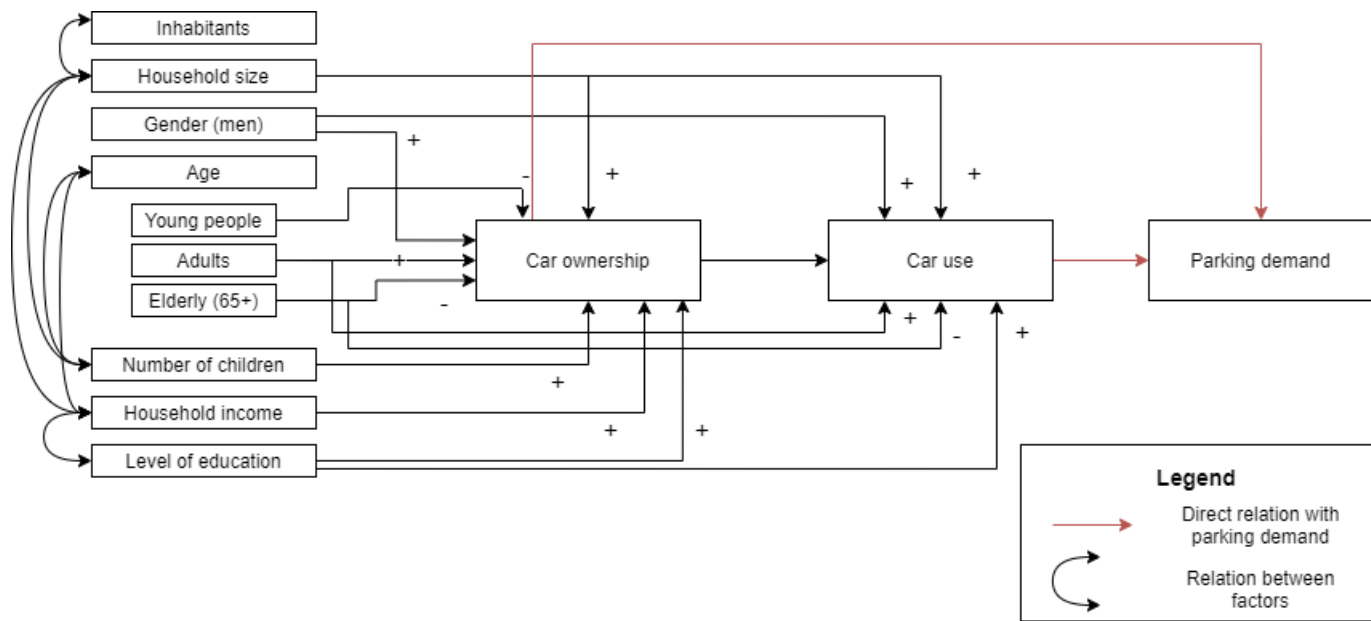


Figure 3.3: Relation between demographic factors and parking demand

### 3.2.2. Geographic factors

As previously discussed, literature often relates parking demand to the 7D's. Furthermore, CROW (2018b) indicated that the urban zone and the urban density affect the parking generation and the required number of parking. Also, the Institute of Transportation Engineers (ITE) uses the urban zone as one of the factors that predict parking demand. In addition, they use the building height and the day of the week to predict the parking demand for residential apartment buildings per dwelling unit (Ghuzlan et al., 2016). These findings indicate a relation between the building environment and the residential parking demand. Therefore, this subsection will explain how the built environment influences the parking demand.

#### Urban density and urban zone

The built environment consists of different measurements, including diversity, density, distance to transit, and destination accessibility (De Gruyter et al., 2020). The density can be quantified both by residential density and employment density (Yin et al., 2018). Different studies showed that higher population density is associated with lower car ownership and car use and subsequently parking demand (Litman, 1995), (Ding et al., 2017) and (Chatman, 2013). Ding et al. (2017) holds the same relation for employment density. Another measure is the urban density, expressed as the number of addresses or buildings per square kilometer (Christiansen et al., 2017), (Ostermeijer et al., 2019), (Engel-Yan and Passmore, 2010). Higher urban densities have lower car ownership levels, possibly because of the availability of alternative modes in dense areas (Ding et al., 2018).

The ITE indicates a relation between the parking demand and the urban zone. In the inner city, they suggest implementing lower standards as a result of lower parking demand. In the outer suburbs, the parking demand is generally higher, resulting in higher parking standards (Ghuzlan et al., 2016). Furthermore, also the land use mix determines car ownership and car use. Baldwin Hess and Ong (2002) proved that the probability of owning a car decreases with the land-use mix changing from homogeneous to diverse. This is due to the commuting distance that is reduced in areas with high land-use mix (Ding et al., 2018). The land use mix can be quantified by the degree of balance across residences, services and commerce, recreation and tourism, and regional and local industry (Van Acker and Witlox, 2010).

#### Land use mix

The findings on the density and diversity apply to residential parking. However, for visitor parking, it can

also be argued that higher densities and land use mix will attract more visitors. Nonetheless, as suggested by Ding et al. (2018), mixed land use also provides the opportunity to use other modes of transport. In addition, high urban densities make it hard to own a car due to lacking parking facilities (Ding et al., 2018). In literature, parking supply is shown to be a strong determinant of household car ownership and use and hence residential parking demand (Guo, 2013a) (Chatman, 2013), (Parmar et al., 2020), (Tong et al., 2004), (Cervero et al., 2010). Furthermore, home parking limitations will help to reduce households' car usage (Guo, 2013b). Additionally, car use can also be decreased by the increased distance between the home and home parking space (Christiansen et al., 2017). With higher walking distances, people are more willing to change modes, especially in dense urban areas. Therefore literature recommends increasing the distance between parking and home in such a way that parking access is at least as far as the distance between the home and the nearest public transport stop (Christiansen et al., 2017). Finally, factors such as the availability of a good bus service, smaller and rental housing, more jobs, residents, and stores within walking distance proved to reduce the parking demand (Chatman, 2013).

#### **Accessibility to public transport**

Ottosson et al. (2013) argue that areas well served by public transport and increased parking prices car use will decrease. This is in line with Sen et al. (2016), who observed that parking demand decreased significantly when the transit accessibility index increased. Litman (1995) showed that households living within 300 meters of a railway station owned on average fewer vehicles than households living more than 1000 meters from the station. Rowe et al. (2011) hypothesized that higher levels of transit service would yield a lower parking demand for multifamily residential developments in urban centres. Ding et al. (2017) used this hypothesis in his research by measuring the straight-line distance from the household's residence to the nearest transit stop. The results showed that households with a shorter distance to transit would own fewer cars. Besides, the likelihood to own a car increases when people live further away from transit stops. All in all, this indicates a relation between the accessibility to transit and the parking demand.

#### **Housing**

Finally, CROW (2018b) considers housing characteristics to influence the parking demand. This is in line with the literature. Chatman (2013) argues that smaller and rental houses produce less parking actions than bigger and owner-occupied houses. This is strongly related to residents' age and income as young people with lower income, and fewer children will live in rental and smaller housing produces less parking actions (Chatman, 2013). Besides, Willson and Roberts (2011) showed that year of construction also influences the parking demand: new houses showed to generate more parking. However, the year of construction proved to be highly significant with household income, and therefore he concludes that parking demand increases with higher income. These results are in contrast to the findings of Chatman (2013). He suggests that new houses near stations resulted in lower parking demand, although this might also be explained by residential self-selection. Furthermore, from the National Household Travel Survey in 2009, it becomes clear that single-family detached houses produce on average more trips than single-family attached houses, which produce more trips than apartments. This confirms the relationships already identified by CROW (2018b). Finally, Ghuzlan et al. (2016) showed that besides the building age, also the gross floor area of buildings increase the parking demand significantly. In addition, they found that the housing price also influences the parking demand. Nonetheless, it is expected that this is correlated with household income: higher incomes are more likely to live in expensive housing.

#### **Conclusion geographic factors**

Figure 3.4 shows how the factors identified from the literature review are related to car ownership, car use and residential parking demand. It can be seen that there is a direct relation between the parking supply and the parking demand. Furthermore, density and land diversity factors determine car ownership and car use and thereby the parking demand. Moreover, the accessibility to other modes of transportation, the parking and shops and restaurants are considered to influence the parking demand, while also factors related to housing influence car ownership and car use. In this figure, the housing price represents not only the value of the property but also whether the property is owner-occupied or rental. Furthermore, relations between the geographic variables exist. These will be taken into account when estimating the regression model.

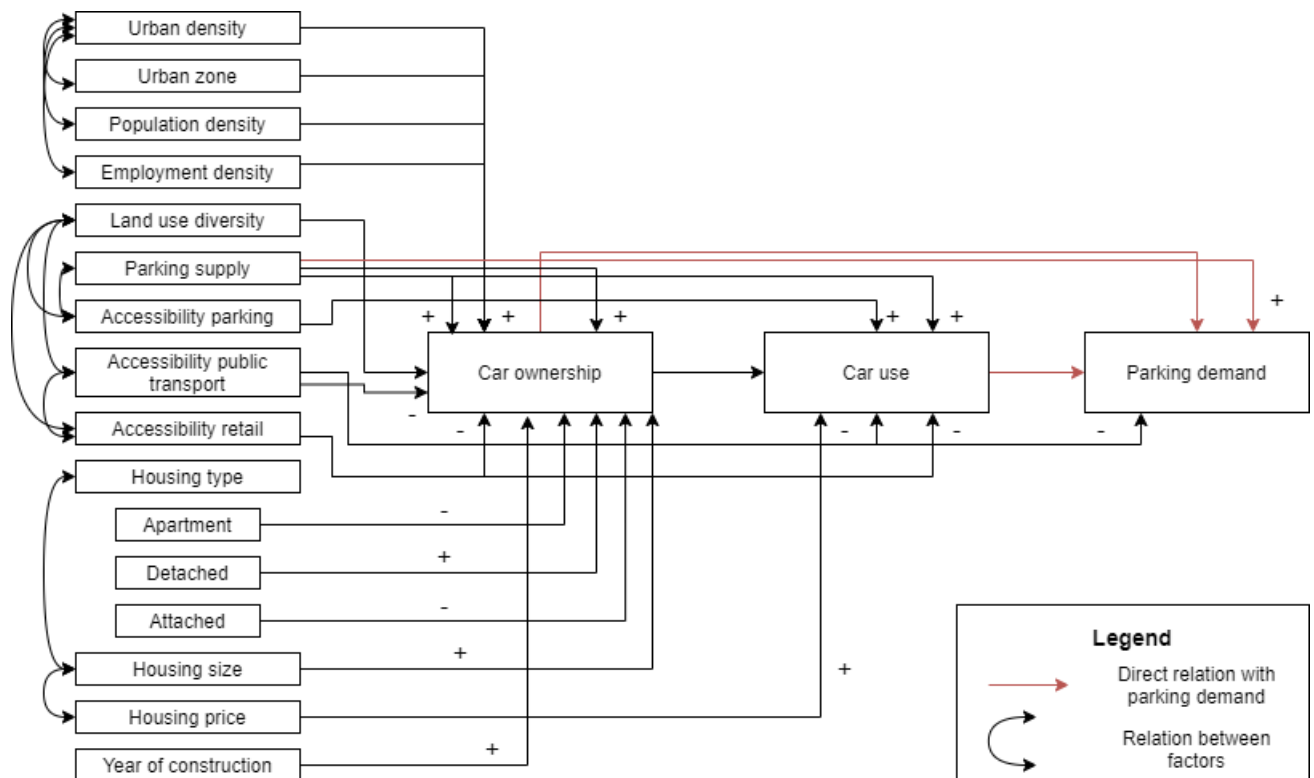


Figure 3.4: Relation between geographic factors and parking demand

### 3.2.3. Policy-related factors

As discussed in section 3.1 parking policy is determined by the local municipality. Marsden (2006) argues that parking policy can be used to reduce the overall travel demand. However, he argues that parking policy should be more integrated into transport strategy. This requires a vision of the number of spaces, regulation, information, and enforcement but requires also thinking about the modes used to connect the city. Consequently, land-use planning and parking policy should be integrated (Marsden, 2006). This conjunction with the land-use is also shown by the parking availability. As part of the parking policy, parking standards and hence the parking supply are determined. Therefore, parking availability can be considered to be both an environmental and a policy-related factor. Furthermore, parking pricing, the inclusion of visitor parking, on-street parking resources and rules on tandem parking are essential choices related to parking policy (Willson and Roberts, 2011). Considering parking choice behaviour, parking cost is one of the most critical factors and an effective measure to control the parking demand (Ruisong et al., 2009). Tong et al. (2004) argue that parking availability and parking cost are the most critical factors influencing travel behaviour.

To make paid parking politically feasible, priority is often given to residents through parking permits (De Groot et al., 2018). Ostermeijer et al. (2019) showed that increasing permit fees in Amsterdam is expected to reduce car ownership by 17-24%. They conclude that residential parking costs can explain around 30% of the difference in low car ownership rates in the city centre and high car ownership rates in the periphery. De Groot et al. (2018) studied the welfare effects of residential parking subsidies by observing the changes in car ownership. They found that waiting for a parking permit reduces car ownership. In contrast, others saw that parking cost had no significant effect on car ownership, while parking regulation did (Albalade and Gragera, 2020). In Chinese cities, however, parking fees showed to significantly impact both car ownership and car usage (Yao et al., 2016).

Yan et al. (2019) argue that most research about parking policy is related to the parking cost and the parking demand. Therefore, he looked into the effects of other policy measures such as parking search time and egress time from the parking space to destination. They found that travellers primarily responded by shifting parking locations rather than switching modes due to a changed parking policy. Additionally, they saw that by combining pricing and measures that reduce search and egress time, the parking demand reduced more

than implementing each measure individually. Furthermore, Christiansen et al. (2017) showed that parking restrictions at both home and the trip destination reduce car use strongly. They argue that the effect of these parking restrictions is the biggest in compact cities.

In Figure 3.5 the relations between policy-related factors and car ownership, car usage, and parking demand are given. In contrast to the demographic and geographic factors, various policy factors directly influence the parking demand.

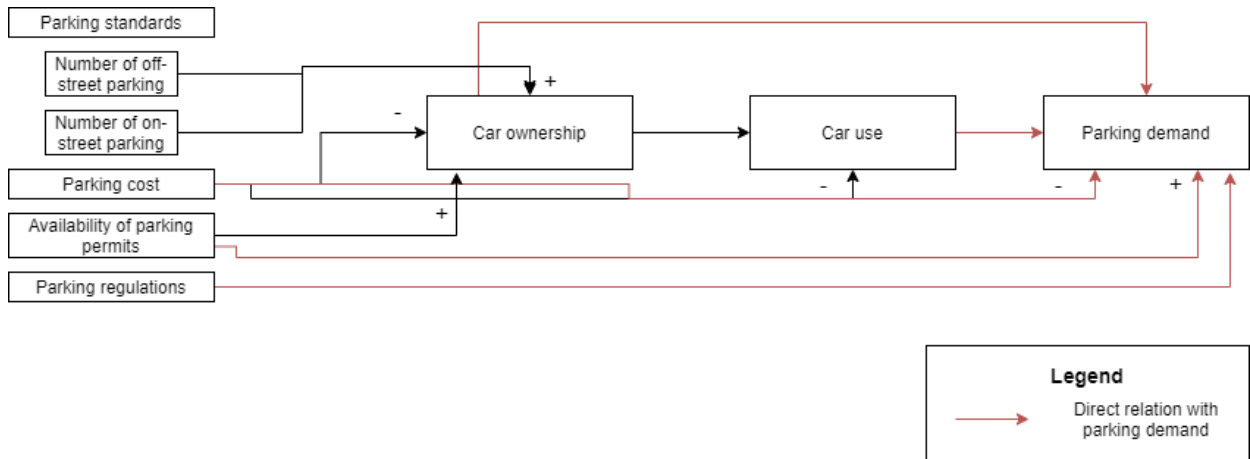


Figure 3.5: Relation between policy related factors and parking demand

### 3.2.4. Conclusion

From the literature review, it can be concluded that three different categories influence car ownership, car use and subsequently residential parking demand. In Figure 3.6 an overview of all identified factors is given. The red arrows describe the direct relation to parking demand. The orange arrows describe the relation with geographic factors, the blue arrows the demographic factors, and the purple ones represent the relations with policy factors. The black curved arrows define the relations between the factors. It can be seen that the demographic factors are not directly influencing the parking demand, but they impact the parking demand via car ownership and car use. The housing variables in the geographic factors are generalised to housing type. These include both the housing type and the housing size. This figure represents the residential parking and does not include the visitor parking. section 3.3 will discuss how the relations identified for residential parking can be used to come up with a conceptual model for the visitor parking demand.

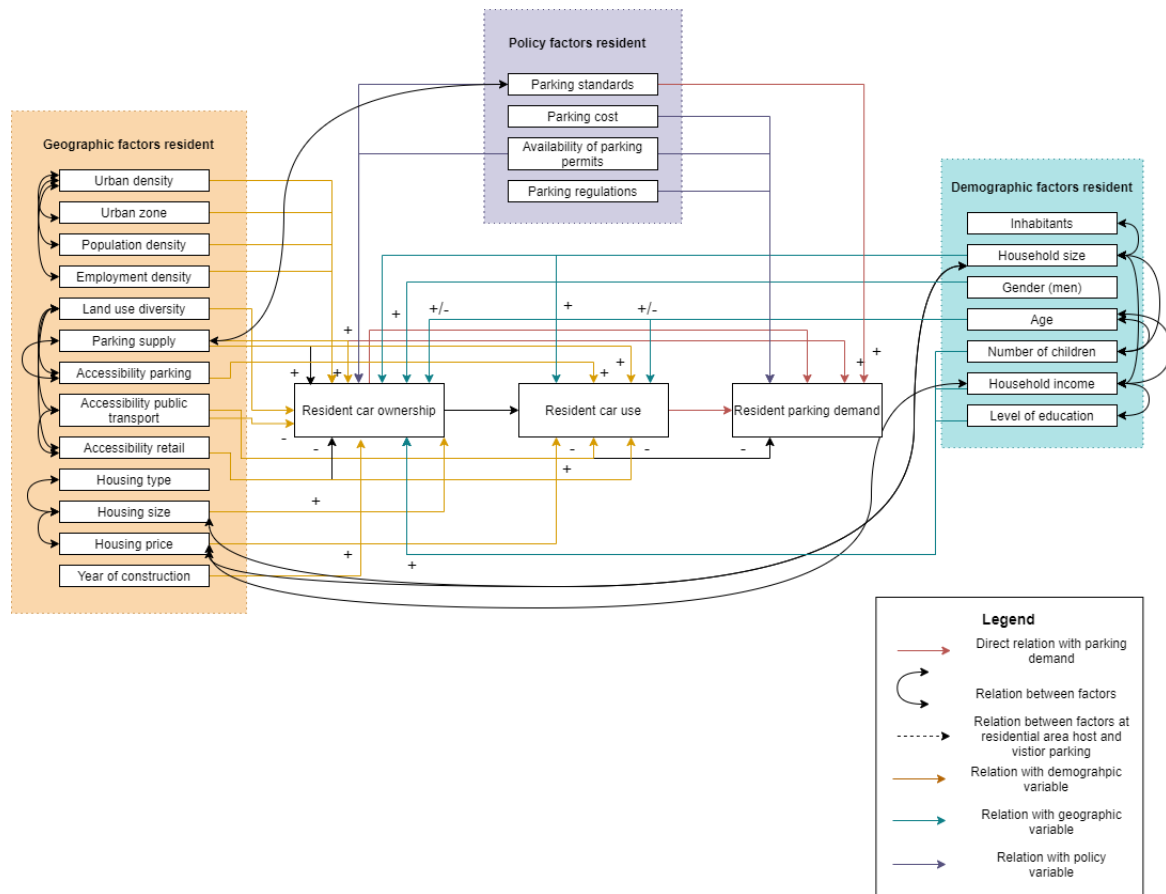


Figure 3.6: Factors influencing the residential parking demand

### 3.3. Conceptual model

In section 3.1 and section 3.2 the factors influencing residential parking are identified. One of the main conclusions from these sections is that car ownership and car use strongly determine residential parking demand. However, the residential parking demand described in section 3.1 is the parking demand generated by the residents living in a certain area. This excludes the demand generated by the visitors of these residents while this is part of the total residential parking demand (De Gruyter et al., 2020).

In this research, visitor parking is defined as the parking generated by visitors of residents. Consequently, the resident who receives visitors is referred to as the host. Since the visitor parking demand depends on the car use of visitors, it is not plausible that car ownership of the host influences the visitor parking demand. However, the car use of visitor parking does. Visitors' car use is influenced by the visitors' car ownership and hence the characteristics of this visitor. As a visitor having a car, the decision to visit another residential area by car then depends on the local conditions in that area. Consequently, it is concluded that visitor parking demand is generated due to the characteristics of the visitor and the characteristics of the residential area of the host. This is also illustrated in Figure 3.7. This figure shows the total residential parking demand and how demographic, geographic and policy factors influence both the regular residential and visitor parking. In Appendix C all relations are defined, the figure in this section is aggregated from the figure in Appendix C.

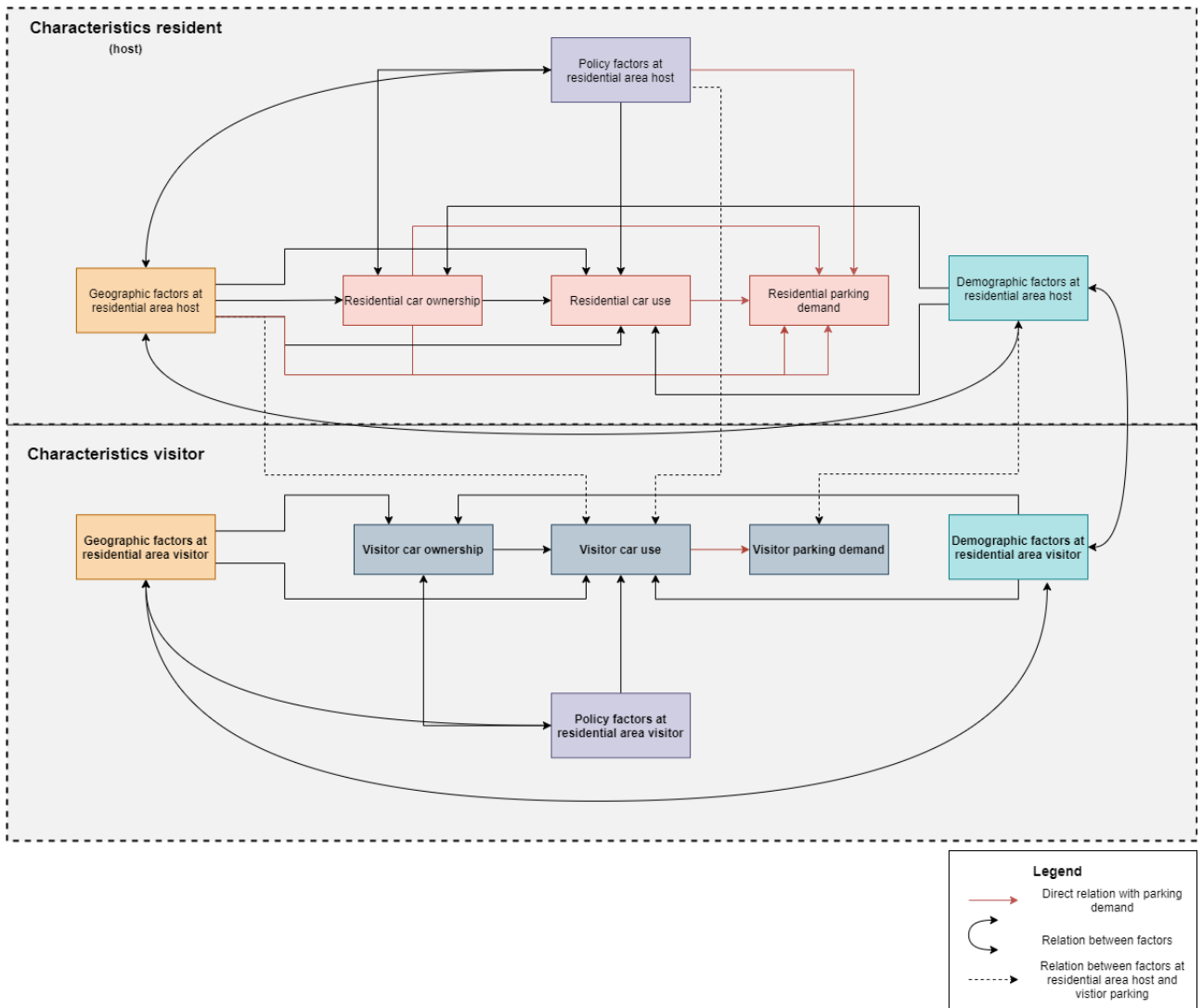


Figure 3.7: Conceptual model of the total residential parking demand

The figure in Appendix C shows that the visitor parking demand is very complex and depends on many different factors. The visitor car ownership and car use will depend on the same factors as discussed in section 3.2. In addition, the visitor car use depends on the local conditions of the residential area of the host. These include demographic characteristics, geographic characteristics and policy-related characteristics.

Initially, the demographic characteristics of the residential area of the host might be expected to have less influence on the visitor car use than the policy and geographic factors. However, one could argue that the demographic factors of residents and their visitors will be similar. For example, friends are often from about the same age and the same educational level. Furthermore, these residents attract visitors to their residential area. This requires considering the characteristics of the host and its impact on visitor car use. In addition, it is expected that bigger households will attract more visitors than single households. Furthermore, people of middle-age are expected to receive more visitors by car than younger and older people. This can be explained by the fact that these people will most probably have visitors in the same stage of life and will be in the same age group. As the middle-aged group proved to have higher car use, it is also expected that they will visit friends and family by car. In addition, households with children may attract more visitors. Moreover, higher incomes are expected to receive more visitors by car than households with lower incomes. The same holds for the level of education.

The geographic factors at the residential area of the host are expected to influence the visitor parking demand the same as the residential parking demand. Since dense urban zones are often good accessible by

other modes of transportation, it is expected that these areas will attract fewer visitors by car. This suggests that there also is a relation with the accessibility of the area by different modes of transportation. However, one could argue that having a dense area with high diverse land use might also attract more visitors and more visitor parking. This is related to the parking availability, which is expected to be lower in dense areas. Following earlier theories, this would result in lower parking demand (see section 3.2). In general, it is expected that more parking supply will result in more usage of visitor parking in a specific area. Finally, the housing characteristics are expected to influence the visitor parking demand, while it is assumed that residents in smaller apartments will attract fewer visitors than people living in big detached houses. However, this again will depend on the parking supply.

Finally, policy factors are expected to influence visitor car use. It is expected that visitor car use will be influenced by the parking cost at the host, the parking regulations, and the number of parking available in the area. Conclusively, it is expected that the same relations will hold regarding the policy factors as for the residential parking of the host (see section 3.2).

Besides the relations between context-specific factors and visitor parking demand, relations between the factors must be considered. Within the geographic factors, it is expected that urban density, urban zone, population density and employment density will be related. In addition, the household size will be related to the housing type. It is assumed that bigger households are more likely to live in bigger houses. In addition, the housing price will also be related to the housing size and the household income since people with higher incomes can afford more expensive housing than lower incomes. Finally, the land-use diversity, parking supply, accessibility to public transport, and retail are expected to be related. These relations are shown in Figure C.1 in Appendix C. Within the demographic factors, the number of inhabitants and household size is related. The household size is expected to be related to household income. Furthermore, the age and the number of children and household income will be related. Besides the relations within different groups, relations between demographic, geographic and policy-related factors are expected. These are also shown in Figure 3.6. Finally, as discussed previously, the demographics of the host and visitor will overlap (see Figure 3.7).

The conceptual model shown in Figure 3.6 shows how the total residential parking demand in a certain area depends on different factors. This research focuses on identifying what factors influence the visitor parking demand to develop a better approach for visitor parking standards. In practice, it will only be possible to consider the local conditions of the parking area and characteristics of the visitors can not be considered. Due to lacking data about the visitors, this research will only focus on the local conditions of the residential area of the host. Furthermore, the visitor parking demand strongly depends on the car use of the visitor. This research assumes that the visitor parking demand is determined by the cars that were actually parked in a certain area. Consequently, visitors that do park their cars in other parking areas are not considered and latent parking demand is not taken into account. The measured car use thereby is equal to the visitor parking demand. Accordingly, the identified factors also directly influence the visitor parking demand. This is represented in Figure 3.8. This framework will be used to test the relationship between different factors and the visitor parking demand. A complete overview of all relations is given in Table C.1 in Appendix C.

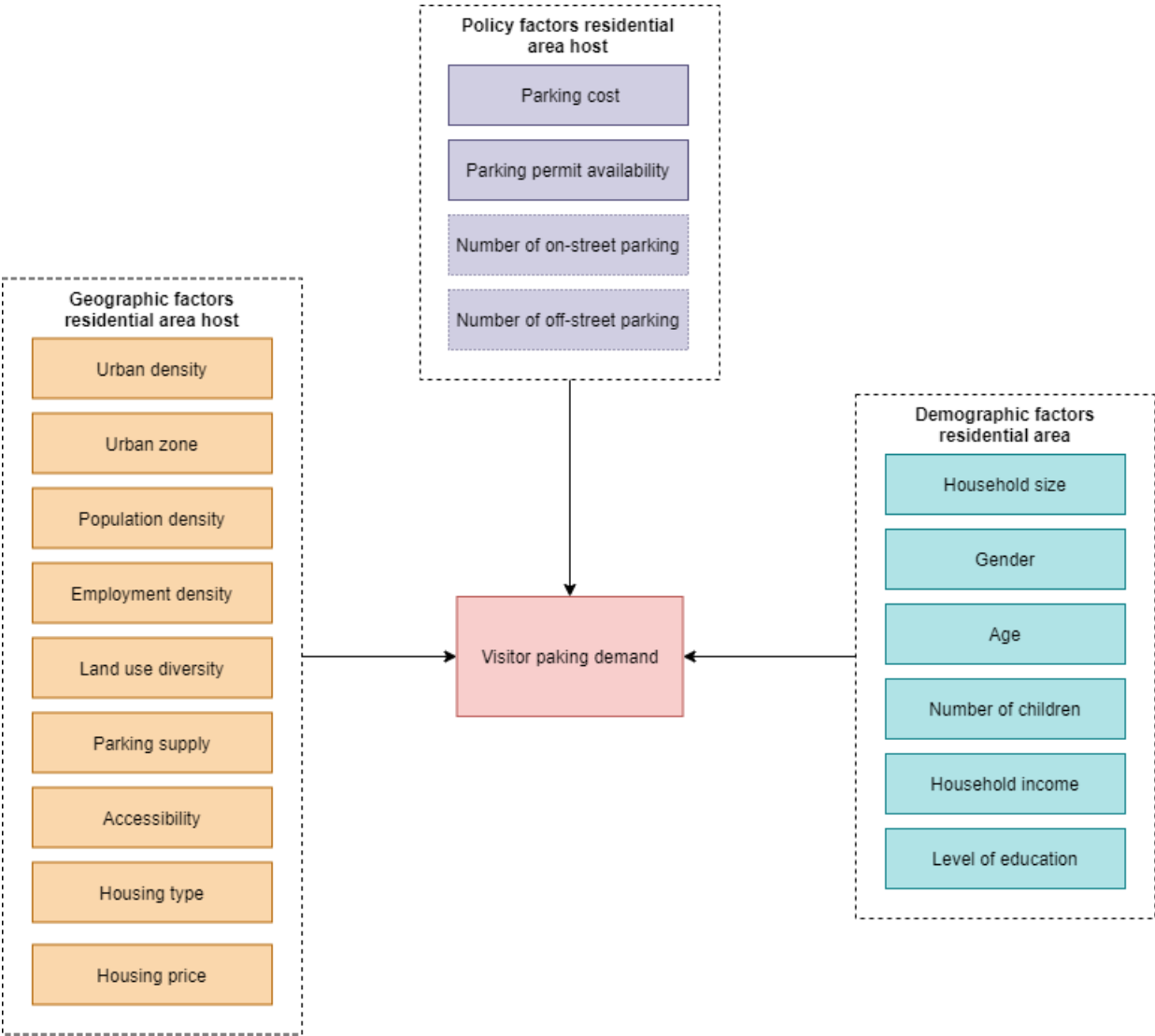


Figure 3.8: Conceptual framework visitor parking demand tested by multiple linear regression

# 4

## Data preparation and analysis

This chapter discusses the data collection and preparation of the data needed for the statistical model. The conceptual framework developed in chapter 3 reveals three different categories of factors that may influence visitor parking in residential areas. This chapter will elaborate on the variables included in the model and how the collected data is prepared for the regression model. Furthermore, the parking data and context-specific data will be analysed. Consequently, this chapter answers subquestion 3.

### 4.1. Parking data

To assess the visitor parking demand, the use of the visitor parking permit in Eindhoven is studied (see also chapter 2). The total number of registered visitors in a certain area is referred to as the number of visitor parking actions. Therefore, this research considers that the visitor parking demand is represented by the total number of registered visitor parking actions. As previously discussed, the data about the visitor parking permit use in Eindhoven is provided by Desyde. These data include all the parking actions between the 1st of January 2019 and the 31st of December 2019. For each parking action, information about the parking action itself and about the permit holder is delivered. The information about the parking action includes the date and time of arrival of the visitor, the date and time of departure of the visitor, the municipality, the parking location, the costs of the parking, and whether the parking actions were registered during the paid parking hours (between 9 a.m. and 9 p.m.). Visitors only have to be registered during these paid parking hours. (Eindhoven, n.d.a). Furthermore, the data contains information about the resident owning the parking permit, the host. This information includes the hosts' year of birth, gender and postcode (measured on a 6 digit level (PC6)).

#### 4.1.1. Parking data preparation

The data provided by Desyde consists of 219,013 parking actions spread over one year and is analysed based on the postcode of the permit holders. 2,258 parking actions are registered on a non-existent postcode (9999 XX) and removed from the data. Furthermore, 322 parking actions missed information about the characteristics of the permit holder and consequently are also removed from the data. Consequently, the final considered data consists of information of about 216,268 parking actions. The data is aggregated based on the postcode of the permit holders to allow data analysis on the number of parking actions. A first analysis showed that 9,450 parking actions were registered on a postcode outside Eindhoven. Furthermore, 8,798 parking actions were registered in another neighbourhood than the parking area indicated by the parking data. To make sure that context-specific factors of a particular parking zone are considered, the postcodes of permit holders registered outside Eindhoven were changed to postcodes within the parking zone. The postcodes were assigned to the parking actions in ratio with the postcodes inside this area. However, parking actions registered at another parking zone were not changed. This allows taking the context-specific factors of the right residential area into account. Postcodes outside the parking area are changed to a postcode within the registered parking zone. Consequently, the postcode of 13,571 parking actions is modified.

### 4.1.2. Parking data analysis

In Figure 4.1 the number of parking actions per parking zone is given. The number of registered visitor parking actions are highest in 'Eliasterrein, Vonderkwartier', 'Schoot', 'Schrijversbuurt' and 'Oude' 'Sporbaan'. Figure 4.2 shows the areas with the highest number of parking actions per zone. The yellow parking areas show the parking areas only allowed for permit holders (in some cases combined with paid parking).

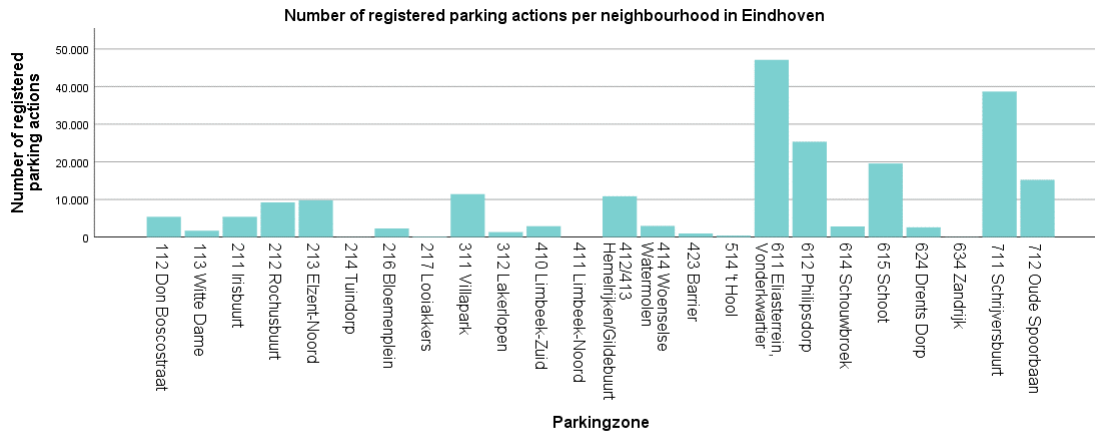


Figure 4.1: Number of parking actions per parking zone in Eindhoven for the year 2019

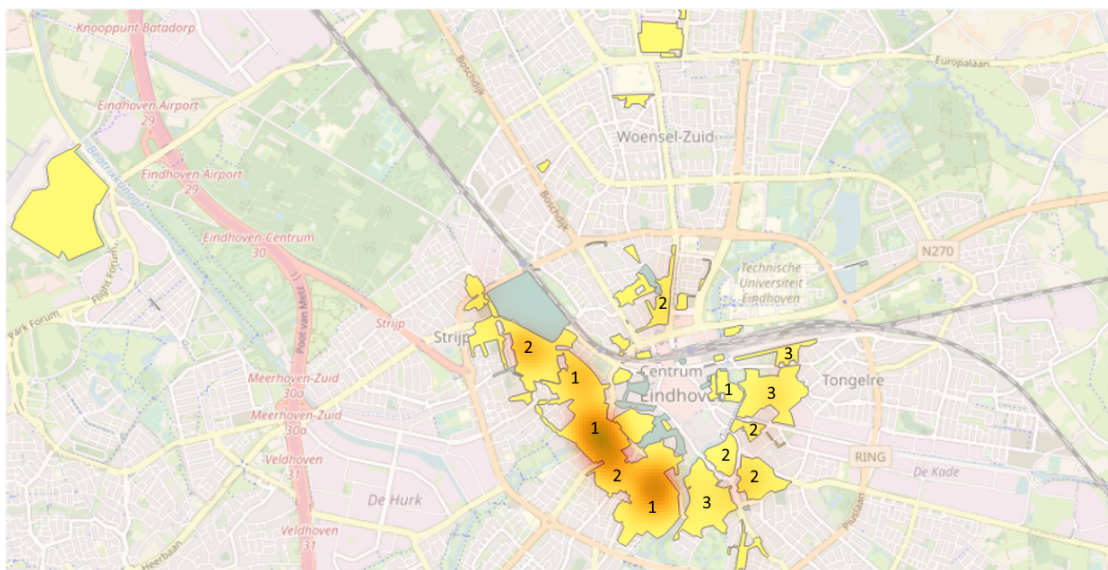


Figure 4.2: Heatmap visitor parkingactions in permit parking zones (yellow) in Eindhoven

Different areas are observed using Google Streetview. Based on these observations, three different types of areas can be distinguished. The areas in Figure 4.2 marked with a '1' represent areas with balanced demand and supply. However, parking outside the paid parking zone is more complicated. Second, areas marked by a '2' represent urbanised areas. In these areas, it is expected that occasionally the demand exceeds the supply. However, some of these areas are close to non-paid parking areas. This enables visitors to park outside the paid parking zones, and therefore it is expected that in these zones, the number of residents with a visitor parking permit is relatively low. Consequently, the considered parking actions in these areas are not likely to represent the entire visitor parking demand. Finally, areas marked with a '3' describe areas with sufficient parking. In these areas, many detached and/or semi-detached housing with on-site parking can be found. Therefore it is expected that the on-street parking is sufficient to serve the parking demand. It should be

noted that within these different area types, differences between streets were observed.

Figure 4.3 shows how the number of parking actions differs during the week. It can be seen that on Saturdays, most visitors are hosted. In addition, Figure 4.4 shows the spread of the visitor parking actions during the day. Most visitors are attracted during the evening hours. However, after 9 p.m., a drop in the number of parking actions can be seen. This can be explained by the paid parking hours being between 9 a.m. and 9 p.m. After 9 p.m., parking is free, and most visitors' cars will be deregistered while still being parked. Consequently, the parking demand represented by the registrations with the visitor parking permit can not represent the complete visitor parking demand.

In Appendix D the number of parking actions during the day is shown for each neighbourhood. The graphs show that the spread over the day varies per parking zone although in most areas a peak of visitors can be observed between 7 and 9 p.m. However, some areas show a peak during the morning or the afternoon. The demographics of the area could explain this variation between parking zones. For example, Zandrijk and 't Hool have relatively many children (see Figure 4.6), which explains the higher number of visitors between 2 and 3 p.m., after schools are over. However, for other neighbourhoods is harder to explain the peak based on the demographic characteristics of the area. For example, Irisbuurt, Drents Dorp, Barrier and Bloemenplein show a peak of visitors between 10 a.m. and 1 p.m., while the distribution of the age groups in the neighbourhoods is comparable to Zandrijk and 't Hool. This suggests that either other factors influence the permit use or that there is no relation between local conditions and the use of the parking permit.

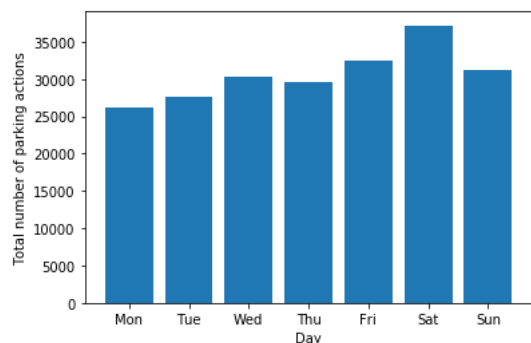


Figure 4.3: Number of parking actions during the week

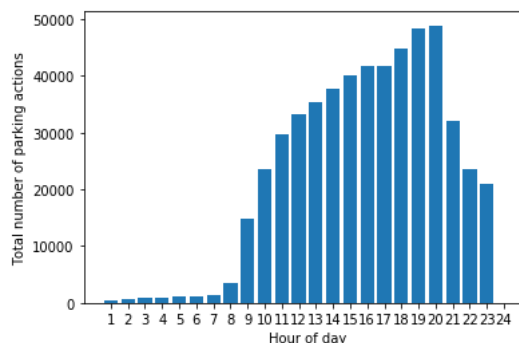


Figure 4.4: Number of parking actions during the day (2019)

## 4.2. Demographic data

As discussed in chapter 3 it is expected that demographic characteristics of the hosts' residential area will influence the visitor parking demand. In addition, data about the personal characteristics of the visitors is lacking. Therefore, demographic characteristics of the hosts are considered. The parking data provided by Desyde also contains information about the permit holder. As discussed, this information includes the post-code of the host, the gender and the year of birth. However, these data do not provide information about the number of unique visitor permit users. Subsequently, demographic characteristics at the residential area are collected from the CBS. They provide data about personal characteristics on a postcode level. To make sure the data is accurate as possible, information on a postcode six-level (PC6) is used, which is the full postcode with six digits (four numbers and two letters). Since the data on PC6 level of 2019 was not freely available, data for the year 2017 was used (van Leeuwen, 2020). The data provides information about all residents at a specific postcode. This data includes information about:

- Number of inhabitants
- Number of men
- Number of women
- Number of inhabitants in the age group of 0-15 years
- Number of inhabitants in the age group of 15-25 years
- Number of inhabitants in the age group of 25-45 years
- Number of inhabitants in the age group of 45-65 years

- Number of inhabitants in the age group of 65 years and older
- Number of households
- Number of households consisting of one person
- Number of households consisting of more than one person without kids
- Number of single-parent households
- Number of two parent households
- Average household size
- Median of the income on household level

#### 4.2.1. Data preparation

The data are assigned based on the postcode of the visitor. The data also included values -99997, indicating that there are less than four cases or no data is available. Data on a neighbourhood level are used to assign values to the postcodes with missing values. Centraal Bureau voor de Statistiek (2019) provides data on a neighbourhood level containing the same variables. From these data, ratios are determined, which are used to assign values on a postcode level. For example, for the age group, the number of inhabitants is known on a postcode level and based on the neighbourhood data, the ratio of the different age groups is determined. Multiplying this ratio with the number of inhabitants results in the number of inhabitants per age group. However, using this method will result in correlations between these values. Furthermore, in the data on the postcode level, it can also be seen that the sum of the age group represents the total number of inhabitants. This is important to consider when estimating the regression model.

To prepare the data for the regression model, the variables are checked for outliers. This is performed by studying the boxplots of the variables in SPSS. In addition, some of the variables are grouped based on factor analysis. The data preparation of each variable will be described below.

#### 4.2.2. Inhabitants

The number of inhabitants per postcode is provided by the CBS. This information is added to the data without making any changes. When looking for outliers, 43 cases are identified as outlier. These outliers include postcodes with 65 to 425 inhabitants. It is expected that these outliers are not a result of measurement errors. The number of inhabitants strongly differ over the postcodes and the number of parking actions per postcode. Furthermore, the data represents a natural phenomenon. It seems plausible that certain postcodes have more inhabitants than others. Therefore, the identified outliers were not removed from the data.

Figure 4.5 presents the number of inhabitants on a neighbourhood level. The number of inhabitants strongly differ per neighbourhood, and comparing the number of inhabitants with the number of parking actions shows that the number of inhabitants does not automatically represent a relation with the parking actions. Some areas having lower parking actions have a relatively high number of inhabitants (e.g. Tuindorp), while other areas show both a high number of parking actions and a high number of inhabitants (e.g. Eliasterrein). This reflects the assumption that the number of inhabitants differs strongly per postcode in relation to the number of visitor parking actions.

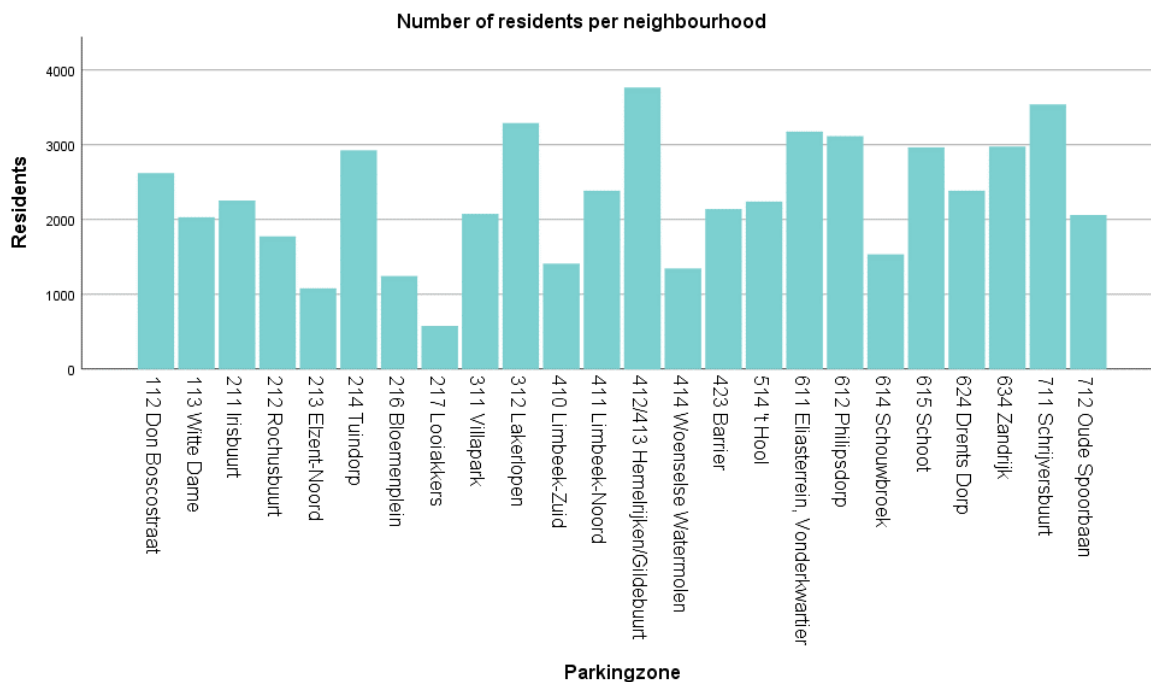


Figure 4.5: Number of residents per neighbourhood

### 4.2.3. Households

As suggested in chapter 3, the household composition is expected to affect the visitor parking demand. The data provided by the CBS contains information about the number of households per postcode, the average household size, the number of households consisting of one person, the number of multi-person households with and without kids, the number of single-parent households, and the number of two-parent households. However, not all variables can be included in the model. The number of one-parent households and two-parent households consists of much-lacking data, or values lower than 4 (indicated by -99997). For one-parent households, 442 out of 457 postcodes had a value of -99997. 310 cells included the value -99997 for two-parent households. Since this is more than 50% of the cases, these variables are excluded from the model. The total number of households, the average household size, the number of one-person households and the number of multi-person households are included in the model.

### 4.2.4. Age

The data provided by the CBS include five different age groups. As previously discussed, many cells included the value -99997, indicating that there were less than four or no observations for that specific postcode and age group. Therefore, based on the distribution of the age groups in the neighbourhood and the number of inhabitants for that postcode, the number of inhabitants in a particular age group is assigned to the cells with lacking data. In addition, the postcodes without lacking data show that the summing over the age groups results in the total number of inhabitants for that postcode. This correlation should be considered when estimating the regression model by analysing which variables will result in a better model fit.

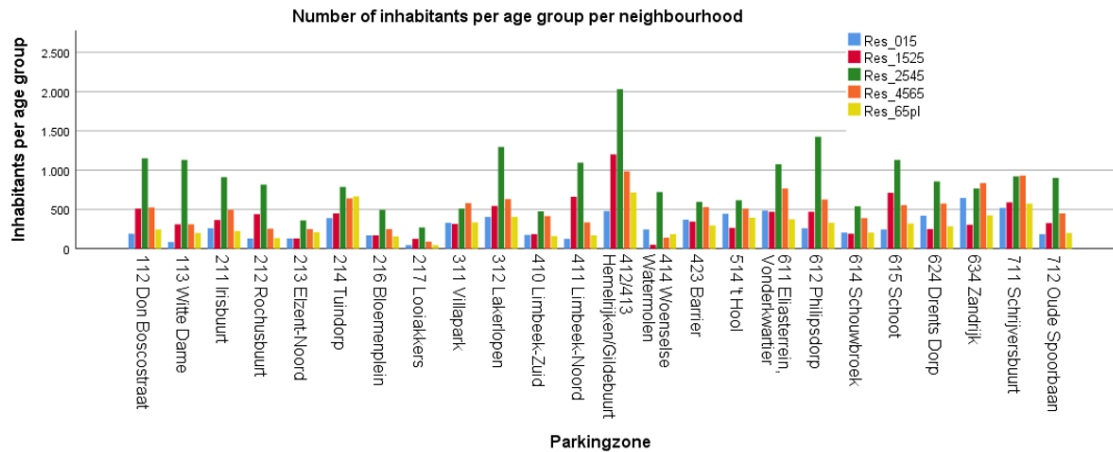


Figure 4.6: Distribution of age groups per neighbourhood

Figure 4.6 shows how different age groups are distributed in different neighbourhoods. The age group of people between 25 and 44 is dominant in each of the neighbourhoods. Therefore, including this age group in the model will not explain the differences between neighbourhoods and their parking actions. In addition, adding five different age groups will make the interpretation of the results complicated. Therefore, factor analysis is used to identify whether some age groups can be aggregated.

Factor analysis can be used to regroup variables into a limited set of clusters based on shared variance (Yong et al., 2013). The factor analysis is performed by SPSS using rotation. The goal of rotation is to attain an optimal structure which attempts to have each variable load on as few factors as possible while maximizing the number of high loadings on each variable (Yong et al., 2013). The results of this factor analysis are shown in Table 4.1. The 'Bartlett's Test of Sphericity' shows that there are patterned relationships ( $p < .001$ ). Based on the factor analysis, two groups with similar patterns can be identified. Group 1 represents children, middle-aged people and elderly. Group 2 represents young people and adults.

Table 4.1: Results factor analysis age groups

Group	1	2
Inh_014	0.744	0.179
Inh_1524	0.01	0.782
Inh_2544	0.017	0.815
Inh_4564	0.782	0.08
Inh_65+	.549	-0.204

#### 4.2.5. Gender

Data about gender is given by the number of men and women registered at each postcode (van Leeuwen, 2020). The data contained 10 missing values for men and 9 missing values for women. These were defined as missing values in SPSS. Analysing this data reveals that, in general, the number of men and women on a postcode level are, in most cases, equally distributed. This is also represented on a neighbourhood level (see Figure 4.7). In addition, the same problem will hold for the age groups. The total number of men and women together is equal to the total number of inhabitants. This will result in high correlations with inhabitants and among the variables men and women. Considering this, it is very likely that these variables will be insignificant in the regression model.



Figure 4.7: Distribution of men and women per neighbourhood

#### 4.2.6. Income

Finally, CBS provides data about household income. The data consists of the median standardised household income. These are determined based on the median standardised income per area compared to the total household income in The Netherlands. Based on the results, the household income is assigned to an income group (low, below middle, middle, above middle or high) (van Leeuwen, 2020). This standardised income is the income corrected for the household size and composition. For the postcodes in Eindhoven, this resulted in the following income groups:

- Low: Median income between €0 and €20,000
- Low to below middle: Median income between €0 and €40,000
- Below middle: Median income between €20,000 and €40,000
- Below middle to middle: Median income between €20,000 and €60,000
- Middle: Median income between €40,000 and €60,000
- Middle to above middle: Median income between €40,000 and €80,000
- Above middle: Median income between €60,000 and €80,000
- Above middle to high: Median income between €60,000 and €100,000
- High: Median income between €80,000 and €100,000

The number of income groups is reduced to three different groups to come up with interpretable results. In the data, this means that the median income was replaced by either '1', '2' or '3'. 1 represents the lower incomes, including the low, low to below middle and the below middle incomes. The second group represents the middle incomes, including the below middle to middle, middle and middle to above middle incomes. Finally, the third group includes the above middle to high and high-income groups.

#### 4.2.7. Data analysis

In the former section, different demographic variables are discussed. Often, it is suggested that the different variables are expected to correlate. In Appendix D the correlation table of the demographic variables is given (see Table D.1). The bold numbers in this table present the strong and significant relations. The number of inhabitants is strongly correlated with the number of men, women, households, one-person households, multi-person households and the number of inhabitants in the age group 15 to 24 years and 25 to 44 years. This is in line with the expectation that inhabitants would correlate with most of the other variables. Adding a variable in the regression model strongly correlating with other variables will add less value to the model. Furthermore, men and women strongly correlate, and therefore only one of these variables should be considered in the regression model. Additionally, households are strongly correlated with the same variables as the number of inhabitants. The average household size does not show significant relations with the other variables

but less strong.

The relation between the variables and the visitor parking actions is also given in Table D.1. In contrast to the expectations, the number of inhabitants does not correlate with the number of parking actions. In addition, most of the other demographic variables show insignificant relations with visitor parking actions. The average household size, however, is significantly having a positive relation. This is in line with the hypothesis that bigger households will attract more visitors. However, this relation is relatively weak. Stronger relations are found for people in the age group of 0 and 14 years and 45 and 64 years. Since these are positive relations, indicating that these age groups attract more visitors than the other age groups. However, also these relations are weak. All other variables show insignificant relations with the number of visitor parking actions.

### 4.3. Geographic data

Geographic data refers to data about the built environment. The geographic data is collected for the conditions at the postcodes of the permit holders. Based on the conceptual framework developed in chapter 3 different factors related to the geographic characteristics of an area are considered. These include the urban zone, the population density, the urban density, the land-use diversity, the housing type, the parking supply and the accessibility to different facilities such as public transport. This section will discuss how these different factors are included in the model.

#### 4.3.1. Urban density, degree of urbanisation and population density

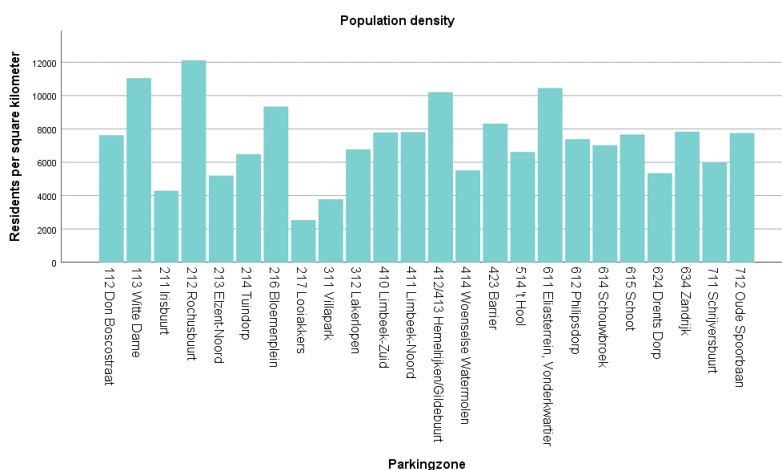
Data about the urban density, the degree of urbanisation and the population density could not be retrieved on a PC6 level. The CBS provides data about these variables on a neighbourhood level (Centraal Bureau voor de Statistiek, 2019). In contrast to the data on PC6 level, this data is from 2019. The information about the urban density, degree of urbanisation, and population density was assigned to the neighbourhood in which each specific postcode is located. In what neighbourhood each postcode is located is determined based on open data provided by the municipality of Eindhoven (Eindhoven, n.d.b).

Using neighbourhood data instead of data on a PC6 level will result in minor variance between the postcodes within the same neighbourhood. In addition, it can be expected that urban density and the degree of urbanisation will be correlated. The urban density represents the number of addresses per square kilometre, while the degree of urbanisation indicates different classes based on the urban density (Centraal Bureau voor de Statistiek, 2019). Table 4.2 shows the correlations between urbanisation, urban density and population density. It can be seen that urbanisation and urban density and urban density and population density are correlated. The relation between the degree of urbanisation and urban density is negative. This is in line with the expectations. Highly urbanised areas are represented by '1', while non-urbanised areas are represented by '5'. High numbers thereby represent a low degree of urbanisation. The degree of urbanisation and population density are not correlated. Therefore these can be included in the same regression model.

Finally, Table 4.2 also indicates the correlations between the variables and the number of visitor parking actions. In this table, values with one asterisk (\*) represent a relation significant at a 0.01 level ( $p < 0.01$ ) and values with two asterisks represent a relation significant at a 0.05 level ( $p < 0.05$ ). The table suggests that a low degree of urbanisation (a high value for the variable urbanisation) results in fewer visitor parking actions, while a high urban density and population density will increase the number of visitors. This implies that dense areas attract more visitors by car.

Table 4.2: Correlations between urbanisation, urban density and population density

	Urbanisation	Urban density	Population density	Visitor parking
Urbanisation	1	-0.573**	-0.095*	-0.136**
Urban_density	-0.573**	1	0.502**	0.171**
Population_density	-0.095*	0.502**	1	0.171**



Population density per neighbourhood

### 4.3.2. Housing

Information regarding the housing in a specific area is retrieved from both the CBS and the 'Basisadministratie Adressen en Gebouwen ('basic registration addresses and buildings')(BAG). van Leeuwen (2020) provides data on housing characteristics for each postcode in The Netherlands. This data is also from 2017 and includes the data on postcode level (van Leeuwen, 2020). This data includes information about:

- Total number of houses
- Number of houses built before 1945
- Number of houses built between 1945 and 1965
- Number of houses built between 1965 and 1975
- Number of houses built between 1975 and 1985
- Number of houses built between 1985 and 1995
- Number of houses built between 1995 and 2005
- Number of houses built between 2005 and 2015
- Number of houses built after 2015
- Average WOZ-value of houses (property value)
- Percentage rental houses
- Percentage owner-occupied houses

From chapter 3 it was concluded that literature differs in the expectations of the year of construction on the residential parking demand. To take the building age into account, the data of the CBS is aggregated to a variable representing 'old housing' and a variable representing 'new housing'. The old housing includes houses built before 1995 while housing constructed after 1995 are included in new housing. This distinction was made based on multiple estimations, and this combination resulted in the most significant results.

The average WOZ value of houses represents the value of the property. It is expected that properties with higher values will attract more visitors by car. The data provided by CBS lacked information regarding 57 of the postcodes. To provide data for these postcodes, the 'WOZ-waardeloket' was consulted (Rijksoverheid, n.d.). This website provides the opportunity to search the WOZ value of a postcode. The average for each postcode was taken as the WOZ value.

The conceptual framework indicated that owner-occupied housing would attract more visitors by car than rental housing. Therefore, data about the percentage of rental houses (P\_rent) and owner-occupied housing is included in the model (P\_sale). In several cases, either the percentage of rental housing or owner-occupied housing was lacking, while occasionally both were lacking. If both were lacking, the percentages on the neighbourhood level are used. When only one was lacking, the percentage is determined based on obtaining 100% when summing rental and owner-occupied housing. Due to high correlations, either one of these variables should be included in the regression model (see Table 4.3 in which values with one asterisk (\*) represent significance at a 0.01 level, two asterisks represent a relation significant at a 0.05 level). A higher percentage of

rental housing indicates a lower number of owner-occupied housing and vice versa. In addition, while rental housing shows a negative relation with visitor parking actions, owner-occupied housing shows a positive relation.

Table 4.3: Correlations rental housing and owner occupied housing

	P_rent	P_sale	Visitor parking
P_rent	1	-0.972**	-0.178**
P_sale	-0.573**	1	0.190**
Visitor parking	-0.178**	0.190**	1

Housing type and housing surface are hypothesised to influence the visitor parking demand. Data about the housing surface is collected from the BAG. The BAG contains information regarding all addresses and buildings within a municipality (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, n.d.). Since it is not possible to download a single dataset that contains the required information, the required data is collected by the BAG plugin in Qgis. The resulting dataset contains information about the year of construction, the type of building and the square meters of the buildings. Unfortunately, data about the housing type can not be collected (apartment, detached housing, semi-detached housing and others). To prepare the data for the regression analysis first five different categories for the housing surface are considered. These categories were based on the categories that are considered in the new visitor parking standards of the municipality of The Hague (see Appendix B).

- Housing with a surface of  $0-40m^2$
- Housing with a surface of  $40-70m^2$
- Housing with a surface of  $70-100m^2$
- Housing with a surface of  $100-160m^2$
- Housing with a surface of more than  $160m^2$

Besides these categories, the data is aggregated into two different variables. Small houses are represented by houses between 0 and  $100 m^2$ , while houses bigger than  $100 m^2$  are included as big houses. Table 4.4 shows the correlations between the different variables representing the housing surface. In addition, the correlations with the visitor parking actions is shown. It can be seen that the variables representing small houses (Housing\_0\_100) and big houses (Housing\_100plus) are correlated with the other housing variables. The housing variables representing the housing surface are not strongly related to each other. Furthermore, a relation can be found between the housing size and the number of visitor parking, which shows that smaller houses do attract fewer visitors than bigger houses. This relation is even clearer from the aggregated variables.

Table 4.4: Correlations between different housing surface variables

	0-40 $m^2$	40-70 $m^2$	70-100 $m^2$	100-160 $m^2$	>160 $m^2$	Housing 0_100	Housing 100plus	Visitor parking
0-40 $m^2$	1	0.160**	0.177**	-0.011	-0.060	0.684**	-0.041	-0.089
40-70 $m^2$	0.160**	1	0.298**	0.023	-0.061	0.610**	-0.008	-0.096*
70-100 $m^2$	.177**	0.298**	1	0.062	-0.166**	0.755**	-0.022	-0.041
100-160 $m^2$	-0.011	0.023	0.062	1	-0.231**	0.036	0.872**	0.157**
>160 $m^2$	-0.060	-0.061	-0.166**	-0.231**	1	-0.145**	0.274**	0.110*
Housing_0_100	.684**	0.610**	0.755**	0.036	-0.145**	1	-0.037	-0.104*
Housing_100plus	-0.041	-0.008	-0.022	0.872**	0.274**	-0.037	1	0.210**
Parking	-0.089	-0.096*	-0.041	0.157**	0.110*	-0.104*	0.210**	1

### 4.3.3. Accessibility to facilities

Finally, the accessibility to different facilities is expected to influence the visitor parking demand. The most important one is the parking supply. The parking supply is the number of parking available and can be distinguished into parking only available by people with parking permits and publicly available (paid) parking. In addition, the accessibility to other modes of transportation, such as public transport, bicycle and shared

cars, are considered. The CBS identified the distance from each postcode to different facilities such as supermarkets, cafes, restaurants and hotels (van Leeuwen, 2020). Furthermore, also the distance to the highway is provided. The distance to the highway might be a good indicator of the accessibility by car. Furthermore, data about the accessibility to public transport is retrieved from OpenStreetMap. These can be obtained by using the OpenStreetMap and QuickOSM plugin in Qgis. Data on the location of the paid parking zones where the visitor permit can be used is obtained by the open data of Eindhoven (Eindhoven, n.d.b). They provide information about the location of the parking zone (see Figure 2.2) and the location and capacity of parking facilities where the parking permit can be used.

Different methods can be used to identify the accessibility to these different facilities. First, a definition of accessibility used in this research will be described. In literature, different definitions of accessibility are given. In this research, the definition of Apparicio et al. (2008) is used. They define geographical accessibility in residential areas as “the ease with which residents of a given area can reach services and facilities” (Apparicio et al., 2008, p.2). In addition, they define four different methods to measure the accessibility: the distance to the closest service, the number of services within ‘n’ metres or minutes, the mean distance to all services, the mean distance to ‘n’ closest service and the gravity model (Apparicio et al., 2008). As part of the accessibility measurement, distance should be taken into account. This can be done by taking the Euclidean distance, the Manhattan distance (the rectangle distance), the shortest network distance and the shortest network time (Apparicio et al., 2008). The latter two take the network into account, while the former ones don’t take any network characteristics into account. Bertolini et al. (2005) divides accessibility measures with both a transport and land use component in three broad types: cumulative opportunities measures, gravity-based measures and utility-based measures.

For this study, both the cumulative opportunity approach and the distance to the nearest facility are used to measure the accessibility to different facilities. These include the accessibility of the hosts’ residential area to the permit parking area, public transportation such as bus and train, and public (underground) parking. First, the cumulative opportunity approach is used to count the number of potential opportunities that can be reached within a predetermined travel time or distance (El-Geneidy and Levinson, 2006). The mathematical formulation for this approach is given in Equation 4.1. For the cumulative approach, a buffer is determined by defining the radius from the location of permit holders. Based on this buffer, the number of facilities within the buffer is determined. As opposed to the gravity-based measures, this approach does not account for the size of the facility or the impedance of reaching it (El-Geneidy and Levinson, 2006). This makes it a simple and easy interpretable method to determine the accessibility of different activities. It should be noted that the buffer distance is determined based on the Euclidean distance from the postcode of the permit holder. The Euclidean distance does not take the road network into account and therefore does not represent the actual travel distance. Furthermore, Apparicio et al. (2008) showed that the choice of distance type and aggregation method could generate different results leading to significant measurement errors. A second method thereby is used to derive the accessibility. This method determines the distance to the nearest facility/activity based on the Euclidean distance. Again, this does not represent the real travel time as the euclidean distance takes the single line distance. Furthermore, only one of the methods should be added to the model to represent accessibility since including both will represent two times the same variable but measured differently. Therefore, the variable that adds the most explaining power will be added in the model.

$$A_i = \sum_{j=1}^J B_j \alpha_j \quad (4.1)$$

Where:

$A_i$  Accessibility measured at point  $i$  to potential activity at  $j$

$\alpha_j$  Opportunities in zone  $j$

$B_j$  A binary value equal to 1 if activity  $j$  is within the predetermine threshold and 0 otherwise

CROW (2018b) argues that a walking distance between 100 and 250 meters to parking is acceptable for visitors. Therefore, for the accessibility to the parking permit zones, a buffer of 100 meters and 250 meters is applied. This buffer indicates the number of unique parking areas that can be reached within 100 and 250 meters walking. This is measured with a Euclidean distance, representing the "as the crow flies" distance

and does not consider the network characteristics. The second method to measure the accessibility to the permit parking areas is by measuring the distance to the nearest parking. Again the Euclidean distance was used. This results in three different variables, one representing the number of parking that can be reached within 100 meters, one within 250 meters and one representing the distance to the nearest parking facility. This measure was also applied for the accessibility to the public (off-street) parking. It is likely that only one variable will end up in the regression model for both the permit parking and the public parking. The number of parking spaces reached within 250 meters will be strongly correlated with the variable representing 100 meters.

The same method is used to determine the accessibility to public transport. Literature suggests that people are willing to walk a maximum of 400 meters to public transport (Knoflacher, 2006). This distance was used to measure the accessibility to public transport: the number of bus stops and train stops within 400 meters. However, since Eindhoven only has two stations, this measure will not result in a good indication of the accessibility to train. In addition, the distance to the nearest bus and train stop was measured. The accessibility measured in this research does not take the service level of the public transport into account. This might result in a distorted view of the accessibility of particular locations.

In Table 4.5 the correlations between the different accessibility variables are shown. From this table, it can be seen that the availability of permit parking within 100 meters and 250 meters are correlated ( $r=.779$ ). In the multiple regression model, therefore, either one of these variables will be included. The other variables show no strong correlations. Furthermore, the table also gives information about the correlation between parking actions and the accessibility measures. Only a parking availability for permit holders shows a significant relation with the number of parking actions. The correlation matrix shows that there is a relation between the parking supply and the parking demand in which higher supplies will increase the parking demand.

#### **4.4. Policy data**

As indicated in the conceptual framework in chapter 3 visitor parking demand is also expected to be influenced by factors related to the parking policy. Parking policy is often a local policy, and therefore, the same policy applies to the whole city. In Eindhoven, parking policy differs between different parking areas. However, regarding the areas studied in this research, the same policy applies. Identifying the effect of different parking policies, such as parking cost, requires a comparison of the number of parking actions in different cities. Therefore, in this research, policy-related factors are not included in the regression models.

#### **4.5. Conclusion**

The data analysis in this chapter showed that the usage of visitor parking permits differs per neighbourhood and over time. The differences over time indicate that during the day, the required parking capacity varies. Consequently, while implementing a parking standard based on the peak demand, not the total visitor parking capacity will be used during the day. Implementing the capacity based on the peak demand would allow using the visitor parking capacity for other purposes during the non-peak hours. Due to missing data about the visitor parking capacity, it can not be determined whether the parking standard of 0.3 exceeds the demand. However, it can be concluded that the differences over the day could indicate that parking standards should be determined on a neighbourhood level instead of a general standard applied in all different new development projects. This can be substantiated by the demographic and geographic differences of the parking areas. This indicates that the required number of parking spaces for visitors depend on the characteristics of an area. Therefore, the standards could be specific for the conditions of the area. In chapter 5 the combined effect of different factors on the visitor parking demand and their magnitude will be estimated.

Table 4.5: Correlations between accessibility variables

	Dist. Highway (km)	Availability parking 250m (permit)	Availability parking 100m (permit)	Availability public parking 100m	Availability public parking 250m	Dist. to nearest public parking	Bus stops 400m	Distance to nearest bus stop	Train station 400m	Train nearest	Visitor parking
Dist. Highway (km)	1	.011	.014	-.009	-.053	.034	-.008	-.035	-.023	-.007	-.024
Availability parking 250m (permit)	.011	1	.779**	-0.013	-.154**	-.119*	.119*	-.016	-.079	-.189**	.494**
Availability parking 100m (permit)	.014	.779**	1	-.017	-.121**	-.077	.067	0.044	-.042	-.191**	.445**
Availability public parking 100m	-.009	-.013	-.017	1	.559**	-.039	.223**	-.264**	.132**	-.303**	-.045
Availability public parking 250m	-.053	-.154**	-.121**	.559**	1	-.129**	.125**	-.108*	.141**	-.491**	-.039
Distance nearest public parking	.034	-.119*	-.077	-.039	-.129**	1	-.057	-.021	-.066	.164**	-.075
Bus stops 400m	-.008	.119*	.067	.223**	.125**	-.057	1	-.513**	.020	.042	-.023
Distance to nearest bus stop	-.035	-.016	.044	-.264**	-.108*	-.021	-.513**	1	.059	-.037	.044
Train station 400m	-.023	-.079	-.042	.132**	.141**	-.066	.020	.059	1	-.222**	-.084
Train nearest	-.007	-.189**	-.191**	-.303**	-.491**	.164**	-.037	-.222**	-.222**	1	-.170**
Visitor parking	-.024	.494**	.445**	-.045	-.039	-.075	-.023	.044	-.084	-.170**	1

# 5

## Results multiple regression model

This chapter will discuss the results of the estimated multiple regression model. First, the assumptions for linear regression will be discussed in section 5.1. For this research three different regression models were estimated, the results of these models will be discussed in section 5.2. The regression models will identify what factors explain the visitor parking demand and the strength of the relation. The results of the regression model will be validated in section 5.3. Consequently, this chapter will answer subquestion 4.

### 5.1. Assumptions of multiple linear regression

In chapter 2 the assumptions that have to be met when estimating a regression model were discussed. The first assumption requires the independent variables to be uncorrelated. In Appendix D the correlation matrix is given, describing all relations between the different variables. The matrix shows that the number of inhabitants is strongly correlated with other demographic variables such as men ( $r=.959$ ), women ( $r=.945$ ), age (especially people in the age group between 25 and 44,  $r=.782$ ), the number of households ( $r=.943$ ), single-person households ( $r=.863$ ) and multi-person households ( $r=.826$ ). These variables are also correlated with each other. Most notably, men and women are correlated ( $r=0.820$ ), the number of households is correlated with both men ( $r=.915$ ), and women ( $r=.881$ ) and some of the age groups are highly correlated with men (Inh\_2544  $r=.836$ ). In addition, also correlations are found with geographic factors such as the number of houses (men  $r=.737$ , women  $r=.806$ ) and the number of new build houses (men  $r=.794$ , women  $r=.823$ ). Either one of the variables (the number of inhabitants, households, men or women) should be included in the model to prevent the model from suffering from multicollinearity. Furthermore, since the number of inhabitants per age group is less correlated, these can be considered in the regression model.

Regarding the geographic factors, minor correlations can be found. The number of houses is correlated with different demographic factors; more inhabitants require more houses ( $r=.805$ ). This also holds for the number of households ( $r=.831$ ). As previously discussed, the percentage of owner-occupied houses is correlated with the percentage of housing for sale ( $r=.972$ ). Consequently, either the percentage of rental houses or owner-occupied houses will be considered in the model. This is also the case for the variables that measure the parking supply, and therefore, only one of these variables is included in the regression model. Furthermore, the aggregated variables representing the house size are correlated with the number of houses (small housing,  $r=.917$ ) and the number of multifamily housing (small housing,  $r=.820$ ).

The second assumption is that the residuals in the population have zero mean and a constant spread of variance about the regression line. Figure D.3 shows that this assumption is not met (see Appendix D). After transforming the dependent variable by taking the root square, this assumption is met (see Figure D.3). Besides, also the assumption on normality was not met while using the number of parking actions as the dependent variable (see Figure D.3). After transforming the dependent variable, the assumption on normality is met (see Figure D.4 in Appendix D).

## 5.2. Results multiple linear regression

In this research, three different multiple regression models were estimated. The results of these models are given in Table 5.1, Table 5.2 and Table 5.3. The first model includes all variables, while the second model excluded the variables with high correlations. The latter is considered the final model, which most accurately explains the variance in the visitor parking demand in different postcode areas. Finally, a model was estimated with variables from which outliers were removed. In chapter 4 it was explained that the outliers for inhabitants and households were not removed from the data as these outliers are due to natural behaviour. A third model was estimated with removed outliers from the data of inhabitants and households. This model was estimated to identify whether removing the outliers of these variables would result in a different model outcome.

Table 5.1: Results regression model including all variables

N	R	R Square	Adjusted R Square	Std. Error of the Estimates	F	Sig.
166	0.755	0.570	0.463	7.748	5.333	0.000

Table 5.2: Results final regression model excluding highly correlated variables

N	R	R Square	Adjusted R Square	Std. Error of the Estimates	F	Sig.
390	0.632	0.400	0.384	8.912	25.270	0.000

Table 5.3: Results regression model with removed outliers

N	R	R Square	Adjusted R Square	Std. Error of the Estimates	F	Sig.
372	0.663	0.439	0.423	8.591	26.708	0.000

### 5.2.1. Model including all variables

The first model includes all geographic and demographic variables which were discussed in chapter 4. From the model results in Table 5.1 it can be seen that the model explains 46.3% of the variance of the dependent variable. Table 5.4 shows the coefficients and the statistics of the model. The VIF values in this table indicate the correlations of this variable with other variables in the model. VIF values higher than 5 indicate multicollinearity (Kim, 2019). It can be seen that this model strongly suffers from multicollinearity. Furthermore, the coefficient matrix in Table 5.4 demonstrates that only the number of inhabitants, the number of households, one-person households, the number of houses, the number of multi-person housing, the number of available parking within 250 meters, and the accessibility to bus significantly influence the visitor parking demand. As previously discussed, the demographic variables representing the number of inhabitants and households are strongly correlated ( $r=.943$ , see also chapter 4). Furthermore, some of the coefficients showed signs not in line with expectations based on theory. For example, the number of inhabitants shows a negative relation with the visitor parking demand when controlling for other predictors, while it was expected that inhabitants would attract more visitors by car. However, the number of households do show a positive relationship with the number of visitor parking actions when controlling for other predictors. Since this model suffers from multicollinearity, the contribution of the single variables is hard to identify and thereby, no conclusions on the results can be drawn. Therefore a second model is estimated in which highly correlated variables are removed.

Table 5.4: Coefficients regression model including all variables

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	14.024	19.072		0.735	0.463		
Inhabitants	-0.620	0.296	-2.852	-2.094	0.038	0.002	556.046
Men	0.167	0.281	0.436	0.595	0.553	0.006	160.573
Women	0.320	0.277	0.726	1.156	0.250	0.008	118.186
Households	1.084	0.309	3.936	3.509	0.001	0.003	376.940
Households_1	-0.781	0.233	-2.342	-3.348	0.001	0.007	146.589
Households_1+	0.216	0.279	0.149	0.776	0.439	0.090	11.064
Avg_hhsize	-1.090	4.181	-0.030	-0.261	0.795	0.245	4.083
Middle aged, elderly and children	0.017	0.073	0.059	0.230	0.818	0.050	19.859
Young people and adults	0.183	0.126	0.190	1.452	0.149	0.195	5.138
Income	-2.306	1.666	-0.131	-1.384	0.169	0.375	2.667
Urbanisation	-4.488	4.010	-0.155	-1.119	0.265	0.175	5.727
Urban density	0.002	0.002	0.081	0.694	0.489	0.246	4.063
Population density	5.203E-05	0.000	0.01	0.157	0.876	0.552	1.813
Houses	0.535	0.216	1.771	2.475	0.015	0.007	153.455
Housing_0_100	-0.142	0.098	-0.425	-1.446	0.151	0.039	25.844
Housing_100plus	-0.129	0.151	-0.137	-0.853	0.395	0.129	7.775
Housing avg_surface	0.006	0.037	0.024	0.166	0.868	0.165	6.053
Housing total surface	0.000	0.001	0.101	0.404	0.687	0.053	18.829
Housing multiple family	-0.250	0.121	-0.850	-2.057	0.042	0.020	51.203
Percentage housing rent	0.032	0.066	0.072	0.479	0.633	0.147	6.814
Percentage housing sale	0.063	0.069	0.142	0.907	0.366	0.136	7.367
Housing value (WOZ)	0.003	0.020	0.015	0.146	0.884	0.305	3.278
Housing old	-0.181	0.162	-0.361	-1.116	0.267	0.032	31.285
Housing new	-0.275	0.165	-0.816	-1.660	0.099	0.014	72.520
Distance highway (km)	-0.948	2.301	-0.041	-0.412	0.681	0.343	2.914
Availability parking 250 m (permit)	0.917	0.159	0.456	5.783	0.000	0.537	1.861
Distance public parking	-0.001	0.002	-0.034	-0.463	0.644	0.623	1.605
Bus stops within 400 meters	-1.732	0.681	-0.184	-2.542	0.012	0.637	1.569
Distance nearest bus	-0.013	0.010	-0.095	-1.389	0.167	0.714	1.400
Train station within 400 meters	1.915	6.033	0.020	0.317	0.751	0.835	1.198
Distance nearest train station	-0.003	0.002	-0.125	-1.398	0.164	0.419	2.389
Distance supermarket	6.830	3.628	0.194	1.883	0.062	0.315	3.177

### 5.2.2. Final model

In the second model, variables with high correlations were excluded from the model. Which variables to include was determined based on their relationship with the dependent variable. The variables with mutual correlations higher than 0.8 were tested on the relation with the dependent variable. Then, based on one of the methods described by (Graham, 2003), the variable with the most substantial relationship with the dependent variable was included in the model, and the other variables were excluded from the model. However, a disadvantage of this method is that it ignores the unique contribution of the omitted variable, resulting in a substantial loss of explanatory power (Graham, 2003).

To determine which variables to include in the model, first, for each independent variable, a simple linear regression with the dependent variable model was estimated. The results can be found in Table D.4 in Appendix D. An overview of the variables that showed significant relations with the visitor parking demand is shown in Table 5.5. This table shows that the number of parking available within 250 meters has the most explanatory power. Furthermore, the degree of urbanisation, urban density, population density, inhabitants between 0 and 14 years, inhabitants between 45 and 64, the percentage of rental housing, the percentage of owner-occupied housing, the distance to the nearest train station, age group representing younger people ( $r=.240$ ,  $R^2=0.049$ ) and big houses have significant relations with the number of visitor parking actions. The other variables were not able to significantly explain the visitor parking demand. Based on this information, the multiple regression model is estimated.

Table 5.5: Significant variables simple linear regression models

Variable	N	R	R Square	Adjusted R Square	Std. Error of Estimate	Unstandardised B	Std. Coeff. Beta	t	Sig.
Inh_0-14	449	0.178	0.032	0.029	11.230	0.344	0.178	3.818	0.000
Inh_45-64	450	0.193	0.037	0.035	11.206	0.305	0.193	4.163	0.000
Middle-aged, children and elderly	449	0.222	0.049	0.047	11.127	0.231	0.222	4.815	0.000
Urbanisation	460	0.136	0.019	0.016	11.255	-5.408	-0.136	-2.939	0.000
Urban density	460	0.171	0.029	0.027	11.194	0.003	0.171	3.707	0.000
Population density	460	0.171	0.029	0.027	11.193	0.001	0.171	3.718	0.000
P_rent	413	0.178	0.032	0.029	11.094	-0.069	-0.178	-3.657	0.000
P_sale	418	0.19	0.036	0.034	11.085	0.074	0.19	3.952	0.000
Parking permit _250m	460	0.494	0.244	0.242	1.015	9.879	0.494	12.155	0.000
Train _nearest	460	0.17	0.029	0.027	11.196	-0.004	-0.17	-3.688	0.000
Housing _100+	459	0.21	0.044	0.042	11.118	0.257	0.21	4.599	0.000

The coefficients of the resulting model are shown in Table 5.6. This regression model can explain the visitor parking demand by different demographic and geographic variables ( $F=25.270$ ,  $p=0.000$ ) and explains 38.4% of the variance of the dependent variable. The age of inhabitants is the only variable representing the demographic factors in this model; only people in the age group of people between 15 and 44 show to significantly impact the visitor parking demand when controlling for the other variables in the model. This relation is positive, meaning that people between 15 and 44 will increase visitor parking actions. Because of high correlations between the number of inhabitants, the number of residents per age group and the number of households, not all variables are included in the final model. Furthermore, the household income is also excluded from the model since this variable reduced the explaining power of the model. In addition,

this variable showed to have a negative relation with the number of visitor parking actions. Since the single relation between visitor parking and income showed a positive relation, it is plausible that other variables in the model explain income. Thereby this variable was excluded from the model.

Regarding geographic factors, the final model shows a strong and significant relation with the number of parking available within 250 meters ( $\beta = .511$ ,  $p = .000$ ). This indicates that visitor parking is very dependent on the parking supply when controlling for other variables in the model. Furthermore, accessibility to public transport also shows significant relations with the visitor parking demand since the accessibility to the bus ( $\beta = -.099$ ,  $p = .023$ ) and train ( $\beta = -.179$ ,  $p = .000$ ) are significant. These variables were included in the model by the number of bus/train stops accessible within 400 meters and the distance to the nearest bus/train stop. In the final model, the number of bus stops accessible within 400 meters negatively influences the number of parking actions, implying that an increased number of bus stops accessible within 400 meters reduces the visitor parking demand. However, the accessibility to the train shows a different relation: higher distances to the train station result in a reduced number of parking actions. Since the train station in Eindhoven is situated in the city centre, this relation might represent the distance to the city centre instead of the distance to the nearest train station. This assumption is in line with the population density results that show a positive relation with the number of visitor parking actions controlling for other predictors. The population density indicates a positive relation with visitor parking demand ( $\beta = .122$ ,  $p = .004$ ) and is often higher in the city centre than in other urban zones. This could explain the negative relation of train and the visitor parking demand. As the train station in Eindhoven is located in the city centre, with higher population densities, the number of visitor parking actions will be higher in these areas and lower when the distance to the city centre increases. A final indicator representing the accessibility of areas is the distance to the highway. The results show that a higher distance to the highway will reduce the visitor parking demand ( $\beta = -.099$ ,  $p = .042$ ), showing that the accessibility by car impacts the visitor parking demand.

Finally, also housing characteristics show to impact the number of visitor parking actions significantly. Firstly, the housing surface affects the visitor parking demand when controlling for other variables. Houses with a surface of more than  $100 \text{ m}^2$  show to significantly increase the visitor parking demand ( $\beta = .0154$ ,  $p = .002$ ). Furthermore, old houses attract more visitors ( $\beta = .097$ ,  $p = .030$ ) while new houses attract fewer visitors ( $\beta = -.098$ ,  $p = .030$ ). This might be due to the location of new houses as if new houses require good accessibility to public transport, visitors might travel by public transport instead of the car. Another explanation can be found in the parking supply. The interviews with municipalities revealed that, in general, a trend is seen of reduced parking standards and consequently the parking supply. Since the parking supply strongly relates to the visitor parking demand, the lower parking standards applied at newly developed projects might explain the reduced visitor parking demand at newly built residential areas. Finally, also the type of tenure influences the visitor parking demand: the results show that owner-occupied housing attract more visitors by car ( $\beta = .100$ ,  $p = .055$ ), although this relation is slightly insignificant ( $p > .05$ ).

Table 5.6: Coefficients final regression model excluding highly correlated variables

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	13.403	4.898		2.736	0.007		
Young people and adults	0.130	0.052	0.130	2.480	0.014	0.576	1.736
Population density	0.001	0.000	0.122	2.876	0.004	0.881	1.135
Housing_100plus	0.186	0.061	0.154	3.045	0.002	0.622	1.608
Percentage housing sale	0.039	0.020	0.100	1.922	0.055	0.579	1.726
Housing old	0.070	0.032	0.097	2.175	0.030	0.798	1.253
Housing new	-0.052	0.024	-0.098	-2.214	0.027	0.805	1.242
Distance highway (km)	-2.554	1.253	-0.099	-2.038	0.042	0.671	1.490
Availability parking 250 meters (permit)	1.017	0.090	0.511	11.327	0.000	0.779	1.283
Bus stops within 400 meters	-0.974	0.427	-0.099	-2.278	0.023	0.839	1.192
Distance nearest train station	-0.004	0.001	-0.179	-3.786	0.000	0.708	1.411

### 5.2.3. Model excluding outliers

Data analysis showed that multiple variables have outliers which include the number of inhabitants and households. Outliers are exceptional values in the dataset that can distort statistical analyses and violate their assumptions. In spatial analysis, it seems plausible that there are significant differences in the number of inhabitants and households per postcode. Therefore, in the final model described in subsection 5.2.2 the outliers were assumed to be a cause of natural behaviour and therefore not removed from the data. The final model showed that both the number of inhabitants and the number of households did not significantly relate to the number of visitor parking actions and could be explained by high correlations with other variables. Furthermore, the simple linear regression also showed no significant relation between the number of visitor parking actions and the number of inhabitants and households. The high variance of these variables are likely to contribute to the insignificant relation between these variables and the number of visitor parking actions. To test whether the model results change as a result of removing the outliers in these variables from the data, a third model was estimated. In this model, the outliers of both inhabitants and households were removed from the data. The resulting model is shown in Table 5.3 and the coefficients are shown in Table 5.7.

The model that removed outliers in the dataset shows a higher predictive power than the final model 2. This model explains 43.9 % of the variance of the dependent variable. However, due to high correlations, either the number of inhabitants or the number of households was included in the model. Therefore, replacing the number of households with fewer inhabitants resulted in a less predicting model (adjusted  $R^2 = .392$ ). Furthermore, due to correlations between households and new housing, new housing was removed from the model.

The resulting model shows that a higher number of households in a particular area will attract more visitors when controlling for other predictors. However, age becomes insignificant and shows a relatively high VIF value (2.069), indicating a high correlation. However, removing this variable from the model reduced the predictive power of the model. Furthermore, also the relation with new housing is insignificant in this model. Since these variables were significant in model 2, these variables might be caused by the number of households since this variable was not present in the first model.

It is important to note that removing the outliers from the data ignores the natural diversity between different postcodes. As was discussed previously, the outliers found in the data are not expected to be due to a measurement error, but it represents the actual situation. Therefore, the results of the final model described in subsection 5.2.2 describe the final results of this research. The model's results described in this section could confirm that there is no relation between the visitor parking demand and the number of inhabitants. However, the model showed that when removing the outliers from the data, the number of households influence the visitor parking demand. However, the high correlations with the other demographic variables do not allow interpret these results. Therefore, the results of this model can not be used.

Table 5.7: Coefficients regression model with removed outliers

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	13.403	4.898		2.736	0.007		
Households	0.162	0.058	0.145	2.805	0.005	0.619	1.616
Young people and adults	0.084	0.066	0.074	1.269	0.205	0.483	2.069
Population density	0.001	0.000	0.114	2.606	0.01	0.86	1.163
Housing_100plus	0.264	0.085	0.166	3.059	0.002	0.57	1.755
Percentage housing sale	0.061	0.023	0.151	2.707	0.007	0.529	1.889
Housing old	0.084	0.055	0.07	1.532	0.126	0.78	1.282
Distance highway	-3.747	1.355	-0.14	-2.765	0.006	0.639	1.566
Availability parking 250 meters (permit)	0.972	0.092	0.491	10.579	0.000	0.764	1.309
Bus stops within 400 meters	-1.018	0.475	-0.100	-2.145	0.033	0.763	1.310
Distance nearest train station	-0.005	0.001	-0.190	-3.964	0.000	0.715	1.399

## 5.3. Validation: analysis of different postcode areas

Since only data of Eindhoven is available, validation of the results is complex. A good validation would estimate a model based on data of another city and compare whether the results are in line with the results of

the regression model of Eindhoven. Validation of the regression model is performed by observing the local conditions of different postcodes by Google StreetView. This is a practical way to validate whether the model gives the right results. Furthermore, this will make the results interpretable.

Figure 5.1 shows the postcode with the highest number of parking actions. In Figure 5.1a the characteristics of the surrounding area is shown while Figure 5.1b shows a street view. The map shows that the postcode is situated near a large road in an area with much housing. Furthermore, the parking spaces are situated next to the road. The demographic data of this postcode indicate a relatively low number of inhabitants (50 inhabitants), of which the most dominant group is between 15 and 44 years. Finally, public transport can be reached within 400 meters.

In Figure 5.2 is the opposite of Figure 5.1. The number of inhabitants is very high at this postcode, while parking actions are also relatively high (425 inhabitants). First of all, it can be seen that the housing consists of apartment buildings. This indicates that less space is used, and as seen from the street view, less space is used for parking. Most importantly, non-paid parking is situated within 100 meters from the postcode. Therefore, it is likely that visitors will park in these areas, and residents do not have or do not use a visitor parking permit.

Figure 5.3 and Figure 5.4 represent cases with a relatively high number of visitor parking actions. However, the areas are quite different. The number of inhabitants at the Frederiklaan (30 inhabitants) is relatively low compared to the number of parking actions, while at Den Bult, the number of inhabitants (60) is twice as much as at the Frederiklaan. The difference between these two areas is that while at Den Bult public transport is accessible within 400 meters, the accessibility to public transport, the Frederiklaan there is not easily accessible by public transport. Furthermore, most of the inhabitants at the Frederiklaan are older than 45 (50% of the inhabitants), while in Den Bult, the number of children is relatively high (25% of the people is between 0 and 14 years). The lack of good accessibility to public transport might explain the relatively high visitor parking demand by car at the Frederiklaan, while the number of children can be seen as the explaining factor for Den Bult. Furthermore, at the Frederiklaan, there is plenty of space, while at Den Bult, the parking space seems very limited. These two figures clearly show that different explanations can be found for visitor parking actions in a certain area.



Figure 5.1: Postcode with high number of visitor parking actions (2733) (source: GoogleMaps)



Figure 5.2: Postcode with low number of parking actions (26) (source: GoogleMaps)

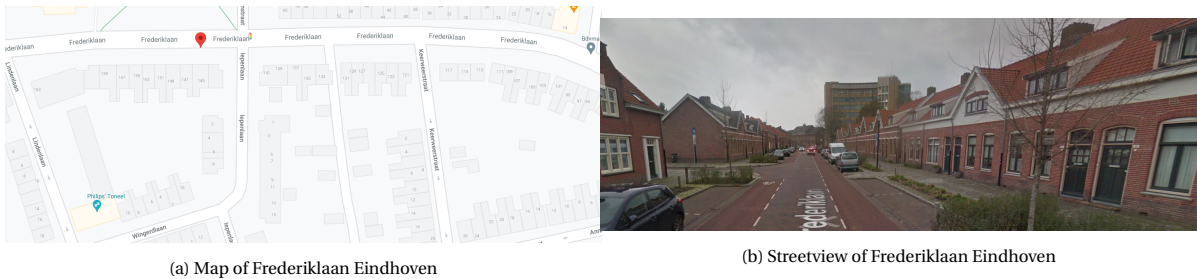


Figure 5.3: Postcode with relatively high number of parking actions (1304) (source: GoogleMaps)

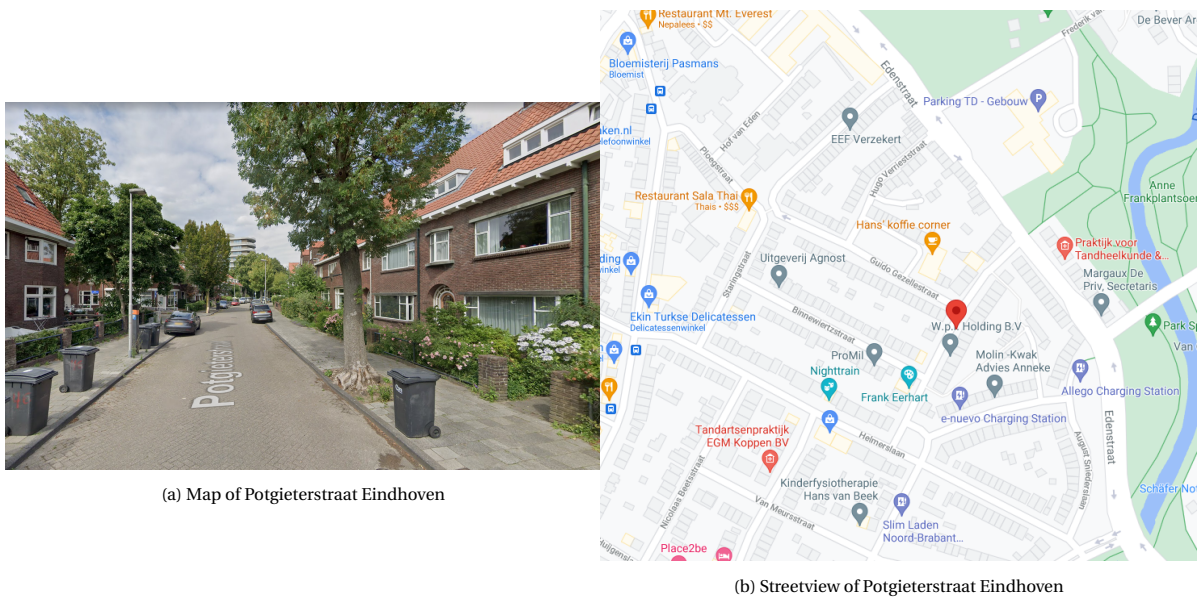


Figure 5.4: Postcode with relatively high number of parking actions (1200) (source: GoogleMaps)

## 5.4. Conclusion

The regression model shows that both demographic and geographic relations influence the visitor parking demand. The final regression model explains 38.4% of the variance of the visitor parking actions by the demographic and geographic variables. However, a big part of the variations in the number of parking actions between different postcodes could not be explained. From this, it can be concluded that visitor parking demand is also influenced by other factors.

From the demographic factors, only the variable age was identified as a variable significantly impacting the visitor parking demand. Other demographic variables were removed from the model due to high correlations. The number of inhabitants did not show a significant and strong relation with the visitor parking demand in simple linear regression. Geographic factors also impact the visitor parking demand. Especially the availability of parking space to permit holders strongly influences the number of visitor parking actions. It can be concluded thereby that visitor parking demand is strongly related to the parking supply. Furthermore, also housing characteristics significantly influence visitor parking demand. The results show that bigger houses attract more visitors, while newly constructed houses negatively influence the visitor parking demand.

The regression model results could not confirm all relations identified in the conceptual framework. Especially the theories related to the demographic variables could not be tested due to high correlations. However, the model with removed outliers did result in a better model, showing that the number of households influences the visitor parking demand. Nonetheless, eliminating these outliers does not consider the natural behaviour regarding demographic variables in different areas leading to wrong results. Therefore, it can be concluded that the number of visitor parking actions is not dependent on the number of inhabitants or households. This is confirmed by the analysis of postcodes by Google StreetView. The analysis showed that postcodes with high numbers of parking actions had a low number of inhabitants while other areas with a higher number of inhabitants had lower parking actions. Furthermore, the validation confirmed that the number of parking actions differs depending on the local conditions such as the parking supply, the accessibility to public transport, the housing characteristics and the dominant age group in the area.

# 6

## Conclusion

High parking standards result in an oversupply of parking places in urban areas. As a consequence, this comes with challenges regarding inefficient land use, unaffordable housing and increased car ownership and car usage. Literature showed that sufficient parking supply is achieved by taking local conditions into account and determine context-specific parking standards. These studies do, however, not take visitor parking into account. In addition, earlier research showed that visitor parking standards applied in The Netherlands often exceed the parking demand. This research aimed to identify how visitor parking demand depends on the local circumstances of a specific urban area. This will contribute to developing a new approach for the determination of visitor parking requirements in Dutch residential urban areas. The main research question answered in this research is: *What factors explain the visitor parking demand in Dutch urban residential areas.* This chapter will answer the main question and indicate what this will mean for the visitor parking standards in Dutch urban residential areas.

Where parking policy was initially focusing on supplying sufficient parking places, it is currently used to obtain other policy goals such as the reduction of car usage. Dutch parking policy therefore has changed from demand oriented to supply oriented. Literature research and interviews with the municipality of The Hague and Eindhoven revealed that there is a dilemma between liveability of cities and the accessibility of cities. Parking policy plays a major role in this dilemma. Visitor parking is often included in parking policies by offering visitor parking permits to residents of paid parking areas. Consequently, residents of such areas assume that they legally deserve (visitor) parking permits and expect municipalities to supply sufficient (visitor) parking places. This makes a reduction of visitor parking standards, in contrast to the regular standards, politically hard to accomplish.

In The Netherlands, parking standards are defined by the CROW. Municipalities adjust these standards to the specific circumstances that apply to their municipality. The residential parking requirements provided by the CROW vary for different housing types and urban zones. However, a parking requirement of 0.3 parking spots per house is provided for visitor parking and does not consider the housing type and the urban zone. The conceptual framework developed in this research identified the total residential parking demand. This framework showed that residential parking demand is dependent on the parking demand generated by residents and the visitors of these residents. In addition, the framework showed that theoretically, the visitor parking demand is dependent on the characteristics of the visited area and the characteristics of the visitor. However, the latter could not be measured in this research. Conclusively, the conceptual framework shows that the visitor parking demand is influenced by many different factors, making it complex to explain.

Data on the usage of visitor parking permits in Eindhoven was used as a proxy for the visitor parking demand in Eindhoven. Data analysis showed that the number of parking actions differed between parking zones. Furthermore, not only the number of parking actions but also the spread during the day differed in each parking zone. This could be explained by different characteristics of the areas, such as the age of residents and the housing type. In general, in Eindhoven, most visitor parking actions are during the evening hours with a peak around 7 p.m. This indicates that the total capacity of 0.3 parking spots per house, as currently used, is not needed for visitors throughout the day. This information could be considered when estimating the required

number of parking, for example, by considering multiple uses of the visitor parking spaces (e.g. by both visitors and business visitors). Furthermore, the variation of the spread over the day in different areas indicates that the visitor parking standard could be based on the local conditions instead of implementing the same general standard for visitor parking.

In order to determine the relations between the different factors influencing visitor parking demand, multiple regression analysis was used. This analysis showed that visitor parking is influenced by the local circumstances of the area that is visited. Due to lacking data, the characteristics of the visitors could not be included in the model. In practice, municipalities will only be able to consider local circumstances when determining the number of visitor parking places. Furthermore, according to the theoretical framework, it is expected that demographic variables in the parking area reflect the same demographics as the visitors. Due to lacking data, the effect of policy-related factors identified by the framework could not be identified. This could explain why the model predicts just 38.4% of the variance in visitor parking demand.

The results showed that visitor parking is influenced by both demographic and geographic characteristics of the area. For the demographic variables, it was shown that age has a significant role. People between 15 and 44 years attract more visitors. Due to high correlations, other demographic variables could not be included in the model. It was expected that the number of inhabitants would significantly affect visitor parking demand. However, simple linear regression did not show a significant effect of inhabitants in the residential area. It can therefore be concluded that the number of inhabitants at the visited residential area does not influence the visitor parking demand. This was also shown in the validation, in which the analysis of different postcodes showed that areas with a low number of visitor parking actions occasionally had high numbers of inhabitants on a postcode level. Other factors such as sufficient parking availability, non-paid parking areas nearby, or good accessibility to public transport were observed in these residential areas. Consequently, it can be concluded that visitor parking depends on different characteristics of the parking area rather than on the number of inhabitants.

Furthermore, the supply of parking places showed to be an important determinant of visitor parking demand. Reducing the visitor parking standards and, consequently, the visitor parking supply will lower visitor parking demand. In this way, municipalities can influence the visitor parking demand. However, lowering parking capacity also requires considering other factors such as the accessibility to public transport, the population density and the housing type. Areas with good access to public transport require less capacity for visitor parking, while higher population densities and bigger housing require more parking. Nevertheless, newly constructed houses showed to reduce the visitor parking demand significantly. New development projects could therefore apply lower visitor parking standards. However, this relation can also be due to lower parking supply in these new areas. The impact of different factors on the visitor parking demand thereby requires an extensive analysis of the context of parking areas which will contribute to a better estimation of the required capacity for visitor parking.

Based on the results of this research, it can be concluded that visitor parking demand is influenced by context-specific factors that include both demographic and geographic characteristics of the parking area. Determining visitor parking standards requires analysing the local conditions of the parking area, including the target group of the area (age), the housing characteristics, the accessibility by public transport, the accessibility to the highway and the visitor parking supply. The results showed that visitor parking supply is an essential determinant of the visitor parking demand, and hence, reducing the supply will reduce the visitor parking demand. Taking these local conditions into account will contribute to a better estimation of the expected visitor parking demand and a better estimate of the required capacity. Policymakers can use this information to underpin why visitor parking standards can be reduced. Besides, the spread over the day shows that the maximum required capacity will not be used during the day, allowing to use of the implemented parking capacity for multiple purposes. Finally, the lacking relation between the number of inhabitants and households in an area implies that visitor parking standards might not be defined as a single value per housing. Visitor parking capacity thereby could be determined based on the local conditions rather than defining a single national standard that provides the number of parking spaces required per house.

# 7

## Discussion and Recommendations

This chapter reflects on the conceptual framework on which this research was based. Secondly, the limitations of this research will be discussed. The final section will reflect on how this research could be used by policymakers, followed by recommendations for further research.

### 7.1. Reflection on conceptual framework

This research gives a new perspective on visitor parking standards. The theoretical framework in this research showed that total residential parking demand depends on both the parking demand generated by residents and by visitors of these residents. While residential parking demand depends on residents' car ownership and car use, visitor parking depends on visitors' car ownership and car use. The car use of residents depends on demographic, geographic and policy factors in the residential area. For visitor parking, car use and visitor parking demand depend on the visitor's characteristics and the local conditions at the parking area. The latter will determine whether visitors owning a car will use their car to visit other residential areas.

This research only measured the impact of context-specific factors at the parking area of the host. Since data of one single city was used, policy factors could not be included in the model. Parking policy is a local policy on a city level, and therefore variation resulting from different parking policies could not be estimated based on one case. Estimating the effect of policy factors on the visitor parking demand requires data of multiple cities with different parking policies. Using data from multiple cities will also contribute to a higher reliability of the results.

From the demographic variables, only age showed a significant effect on the visitor parking demand in attendance of other variables. High correlations of the demographic variables did not allow to test all identified relations, and consequently, no conclusion can be drawn regarding the relation of these variables and the visitor parking demand. However, based on this study, the results might indicate that demographic variables at the residential area of the host do not influence the visitor parking demand. Nonetheless, follow up research with more accurate data is required to draw this conclusion. Thereby, the conceptual framework should not yet be revised.

The parking supply showed to have the most substantial impact on the visitor parking demand of the geographic factors. Consequently, this research proves that these relations already defined in earlier studies of Litman (2016) and Christiansen et al. (2017) does not only apply for residential parking demand but also holds for visitor parking demand. Nonetheless, using a multiple regression assumes that the attendance of multiple factors influences the visitor parking demand. One of these factors is the accessibility to the bus, suggesting that good accessibility to public transport will reduce the visitor parking demand. Previous research showed that reduced residential parking standards should be accompanied by good accessibility to other modes of transportation (Antonson et al., 2017) (Johansson et al., 2019). This research verifies that visitor parking standards could be reduced when good accessibility to public transport is assured. However, the accessibility in this research was a simplification of the real world by only taking the straight distance to bus stops into account. Taking the service levels of different modes of transportation will allow giving a better approach to the

mode choice, and hence the results will be more reliable. Besides, the conceptual framework indicated that the accessibility of the area by other modes was expected to influence the visitor parking demand. However, this research could not capture the effect of the accessibility of other modes such as bicycles, walking and new modes of transportation such as shared cars.

In general, based on the results, it can be concluded that the developed conceptual framework gives a good overview of the factors influencing the visitor parking demand. However, it is important to note that these framework identifies the potential effect of individual factors on the visitor parking demand while the regression model estimated the effect of individual variables in the attendance of other variables. Consequently, not all relations identified in the framework showed significant relations with the visitor parking demand. In addition, from the demographic factors only age showed to significantly impact the visitor parking demand implying that the demographic factors at the residential area of the host have less impact than the geographic characteristics. However, since data used in this research was limited, future research is needed to confirm whether this holds true. Besides, only factors related to the residential area of the host was considered. Theory suggests that the visitor parking demand also depends on characteristics of the visitor and thereby from a theoretical perspective also these factors could be considered. In practice however, this information is less useful since municipalities will not be able to base their standards on the characteristics of their visitors. Finally, the regression model showed to explain about 40% of the variance in the number of parking actions. This means that the other 60% is explained by factors that were not captured by the multiple regression model. Further research is required to determine the impact of the variables that could not be considered in the model.

## 7.2. Research limitations

This section reflects on how limitations of the research and decisions made in the research have impacted the outcomes. These are related to the research methodology and the data collection. First, the limitations regarding the used method are discussed. Second, the limitations of the data collection are discussed.

### 7.2.1. Limitations regarding the research method

This research is based on the use of visitor parking permits in one single city in The Netherlands, Eindhoven. This comes with several drawbacks. To start, this did not allow to test the policy-related factors. However, literature suggested that not only demographics and the built environment influences the car ownership and car use but also policy factors, such as the availability of parking permits and parking regulations were expected to visitor parking demand. Since parking policy is a local policy that applies to a whole city, differences within the same city will not occur. Estimating the impact of policy factors requires analysing the visitor parking demand and the context-specific factors, including the parking policy in various cities. Comparing the parking actions in cities with different parking policies will identify the effect of parking policy on the visitor parking demand and might contribute to a higher explained variance. Furthermore, a comparison with parking data of other cities will indicate whether the identified factors also explain the visitor parking demand in other types of cities. Eindhoven has with a number of 223,209 inhabitants, a relatively low number of inhabitants compared to bigger cities such as Amsterdam (821,752 inhabitants), Rotterdam (623,652 inhabitants) and The Hague (514,861) and thereby show other characteristics regarding the spatial layout, demographic composition and their mobility policy. Using data of multiple cities regarding the number of parking actions using parking permits would have contributed to more reliable results and thereby help to come up with a better approach to estimate the number of required parking for visitors.

This leads to the second limitation of this research. This study could not identify how the results of this research can be used to come up with a new approach to set visitor parking standards. From a practical perspective, this research aimed at gaining insight into how different factors could be used to determine an approach to set visitor parking standards and show that the 0.3 parking spaces per house in The Netherlands exceeds the demand. The analysis of parking actions showed differences between areas regarding the number of visitor parking actions and are depending on the parking supply. However, the number of parking actions could only be accurately observed between 9 a.m. and 9 p.m. when paid parking applies. Outside these hours, visitors do not have to be registered when they park their cars in paid parking areas. Additionally, accurate data about the actual parking capacity and the applied visitor parking standards in each area

was missing. Consequently, it could not be determined whether Eindhoven's current visitor parking standards result in oversupply or a deficit of visitor parking. Nonetheless, this research concludes that it could be better to use local conditions of the visited parking area instead of using a single fixed number that applies to all new development projects in the city. One could argue that the equation that resulted from the multiple regression can be used to determine the visitor parking standards. However, this equation determines the static visitor parking demand and does not consider that the visitor parking demand differs during the day. Moreover, the regression model explains about 40% of the variance, meaning that other factors might explain 60% of the variance. Conclusively, a new method to determine the visitor parking standards requires further research that focuses on identifying other factors that influence the visitor parking demand and developing a method to translate the identified factors into new visitor parking standards.

This study applied the usage of visitor parking permits as a proxy for the visitor parking demand. However, this approach considers only the observed parking demand and does not take visitors into account that parked outside the parking zones for permit holders, paid for their parking or parked outside the paid parking hours. Taking these other visitors in consideration, a more accurate visitor parking demand could have been determined resulting in more reliable outcomes. However, the validation showed that the identified factors were also observed in practice suggesting that the visitor parking permit is a sufficient indicator to explain the visitor parking demand.

Finally, the modelling approach used in this research relies on a simplification of the actual visitor parking system. The theoretical framework showed that visitor parking demand most importantly depends on the car use of visitors. Using the visitor parking permit registrations as a proxy for visitor parking demand neglects car use. Consequently, the multiple regression model only estimated the direct relation between different factors while neglecting the indirect relation between the visitor parking demand and the demographic and geographic factors via car use. A structural equation modelling (SEM) is able to capture interrelationships among variables (Weston and Gore Jr, 2006). A SEM allows estimating relationships among constructs and thereby would have allowed estimating the car use based on the context-specific factors and consequently the visitor parking demand. However, this requires information regarding the characteristics of the visitors, the trip characteristics and information about the transport systems. Using a SEM will enable to confirm the theory that visitor parking demand depends on both visitor characteristics and characteristics of the parking area. In this research, only the latter could be estimated as a result of limited data availability. On top of this, in practice, municipalities will base their parking standards on the local conditions rather than considering the characteristics of potential visitors' characteristics. Nonetheless, from a theoretical perspective, it would be interesting to consider visitor travel behaviour.

### **7.2.2. Limitations from data collection**

The results of this research depend on the collected data and are therefore influenced by the data collection limitations. First of all, the parking data was prepared based on the postcode of the host. This method allowed to determine the local conditions of the parking area but also comes with several drawbacks. The parking actions registered on a postcode outside Eindhoven and actions registered outside the parking areas for permit holders were changed to postcodes within the parking area. These changes were made based on the ratio of parking actions on other postcodes in that specific parking area. Assigning the postcodes differently may result in more or less parking actions in certain areas and thereby could reveal to depend on other local conditions. Consequently, the results of the regression model could be different. However, excluding the cases registered on a postcode outside Eindhoven or a permit parking zone did not result in different model results suggesting that the estimated factors are stable.

The demographic data retrieved from the CBS were highly correlated. Subsequently, not all demographic variables could be considered in the model. In addition, the data included a lot of missing values which were replaced by ratios found on a neighbourhood level. However, this made the demographic data less reliable. More accurate data could have identified the relation between the visitor parking demand and demographic variables with more certainty. Additionally, this might have changed the conclusion that from the demographic variables at the hosts' residential area only age determines the visitor parking demand. An example of more accurate data is the age being represented by the average age in a neighbourhood instead of the number of people per age group. This will allow to include other demographic variables in the regression

model, such as the number of inhabitants. In addition, this research only used demographic data about the residential area. The theoretical framework identifies that visitor parking demand also depends on the characteristics of the visitor. As previously discussed, this will contribute to a higher explanation of the variance of visitor parking demand. Furthermore, it would give a better overview of the residential parking system and how different factors influence the visitor parking demand. However, it should be considered that this is only useful from a theoretical perspective since, in practice, information regarding the visitors will not be available and not be used to determine the visitor parking standards.

Data collection of geographic variables was based on different assumptions. Variables related to the urban zone and density (urban density, degree of urbanisation and population density) were measured on a neighbourhood level instead of a PC6 level. This results in fewer differences between postcodes, and thereby explaining the variance in the number of actions could be more complex. Nonetheless, population density showed to impact the visitor parking demand significantly. Furthermore, in contrast to the expectation, the housing value was not included in the final model. This can be explained in various ways. First, the missing values were determined manually and are highly sensitive to measurement errors. Another explanation is the relation between the percentage of owner-occupied housing and the income. Retrieving accurate data about the housing value requires access to the entire database of the 'waarderingkamer' instead of retrieving the data for each individual house of a postcode by the 'WOZ-waardeloket'. Including this data in the regression model might identify a relation between the housing value and the visitor parking demand.

Another assumption in the data gathering of geographic variables was how the accessibility to different facilities was measured by GIS. Two different methods were used, one indicating the number of facilities within a certain distance and the second using the nearest distance to these facilities. However, the distance was measured based on a single line distance, without including network characteristics and ignoring the walking distance. In addition, the variables that considered the number of facilities within a specific distance increases with increasing distance. This also resulted in higher coefficients in the model. However, it was not considered that utility of these facilities (such as transportation mode, parking, supermarket) decrease when walking distance increases. Conclusively, the variable representing the accessibility to different facilities simplifies the actual accessibility and does not consider actual travel behaviour. The resulting coefficient in the regression model therefore might overestimate the effect on the visitor parking demand. Finally, also the accessibility to public transport was measured only based on the single line distance. In theory, the accessibility to public transport also considers the service level and the travel time/walking distance to public transport. Taking these factors into account will result in a better approach to the accessibility of public transport. In the final model, only the number of bus stops significantly impacts the visitor parking demand, while the distance to the nearest bus stop did not influence the demand significantly. Including service level into the accessibility measures of public transport will probably identify a more substantial relation between the visitor parking demand and accessibility to public transport.

The relation between the supply and the usage of the visitor parking permit showed to be highly significant. It is essential to consider that the car use and the visitor parking demand strongly depend on the utility that visitors gain from taking the car. This utility is determined by the walking distance, the availability of parking and the parking cost. In this research, the parking accessibility was measured by the number of parking available within 100 and 250 meters. The problem with this approach is that increasing distances automatically result in higher availability of parking. In order to solve this problem, the utility of increased walking distance should be used. This requires considering both network characteristics and characteristics of the visitors. Considering the dis-utility of higher walking distances will reveal that higher walking distances decrease the visitor parking demand and result in a more reliable relationship with the visitor parking demand.

### 7.3. Recommendations

Based on the results and limitations of this research, recommendations can be done. First, the implications of this research and the recommendations for practice will be discussed. Second, recommendations for further research will be done.

### 7.3.1. Implications and recommendations for practice

Given the results of this research, recommendations for practice can be made. First of all, this research showed that parking supply is a fundamental determinant for the usage of the visitor parking permit. Policymakers can use this information to underpin why lower visitor parking standards can be used. However, the results also show that other factors influence the visitor parking demand, such as the accessibility to public transport, the distance to the highway, housing characteristics and the age of the residents in the parking area. Policymakers can use this information to reduce parking standards, while developers can use this to implement lower parking standards depending on the development project. For example, when developers provide good accessibility to public transport, visitor parking standards can be reduced. This requires that municipalities consider these reductions in their local parking policies.

The analysis of parking standards in different municipalities already showed that some municipalities changed their parking policy and differed their parking standards based on the urban zone or implement reduction factors when good accessibility to other modes is guaranteed. This research supports the indicators used by these municipalities from a theoretical perspective. New parking policies identify different zones and apply different standards in these zones. These zones are identified based on the car dependency of the area, the accessibility to public transport, and the quality of cycling and walking facilities in the area. It was seen that in the zones near the city centre, a lower visitor parking standard is applied while getting further away from the city centre higher standards are applied. This contrasts with the outcome of this study, showing that higher distances to the city centre decreased the visitor parking demand. However, municipalities consider that sufficient parking is provided by underground and off-street parking facilities in the city centre, and therefore lower standards can be applied in these areas. The usage of different visitor parking standards based on the urban zone conclusively shows to be a suitable method to determine more accurate visitor parking standards.

A second option is to design custom visitor parking standards that are specific to a particular area. Thereby, municipalities could determine a baseline standard from which can be deviated based on the local conditions of the (new) developed area. Furthermore, determining the visitor parking standard does not only require taking local conditions into account but also the fact that the visitor parking demand differs during the day. As already suggested, basing the visitor parking standards on the peak demand will leave parking spaces for visitors unoccupied during most times of the day. It is therefore recommended to determine the parking capacity at a neighbourhood level, taking not only the parking capacity of the residential area into account but also other facilities. This will prevent the construction of too many parking facilities being unoccupied during the day and inefficient land use. Nonetheless, this requires insight into the expected distribution over the day and how different factors explain this spread.

From a practical perspective, the reason for this research was an article published by Spark (2018) that revealed that current visitor parking standards could be lowered to 0.1 parking spots per housing instead of the currently used 0.3. Due to a lack of sufficient data about the capacity of parking and the applied parking standards, this research could not confirm this statement. However, the analysis revealed that visitor parking demand differs per neighbourhood, during the day and even per day of the week. Municipalities can use this information during parking policy development. For example, based on this information, multiple uses of parking can be considered for residential visitor parking. Thereby municipalities have to establish their visitor parking policy on observed circumstances in their city. Furthermore, the relation between parking supply and demand confirms that lower parking standards will reduce the visitor parking demand. This proves that lowering parking standards will not directly result in more parking pressure.

Finally, this research showed that the usage of visitor parking permits depends on context-specific factors. It is therefore recommended for municipalities to determine the visitor parking standard based on the context of an area. This includes the neighbourhood's location (the distance to the city centre), the population density, the distance to the highway, the accessibility to public transport, the housing characteristics and the age of the target group. Taking the context-specific factors into account will help municipalities and developers determine what locations require more or less visitor parking capacity. The interviews with the municipalities revealed that lowering the visitor parking standards is politically infeasible. This research will help municipalities prove that lower parking requirements can be feasible, depending on the circumstances of an area.

### 7.3.2. Recommendations for further research

This study provided an initial insight into visitor parking residential areas. However, this research only revealed a small part of the complexities of residential visitor parking and therefore follow-up research is needed.

Most importantly, the estimated regression model in this research explained 38% of the variance in the visitor parking demand. The first recommendation therefore is to do further research into the factors that influence the visitor parking demand. As discussed in section 7.2 this is related to both insufficient data and the statistical model used. Consequently, future research should first collect more accurate data regarding the demographic and geographic variables. As previously discussed, the data used in this research was strongly correlated and based on different assumptions. For the demographic variables, more accurate data include the average age of the residents in an area and more accurate numbers for the household income. Lastly, the median income was used to identify three different income groups. It is recommended to use the average income or base the income classes based on the actual household income.

Regarding the data collection of the geographic variables, it is recommended to take the utility of different modes into account. The accessibility was only measured based on the single line distance. Therefore future research should take the service level of public transport into account by considering the actual walking time to public transport by the network characteristics, the number of different lines at each bus stop and the frequency of the public transport. Moreover, this research measured the availability of parking and the accessibility to public transport as the number of parking and bus stops/train stations within a certain distance. Consequently, increased distances resulted in better accessibility. Future research should consider that higher distances will decrease the experienced mode utility and hence the mode choice. This requires gaining more insight into the preferences of visitors.

To gain more insight into visitors' preferences and identify the effect of visitor characteristics on the visitor parking demand, it is recommended to conduct a survey among the visitors that park their cars in residential areas to visit residents in these areas. Furthermore, a stated choice experiment among all visitors of a residential area, including visitors using other modes of transportation, will reveal the factors that visitors consider in their mode choice when visiting a residential area. These surveys can be used to gain better insight into how visitor characteristics influence the visitor parking demand. Furthermore, it allows the estimation of a structural equation model. However, it should be noted that determining the impact of characteristics of the visitor are only interesting from a scientific perspective. In practice, only information about the parking area will be available, and consequently, municipalities will base their parking standards only on this information.

This leads to the fourth recommendation, which is to estimate the structural equation model (SEM). The statistical regression model in this research is based on many assumptions and simplifications, and the characteristics of the visitor itself were neglected. A structural equation modelling will allow to consider the factors that influence the car use and thereby the visitor parking demand instead of deriving the visitor parking demand from the observed usage of the visitor parking permit. This method will provide a deeper understanding of the visitor parking system. Furthermore, a SEM analysis will allow to include indirect relations in the model.

This research could not identify the relation between visitor parking demand and policy-related factors. Therefore, it is advocated to run the multiple regression model again considering the visitor parking actions of different cities and variables representing the policy factors that apply in each city. Herewith, the policy-related factors identified in the conceptual framework of this research can be used. Furthermore, other relations identified by the conceptual framework were not considered and it is thereby recommended to include these in future regression models. Literature suggests that not only the accessibility to car and public transport influence the visitor parking demand but also the quality of the cycling infrastructure, walking infrastructure and the availability of newer modes of transportation such as shared cars will influence the visitor parking demand. This requires taking the cycling and walking network characteristics into account. Furthermore, data about the availability of shared cars should be made available. Qgis already allows to include network characteristics and has a function to identify the accessibility of shared cars. However, this research could not use these functions due to limited time. Future research should use these functions and include the accessibility of different modes.

Although this research showed that context-specific factors significantly influence visitor parking demand, it could not develop an approach on how the influencing factors can be used to determine new visitor parking standards. This research aimed to identify the factors that explain the visitor parking demand. To make the results useful for practice, it is recommended to develop a method that translates these factors to a valid visitor parking standard. First of all, this requires improving the model with the earlier described suggestions. Second, the regression equation should be translated to an equation that determines the required visitor parking demand. The equation estimated in this model estimates the visitor parking demand for a whole year. However, to determine a visitor parking standard, the parking demand for a representative hour has to be used. Consequently, further research should identify how the spread of the number of parking actions can be explained. Based on this information and a complete overview of all factors influencing the visitor parking demand, an appropriate visitor parking standard could be determined.

Finally, this research used data for 2019. It is expected that trends in mobility will change car use and hence the visitor parking demand. As already pointed out by Engel-Yan and Passmore (2010), determining context-specific requirements are sensitive to existing conditions and therefore do not take future conditions into account. Hence it is recommended to conduct additional research into the effects of future developments on visitor parking. This includes developments in the demographic composition of a particular area and trends in mobility. For example, it is useful to consider that people moving to new residential areas will grow older or move to other residential areas. This might change the demographic conditions of a specific parking zone. In addition, trends in mobility such as the development of shared mobility and autonomous vehicles create opportunities to reduce car use and hence impact the visitor parking demand. Further research should therefore aim to identify how visitor parking will be affected by these trends and how this can be considered in parking policies.

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# A

Scientific Paper

# A new perspective on residential parking policy

## A multiple regression analysis to explain visitor parking demand in Dutch urban residential areas

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### Abstract

Cities are growing, leading to challenges to keep cities sustainable, liveable and accessible. In Europe, passenger mobility is focused on personal car usage, making parking availability an essential and challenging subject in development projects. The required parking capacity is determined based on parking standards, indicating the minimum number of spots developers need to construct. High parking standards result in an oversupply of parking places in urban areas. Literature advocates to implement context-specific parking standards that depend on the local conditions of the residential area. However, these studies neglect the visitor parking standards while in practice an oversupply is often observed. This research aims to identify factors that explain the visitor parking demand and what this means for the visitor parking standards. The developed conceptual framework showed that visitor parking demand depends on the demographic characteristics of the visitor, the geographic and policy factors at the residential area of the visitor and the demographic, geographic and policy characteristics at the residential area of the host. The usage of visitor parking permits in Eindhoven was used as a proxy for visitor parking demand to estimate a multiple regression model. The results showed that age, population density, distance to the city centre, housing characteristics, accessibility to public transport, and parking supply at the residential area of the host influence visitor parking demand significantly. Characteristics of the visitor and policy factors at the parking area could not be considered due to lacking data. The results show that visitor parking standards could be determined based on the local conditions of the parking area rather than as a fixed standard applied in all development projects.

*Keywords:* Residential parking standards, Visitor parking demand, Visitor parking standards, Parking policy, Multiple regression

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### 1. Introduction

#### 1.1. Motivation

Urban areas are growing. In 2019, 75% of European citizens lived in cities [1], and it is expected that this will increase to approximately 84% by 2050 [2]. Although urbanisation has advantages from an economic perspective [2], there are also some disadvantages of urbanisation. Disadvantages include topics as congestion, air pollution, sprawl and pressure on housing markets [3, p.3]. The increasing rate of urbanisation brings challenges to keep cities sustainable, liveable and accessible. One of the most critical challenges is housing [3]. Due to urban population growth, demand for affordable housing increases resulting in high pressure on the housing market. In The Netherlands, urbanisation requires building 1 million houses before 2030 [4]. This requires not only new housing but also good accessibility to these houses.

In Europe, passenger mobility is highly focused on personal car usage [5]. However, especially in urban areas, residents using cars experience congestion and difficulty of parking [5]. Furthermore, [6] states that during their lifetime, cars are parked 95% of the time. For The Netherlands, this requires

about 15 million parking spaces to provide parking to 8 million cars [7]. This makes the availability of parking an important and challenging subject in area development projects. On the one hand, insufficient availability of parking results in cruising cars searching for a parking space, increasing the number of vehicle-kilometres driven and contributes to increased levels of congestion and pollution [8]. On the other hand, excessive parking supply supports car use and car ownership [9] [8]. On top of that, a good parking policy is required.

In practice, the required number of parking spaces is often determined based on parking requirements [10]. Municipalities use these parking requirements to indicate the minimum number of parking spaces developers need to take into account [10]. More specifically: minimum standards set up the minimum level of parking developers have to provide in terms of the number of spaces per square feet or per housing unit [11]. Both in practice and literature, problems with parking requirements are acknowledged. In practice, it was shown that various new development projects failed due to the required parking capacity being both physically and financially infeasible within the developing area [12]. Furthermore, [13] showed that reduced standards resulted in less realised parking and consequently reduced costs for developers and lower housing prices. Furthermore, often the realised parking is unoccupied, and thus there

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is an oversupply of parking, contributing to urban environments being unfriendly to pedestrians, cyclists and transit passengers [9].

Literature suggests that the parking oversupply is related to how the visitor parking standards are determined. For example, in the U.S., two different methods are used; the first method determines the parking supply based on the observed demand and the supply in nearby cities, the second method consults the handbook of the Institute of Transportation Engineers (ITE). The ITE determines the parking generation based on a survey for observed peak parking occupancy for different land uses. However, [6], and [14] argue that the parking standards are based on peak demand and reflect national averages and thereby are less applicable to local conditions. Furthermore, the utilisation studies are not able to capture different local conditions resulting in realised parking standards that do not depend on the physical environment of the development project [15] and parking standards that are applied with little consideration of demographic, geographic and policy factors [16].

### 1.2. Visitor parking

Residential parking standards consist of a number of parking spaces required for residents and a number of parking required for visitors of residents [17]. Visitor parking thereby can be defined by the parking generated by the visitors of residents in a specific residential area and only include the visitors of the residents living in that neighbourhood. Thereby, visitors of other activities or facilities such as business and shops, are not considered. The visitor parking demand then is the number of parking spaces needed in a specific area to accommodate the number of visitors at a specific time. These spaces are summed to the total parking capacity and thereby not reserved for visitors. In The Netherlands, the parking requirements are based on the standards determined by the CROW, 'the Platform for transport, infrastructure and public space' [10] [18]. Based on literature and experiences in the field, they determine standards for different land usage types, such as working, shopping and living. The parking standard for residents is defined based on different local conditions such as the urban zone and housing. For visitor parking, however, the parking standard is not specifically set for the local circumstances.

Earlier studies show that applying lower visitor parking reduced the parking demand [19] and advocate to use context-specific standards that account for factors at a specific location [16] [15]. [15] developed a method to define 'context-sensitive residential parking standards' (p.44). Due to insufficient data, visitor parking demand was not taken into account. However, the researcher argues that visitor parking standards have a share over 50% of the total residential parking requirement in some areas. Therefore, he recommends doing further research into the visitor parking demand [15, p.133]. Moreover, earlier research showed great levels of dissatisfaction among residents to visitor parking [20]. In addition, in interviews held by [19], residents stressed the importance of visitor parking in residential areas.

### 1.3. Research

Previous research is focused on applying context-specific parking standards without considering visitor parking standards. Although these studies argue that visitor parking standards are emphasised to be important by residents and excessive spaces for visitors are provided, visitor parking standards are just based on national average standards. An earlier study on visitor parking standards showed that in The Netherlands, these standards often exceed the actual parking demand [21]. They found that a visitor parking standard of 0.3 parking spaces per house is more than sufficient to meet the visitor parking demand and could be reduced to 0.1 parking spaces per house. This indicates that also visitor parking standards result in excessive parking capacity. Furthermore, [22] indicated that the supply of visitor parking might exceed the demand. In his research, he showed that in The Hague, 20% of the visitor parking permits was not used. From these studies, it can be concluded that also visitor parking has a share in the oversupply of parking. However, literature on this topic is still lacking.

This study focuses on identifying the factors that influence the visitor parking demand. Thereby, the objective is to gain more insight into the demand for visitor parking and how this might be affected by local circumstances in the parking area. Since problems arise due to pressure on space resulting from urbanisation, this research will focus on Dutch urban residential areas

## 2. Approach

This section provides the approach of this research. First, a conceptual framework indicating the factors that influence the visitor parking demand from a theoretical perspective is described. Thereafter, the used methodologies are elaborated in the application section.

### 2.1. Conceptual Framework

This research focuses on identifying what factors influence the visitor parking demand. Since the literature on visitor parking in residential areas is limited, a conceptual framework is developed. The conceptual framework is based on literature about residential parking demand. The conceptual framework in Figure 1 shows how visitor parking is related to different factors. In Appendix A all factors that influence visitor parking demand and how these factors influence the visitor parking demand is represented.

Literature shows that parking demand is dependent on mode choice, which depends on the individual characteristics of the traveller, the journey type, the perceived service performance for each mode and situational variables [23] which are related to the built environment [24]. The author argues that travel mode choice behaviour is directly influenced by the built environment, car ownership, travel distance and socio-demographic factors. [25] describes that travel behaviour is influenced by personal and household characteristics and the residential environment. Thereby it is argued that car ownership is the most

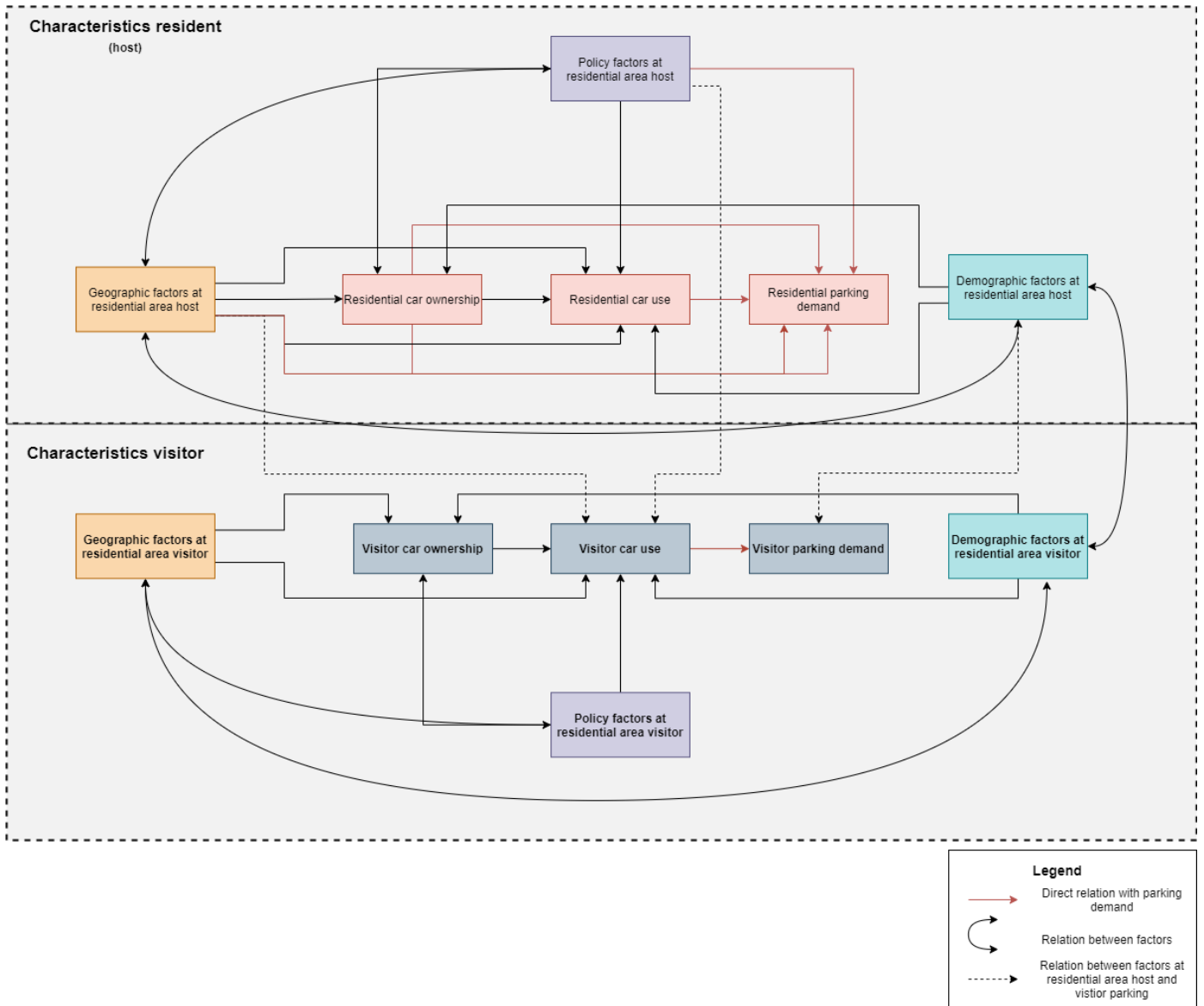


Figure 1: Factors influencing visitor parking demand

important personal characteristic that determines car use, 'if people own a car, they use it' [25, p.18].

Since each car has to be parked before or after any activity, car ownership generates parking demand. According to [26] car ownership is even one of the most important aspects influencing parking demand. As the number of vehicles grows, the need for parking space and therefore parking demand increases as well [27]. Consequently, various studies use car ownership as a proxy for the parking demand [17], [28] [29]. This implies that the overall parking demand is dependent on car ownership in an area.

Finally, factors related to the built environment influence the parking demand. These are referred to as geographic factors and include aspects such as the urban zone, the land use mix, the accessibility to public transport, and the population- and urban density.

From the literature, it is concluded that visitor parking demand depends on car ownership and car use of the visitor and consequently by the characteristics of the visitor. These include demographic characteristics of the visitor and geographic- and policy factors that influence the visitor's car ownership and car use. Furthermore, attributes at the residential area of the host influence the car use of the visitor and hence the visitor parking demand. Therefore, besides the visitor's characteristics, the demographic, geographic and policy factors at the destination residential area influence the visitor parking demand.

This research focuses on identifying what factors influence the visitor parking demand to develop a better approach for visitor parking standards. In practice, it will only be possible to consider the local conditions of the parking area. Characteristics of visitors cannot be considered. Due to missing data about the visitors, this research will only focus on the local conditions

of the residential area of the host. Furthermore, the visitor parking demand strongly depends on the car use of the visitor. This research assumes that the visitor parking demand is determined by the cars parked in a certain area. Consequently, visitors parking their cars in other parking areas are not considered. In other words, latent parking demand is not taken into account, and the measured car use is equal to the visitor parking demand. Accordingly, it is assumed that demographic, geographic, and policy factors at the residential area of the host directly influence the visitor parking demand. This is represented in Figure 2.

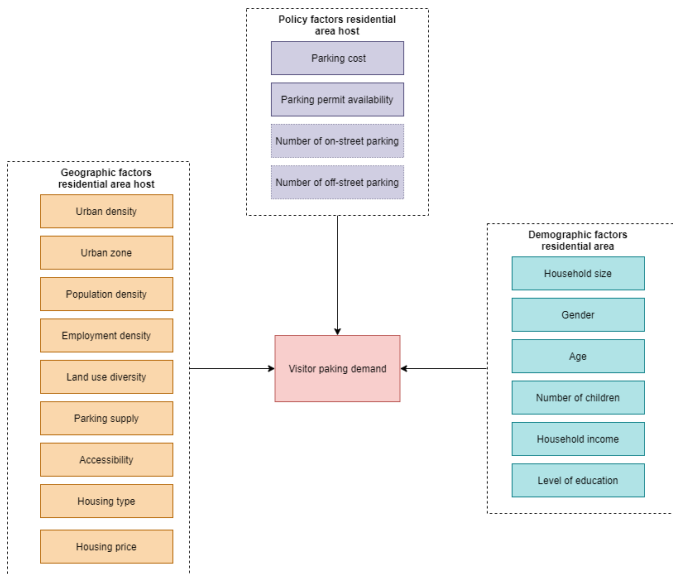


Figure 2: Conceptual framework visitor parking demand

### 2.1.1. Demographic factors

Car ownership, car usage, and indirectly residential parking demand are influenced by different demographic factors, including age, gender, income, population density, and the number of children [30] [31] [24]. It is expected that residents in a particular area attract visitors with similar characteristics. Furthermore, the demographics determine the number of visitors that residents will have; areas with an increased number of inhabitants will attract more visitors than areas with fewer inhabitants. Furthermore, the household composition affects the visitor parking demand. Bigger households are expected to attract more visitors, while the number of children also affects visitor parking demand [24]. In addition, since car-ownership is low among younger people and elderly [24] and car use is higher among people older than 25 [32], it is expected that visitor parking demand is higher in areas with middle-aged people. Finally, also gender is indicated to play a role since men and women show different car ownership and car usage levels [32]. In The Netherlands, men use cars more often than women while women are more frequent users of public transport and bicycle [32].

Furthermore, household characteristics such as income affect the visitor parking demand. Research shows that higher incomes show increased car ownership [33] [34]. For example,

in Beijing, the car purchasing demand increased as a result of increased income [35]. Furthermore, income is related to education and employment status [30]. Highly educated persons are more likely to obtain more specialized jobs, often involved in more long-distance commuting and more car usage. As these variables are related, it will result in comparable results [30].

For visitor parking, it is expected that bigger households will attract more visitors than single households. Furthermore, people of middle-age are expected to receive more visitors by car than younger people and elderly. This can be explained by the fact that these people will most probably have visitors in the same stage of life and will be in the same age group. Moreover, as the middle-aged group proved to have higher car usage, it is expected that they will visit friends and family by car. In addition, households with children may attract more visitors. Moreover, higher incomes are expected to receive more visitors by car than households with lower incomes. The same holds for the level of education.

### 2.1.2. Geographic factors

The built environment consists of different measurements, including diversity, density, distance to transit, and destination accessibility [17]. Different studies showed that higher population density is associated with lower car ownership and car usage and hence lower residential parking demand [36], [24] and [37]. Urban density expressed as the number of addresses or buildings per square kilometre negatively relates to car ownership; higher urban densities produce lower car ownership levels. This can be explained by the availability of alternative modes in dense areas [38]. Furthermore, lower parking standards are applied in the city centre in the US as it is expected that the parking demand is lower in these areas. This also applies to the standards applied by Dutch municipalities [39]. In the outer suburbs, the parking demand is generally higher, resulting in higher parking standards [40]. Furthermore, the probability of owning a car decreases with the land-use mix changing from homogeneous to diverse [41]. For visitor parking, however, it is argued that higher densities and land use mix will attract more visitors. Nonetheless, as suggested by [38], mixed land use also provides the opportunity to use other modes of transport. In literature, parking supply is shown to be a strong determinant of household car ownership and use and hence residential parking demand [11] [37], [27], [42], [43]. Besides, car use decreases as the distance between the home and home parking space increase [44]. With higher walking distances, people are more willing to change modes, especially in dense urban areas. In addition to parking availability and accessibility, accessibility to high-quality bus services, smaller rental housing, a high number of jobs, residents and stores within walking distance proved to reduce the parking demand [37].

Smaller houses produce less parking actions than bigger and owner-occupied houses [37]. However, this relation strongly relates to residents' age and income; young people with lower income and fewer children will live in rental and smaller housing producing less parking [37]. In addition, the year of construction is expected to influence the visitor parking demand, although the relation of this factor differs among various stud-

ies. Some argue that new houses generate more parking [45] while others suggest that newly built houses generate less parking [37]. Furthermore, from the National Household Travel Survey in 2009, it becomes clear that single-family detached homes produce on average more trips than single-family attached houses. Finally, the gross floor area of buildings and housing prices significantly increase the parking demand [40]. Nonetheless, it is expected that this is correlated with household income.

Furthermore, it is advocated that car use decreases in areas well served by public transport and increased parking prices [46]. Good accessibility to high-quality public transport is likely to reduce the visitor parking demand [47]. Good accessibility in these cases are indicated by the walking distance to public transport [36] [33] [24]. These relations can also be used for visitor parking demand, whereby it is hypothesised that residential areas near high-quality public transport are expected to attract fewer visitors by car.

Since dense urban zones are often suitably accessible by other modes of transportation, it is expected that these areas will attract fewer visitors by car. Thereby it is expected that the visitor parking demand is influenced by the accessibility to different modes of transport. However, one could argue that having a dense area with high land use diversity might also attract more visitors and, therefore, more visitor parking. This is related to the parking availability in the area. While dense areas are expected to have a lower parking supply, it is expected that the parking demand is reduced in these areas. In general, it is expected that more parking supply will result in more use of visitor parking in a specific area. Finally, the housing characteristics are expected to influence the visitor parking demand. It is assumed that residents in smaller apartments will attract fewer visitors than people living in big detached houses. However, this again will be dependent on whether there is sufficient parking supply.

### 2.1.3. Policy factors

Finally, policy factors significantly influence the residential parking demand. [48] argues that parking policy can be used to reduce the overall travel demand. As part of the parking policy, parking standards and hence the parking supply are determined. Therefore, parking availability can be considered to be both an environmental and a policy-related factor. Parking pricing, the inclusion of visitor parking, on-street parking resources and rules on tandem parking are essential choices related to parking policy [45]. In parking choice behaviour, parking cost is one of the most critical factors and an effective measure to control the parking demand [31] [42]. Finally, parking regulations impact the visitor parking demand. Earlier research showed that travellers primarily respond to changed parking policies by shifting parking locations rather than switching modes [49]. Combining measures thereby has a more substantial effect on parking demand than individual measures [49]. Parking restrictions at both home and end trip destinations reduce the car use strongly and thereby show to be an essential determinant of the visitor parking demand [44].

This research hypothesises that visitor car use will be influenced by the parking cost at the host, the parking regulations, and the number of parking available in the area. Thereby, the visitor parking demand will decrease when parking cost increase. Furthermore, a lower parking supply is expected to reduce the visitor parking demand. Finally, parking regulations can influence the visitor parking demand in different ways and depend on parking measures.

### 2.2. Application

The conceptual framework in Figure 2 is used as input of a multiple regression model. Multiple regression is an often-used method to study the relationship between a single dependent variable and one or more independent variables [50]. Furthermore, it allows identifying the individual contribution of each independent variable on the dependent variable [50].

The visitor parking demand is the dependent variable, and the factors represented in the conceptual model are the independent variables. The visitor parking demand is based on the usage of visitor parking permits. In most Dutch cities, visitor parking permits are provided to residents in paid parking zones and enable residents to buy parking hours against reduced prices and thereby allow visitors to park in paid parking areas for free [22, p.76].

This study uses the case study of Eindhoven, the fifth biggest city in The Netherlands. In Eindhoven, residents living in or near the city centre can buy a visitor parking permit by an online application. The parking zones are shown in blue in Figure 3. Besides, this application enables residents to register the license plate of their visitors at their arrival and deregister the visitors after leaving. The registered parking actions of 2019 are used to determine the visitor parking demand. The parking data contains information about the parking location, the postcode of the permit holder, and the age and gender of the permit holder.

The postcode of the permitholder is used to aggregate the total number of parking actions per postcode. Furthermore, the postcode is used to collect data regarding demographic and geographic factors. Demographic data contains information regarding the residents' characteristics on a postcode level. GIS is used to collect data about geographic factors. Finally, since only the number of parking actions of one single city is considered, policy factors will not be tested in this research. Parking policy is a local policy that applies to a whole municipality, and thereby, no differences between the postcodes regarding the policy factors are expected. Consequently, the regression model estimated in this research does not allow to test the impact of policy factors.

## 3. Results

This section provides the results of this research. First, the analysis of the visitor parking actions will be presented. This represents how the number of parking actions differs per parking zone and during the day. Thereafter, the results of the multiple regression will be elaborated.

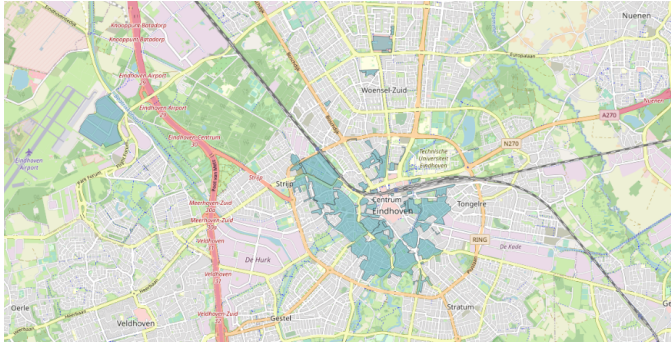


Figure 3: Parking zones in the case study of Eindhoven

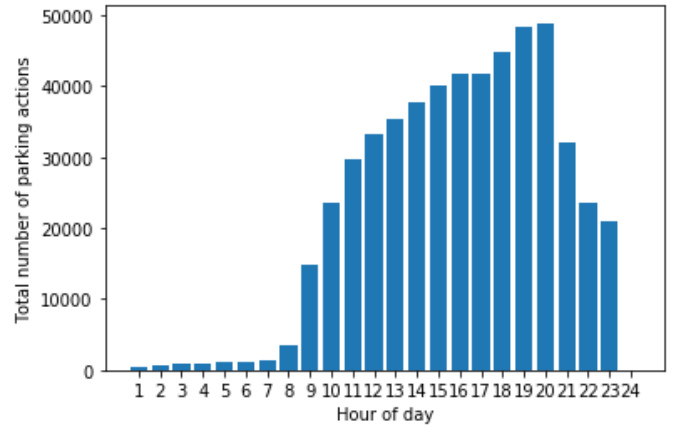


Figure 5: Total number of parking actions during the day

### 3.1. Visitor parking actions

In Figure 4 the number of parking actions per parking zone is given. Figure 5 represents how the visitor parking actions differ over the day. These figures show that, while taking all parking actions in 2019 into account, most parking actions occur around 7 p.m. However, after 9 p.m., a drop in the number of parking actions can be seen. This is explained by the paid parking hours between 9 a.m. and 9 p.m. After 9 p.m., parking is free, and visitors will be deregistered. Consequently, the parking demand represented by the registrations with the visitor parking permit and cannot represent the total visitor parking demand. The differences over time indicate that during the day, the required parking capacity varies. Consequently, while implementing parking standards based on the peak demand, not the total visitor parking capacity will be used during the day. Implementing the capacity based on the peak demand would allow using the visitor parking capacity for other purposes during the non-peak hours. Due to missing data about the visitor parking capacity, it cannot be determined whether the parking standard of 0.3 exceeds the demand. However, the differences over the day could indicate that parking standards should be determined on a neighbourhood level instead of a general standard applied in all different new development projects.

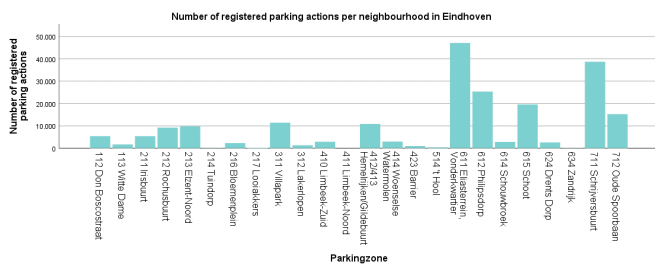


Figure 4: Number of parking actions per parking zone

### 3.2. Results multiple regression model

In Table 1 the results of the regression model are shown. Table 2 shows the variables and their coefficients in the regression model. To prevent the model from suffering from multicollinearity, not all variables are included in the model.

The regression model explains 38.4% of the variance of the dependent variable by different demographic and geographic variables. The age of the inhabitants is the only variable representing the demographic factors. People in the age group of people between 15 and 44 show to impact the visitor parking demand significantly when controlling for the other variables in the model. This relation is positive, meaning that people between 15 and 44 will increase the number of visitor parking actions. Because of high correlations between the number of inhabitants, the number of residents per age group and the number of households, not all variables could be included in the final model. Furthermore, as household income reduced the explaining power of the model, this variable was excluded from the model.

Regarding geographic factors, the final model shows a strong positive and significant relation with the number of parking available within 250 meters ( $\beta = .511, p = .000$ ). This suggests that visitor parking is very dependent on the parking supply when controlling for other variables in the model. Furthermore, the factor representing the accessibility to the bus influences the visitor parking demand negatively ( $\beta = -.099, p = .023$ ). From this, it is shown that visitor parking demand depends on the accessibility to public transport, which was measured by the number of bus/train stops accessible within 400 meters and the distance to the nearest bus/train stop. The number of bus stops accessible within 400 meters is negatively influencing the number of parking actions, meaning that an increased number of bus stops accessible within 400 meters reduces the visitor parking demand. Furthermore, increasing distance to the city centre reduces the visitor parking demand ( $\beta = -.179, p = .000$ ), which is a surprising result based on the conceptual model. However, this result is in line with the population density, showing a positive relation with the number of visitor parking actions controlling for other predictors ( $\beta = .122, p = .004$ ). The population density, in general, is higher in the city centre than in other urban zones. This could explain the negative relation between the distance to the city centre and the visitor parking demand. A final indicator representing the accessibility of residential areas on a postcode level is the distance to the highway, implying a negative rela-

Table 1: Results final regression model excluding highly correlated variables

N	R	R Square	Adjusted R Square	Std. Error of the Estimates	F	Sig.
390	0.632	0.400	0.384	8.912	25.270	0.000

Table 2: Coefficients final regression model

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	13.403	4.898		2.736	0.007		
Young people and adults	0.130	0.052	0.130	2.480	0.014	0.576	1.736
Population density	0.001	0.000	0.122	2.876	0.004	0.881	1.135
Housing_100plus	0.186	0.061	0.154	3.045	0.002	0.622	1.608
Percentage housing sale	0.039	0.020	0.100	1.922	0.055	0.579	1.726
Housing old	0.070	0.032	0.097	2.175	0.030	0.798	1.253
Housing new	-0.052	0.024	-0.098	-2.214	0.027	0.805	1.242
Distance highway (km)	-2.554	1.253	-0.099	-2.038	0.042	0.671	1.490
Availability parking 250 meters (permit)	1.017	0.090	0.511	11.327	0.000	0.779	1.283
Bus stops within 400 meters	-0.974	0.427	-0.099	-2.278	0.023	0.839	1.192
Distance to city center	-0.004	0.001	-0.179	-3.786	0.000	0.708	1.411

tion ( $\beta = -.099$ ),  $p=0.042$ ). This means that higher distances to the highway will reduce the visitor parking demand. Consequently, it can be concluded that the accessibility of an area by car impacts the visitor parking demand.

Finally, also housing characteristics show to impact the number of visitor parking actions significantly. First of all, the housing surface affects the visitor parking demand when controlling for other variables. Houses with a surface of more than 100  $m^2$  are shown to significantly increase the visitor parking demand ( $\beta=.0154$ ,  $p=.002$ ). Furthermore, old houses attract more visitors ( $\beta=.097$ ,  $p=.030$ ) while new places attract fewer visitors ( $\beta=-.098$ ,  $p=.030$ ). This might be due to the location of new houses; if new housing requires good accessibility to public transport, visitors might travel by public transport instead of using a car. Another explanation can be found in the parking supply. In The Netherlands, a trend is seen of reduced parking standards and consequently the parking supply. Since the parking supply strongly relates to the visitor parking demand, the lower parking standards applied at newly developed projects might explain the reduced visitor parking demand in these areas. Finally, also the type of tenure influences the visitor parking demand. The results show that owner-occupied housing attracts more visitors by car ( $\beta=.100$ ,  $p=.055$ ), although this relation is slightly insignificant ( $p > .05$ ).

#### 4. Conclusion

High parking standards result in an oversupply of parking places in urban areas. This results in inefficient land use, unaffordable housing and increases car ownership and car use. In The Netherlands, visitor parking standards often result in an oversupply of parking. This research aimed at identifying how visitor parking demand depends on the local circumstances of a

specific urban area. This will contribute to the development of new visitor parking standards.

The conceptual model underpins that theoretically, residential visitor parking depends on both characteristics of the visitor itself and the local conditions at the parking area. However, in practice, the visitor parking standards would only be based on the conditions at the parking area, and thereby the multiple regression model was based on only the characteristics of the residential parking area of the host.

The analysis showed apparent differences in the number of parking actions in different areas. Furthermore, various local conditions explained the different patterns of parking occupancy during the day. In general, in Eindhoven, most visitor parking actions happen during the evening hours with a peak around 7 p.m. Therefore, it can be concluded that during the day, not the total capacity of the currently used 0.3 parking spaces per house will be needed. This information could be considered when estimating the required number of parking. Furthermore, the differences of the spread over the day in different areas indicate that the visitor parking standard could be based on the local conditions instead of implementing the same standard for visitor parking in the whole city.

The results of the multiple regression model showed that both demographic and geographic characteristics of the parking area influence the visitor parking demand. Policy-related factors, such as parking cost and parking measures, could not be tested in this research. However, one can conclude that context-specific factors impact the visitor parking demand and therefore could be considered when determining the visitor parking standards. This requires analysing the local conditions of the parking area, including the target group of the area (age), the housing characteristics, the accessibility by public transport, the accessibility by car and the visitor parking supply. Furthermore,

since the relation with the parking supply showed to be an essential determinant of the visitor parking demand, this allows reducing the visitor parking standards. Taking the local conditions into account will better estimate the expected visitor parking demand and the required capacity. Finally, the lacking relation between the number of inhabitants and households in an area implies that visitor parking standards can be defined based on the local conditions rather than representing a single national standard that provides the number of parking spaces required per house.

## 5. Recommendations

This research sheds new light on residential parking policy by showing that the visitor parking demand depends on different context-specific factors. Thereby recommendations for policymakers can be made. Furthermore, recommendations for further research can be directed.

### 5.1. Recommendations for practice

Policymakers can use the results of this research to underpin that visitor parking standards in urban areas can be reduced. The identified factors could be used to allow reduced visitor parking standards. Municipalities thereby need to consider these reductions in their local parking policies. Currently, a switch is seen in parking policies that use visitor parking standards varying between different urban zones. This research confirms that this is a suitable method to determine more accurate visitor parking standards. Thereby it is recommended that policymakers define the visitor parking standards on the local conditions of the urban zone. A second method is to design custom visitor parking standards specific to a particular area. Municipalities could determine a baseline standard from which can be deviated based on the local conditions of the (new) developed area. Finally, it is recommended to determine the parking capacity at a neighbourhood level, taking not only the parking capacity of the residential area into account but also other facilities. This will prevent the construction of too many parking facilities being unoccupied during the day and inefficient land use. Nonetheless, this requires insight into the expected distribution over the day and how different factors cause this spread.

### 5.2. Recommendations for further research

Future research could focus on a couple of topics. First of all, further research is needed to identify other factors that explain the visitor parking demand. This requires more accurate data for both the demographic characteristics and the geographic factors. Regarding the data collection of the geographic variables, it is recommended to take the utility of different modes into account. In this study, the accessibility was only measured based on the single line distance. Future research should take the service level of public transport into account by considering the actual walking time to public transport, the number of different lines at each bus stop, and the public transport frequency.

Second, it is recommended to conduct a survey among the visitors that park their cars in residential areas with a visiting purpose. Such a survey can be used to gain better insight into how visitor characteristics influence the visitor parking demand. Furthermore, it allows the estimation of a structural equation model (SEM). The statistical regression model in this research is based on various assumptions and simplifications. Besides, the characteristics of the visitor itself were neglected. A SEM will allow considering the factors that influence the car use and consequently the visitor parking demand instead of deriving the visitor parking demand from the observed use of the visitor parking permit. This method will provide a deeper understanding of the visitor parking system and consequently visitor parking demand. Furthermore, a SEM will allow to include indirect relations in the model.

Finally, trends in mobility will change car use and hence the visitor parking demand. As already pointed out by [51], determining context-specific requirements are sensitive to existing conditions and therefore do not take future conditions into account. Hence it is recommended to conduct additional research into the effects of future developments on visitor parking. This includes developments in the demographic composition of a particular area and trends in mobility. Further research should identify how visitor parking will be affected by these trends and how this can be considered in parking policies.

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## Appendix A.

In Figure A.6 an overview of all factors influencing the visitor parking demand and its relations are given. This figure is based on the literature in section 2 and shows that the visitor parking demand depends on many different factors, and thereby, estimating the demand is very complex.

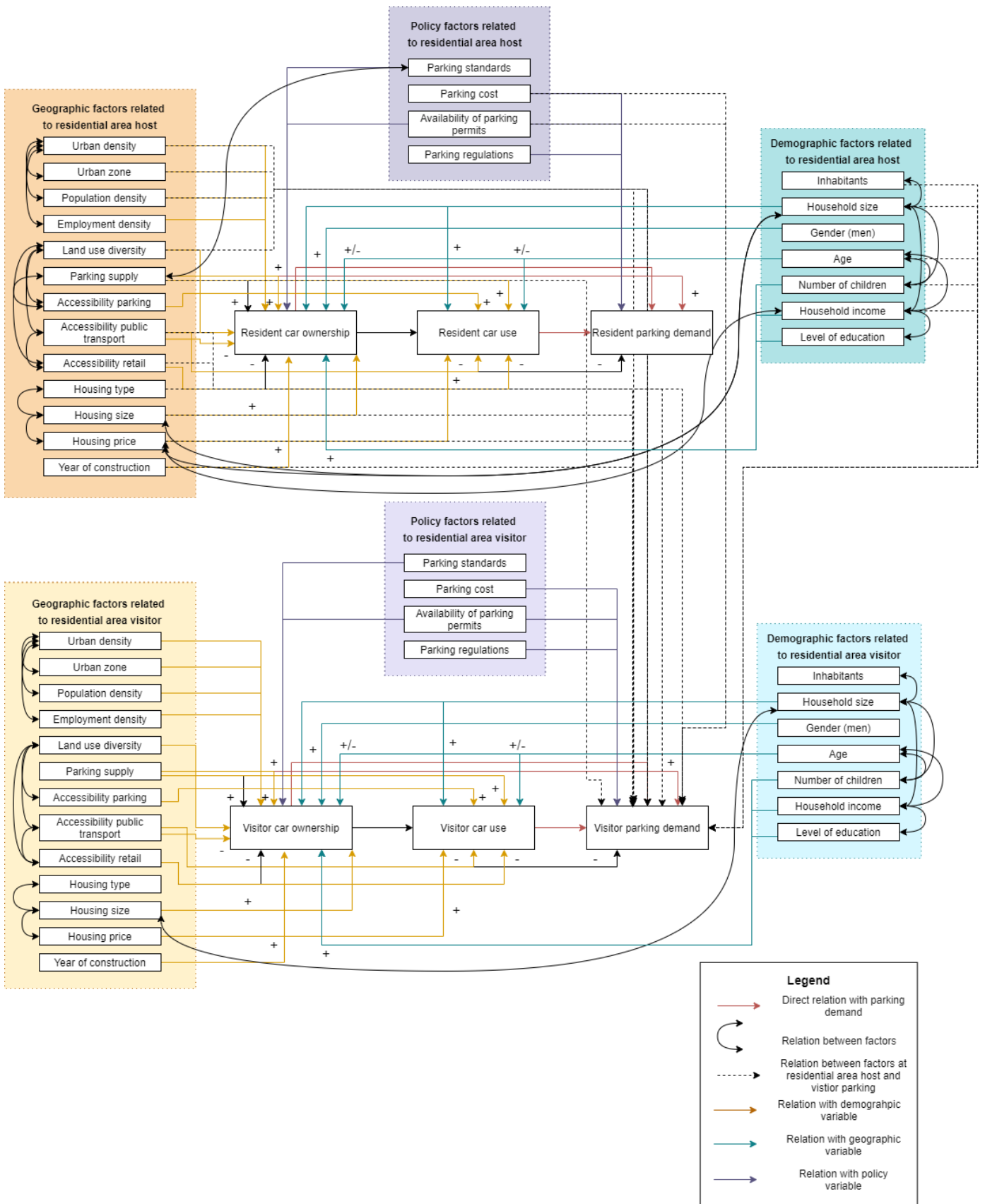


Figure A.6: Total residential parking demand

# B

## Interviews municipalities

To get more insight into how municipalities develop their parking policy, what instruments they use to implement this policy, and consider future developments in their policy, two interviews were conducted. The first interview was conducted on the 23rd of April 2021 with Diede Labots. Diede Labots is policymaker for the municipality of The Hague and is specialised in traffic. He developed the parking policy of 2011 for the municipality of The Hague and is currently developing a new parking strategy for The Hague. The second interview was held on the 7th of May with Fleur Wouters. Fleur is traffic engineer at the municipality of The Hague and also involved in the parking policy of the municipality.

The interviews aimed at gaining more insight into how municipalities determine their parking policies and how they implement parking standards. The main focus is on context setting, and therefore an informal interview was held. Five different questions were considered, while during the interview, additional questions were answered. The main questions were:

1. *What goals does the parking policy aim to achieve? How does this contribute to the general policy of the municipality?*
2. *What instruments are in general implemented to achieve these goals?*
3. *How did the parking policy of your municipality change in the last couple of years?*
4. *What future developments do you consider to impact the parking demand?*
5. *How are future developments considered in the parking policy of the municipality?*

The interviews were conducted in Dutch. Therefore no full transcript is made. However, a summary of the interviews is made. These will reveal the most important findings of the interviews.

### **B.1. Interview municipality of The Hague**

The first interview was held with Diede Labots. He works as policymaker at the municipality of The Hague. The interview consisted of two parts. In the first part, we discussed how the parking policy of the municipality developed over the years. In the second part, we took a look into the future; how are future developments considered when developing parking policy? As the main focus of this research focuses on visitor parking, the interview was focused on visitor parking.

The first parking nota was published in 2011. Before this time, parking policy was focused on satisfying the parking demand while the parking standards of the CROW were used to determine the number of parking. This was referred to as the 'parking standard policy'. As part of the development of a new parking policy, in 2010, research was conducted to identify car ownership for different housing types. Based on this research, new parking standards were determined. In 2016 this new parking policy was revised to the current situation. Currently, the municipality is developing a new parking strategy and consequently a new parking policy. The parking policy of 2011 did not take into account any flexibility. Current developments in mobility require more flexible standards and therefore needs a new parking policy. The flexibility of the standards is considered discount on the required parking when alternative modes are accessible in newly developed areas. First,

this was only applied in The Binckhorst, for which they developed an exclusive parking policy. However, as there are more development projects in the Southwest of The Hague, the parking policy is revised.

Whereas the parking standards for residential parking could be based on the car ownership and the presence of alternative modes, it is harder to determine the parking standards for visitor parking since data on the visitors' car ownership and use is lacking. Therefore they based their parking standards on the research published by Spark (see Spark (2018)). Furthermore, in their new parking nota, they publish visitor parking standards that differ on the location and the type of housing. First of all, there are three different areas; pre-war, post-war and the centre. The accessibility of the post-war zone by public transport is worse than in the other two zones. Therefore it is expected that in these zones there will be more visitors by car and more parking standards are required. Furthermore, the housing characteristics are also expected to declare the number of parking required; smaller apartments may have fewer visitors than big family houses. Therefore, this can be considered as a factor influencing the visitor parking demand.

The parking policy of The Hague used to be demand-driven. However, the new parking policy will be more steering and is mainly focused on keeping a liveable environment and reducing the pressure of parked cars. Furthermore, by reducing the parking standards, they move more towards the parking policy of Amsterdam and Utrecht. Nonetheless, different from those municipalities is that The Hague still requires to build sufficient parking. This is also visible in the parking standards, which are still demand-driven. The new parking policy offers developers to implement less parking when other mobility solutions are offered and thereby gives developers a fixed discount when they implement specific mobility solutions.

Future developments considered by The Hague are mainly developments in mobility and do not contain any socio-economic or demographic trends. Diede states that developers think about the changes in demographic or economic factors, but the municipality does not consider these. The main development that is considered by the municipality is the implementation of shared mobility. As already mentioned, discount rates are offered for the number of required parking when alternative modes are offered in the newly developed area. These alternatives can include shared cars, shared mopeds, but also the accessibility of public transport and the implementation of shared bikes. Furthermore, they consider Mobility as a Service an important measure to reduce car usage. Conclusively, the municipality offers ways to implement less parking to stimulate the implementation of shared mobility services. The municipality can stimulate this by offering different services (such as Felyx, Check, Go, and shared bikes). They do not take any socio-economic developments into account. To make sure that the parking policy will be up to date, various evaluations moments are defined in the parking policy. However, these will not be focused on a certain moment in time, but will be based on the development projects (for example after the building of 5.000 houses (specific for the Binckhorst)).

As previously discussed, visitor parking plays a less critical role in the parking policy as it is hard to determine what the visitor parking demand will be. Besides, it is hard to realise visitor parking on private property, which requires space for visitor parking. Therefore, often central parking is realised by decoupling parking costs from the housing price and allowing to use the parking for multiple parking activities (such as work, shopping, and residents). Another mentioned problem is the political support of visitor parking. Lowering visitor parking standards is very hard. Politics want to offer sufficient parking to the residents. Therefore, visitor parking permits are considered to be prerogatives for residents, resulting in low prices. This raised the question of whether the municipality changed their policy as a result of the study of Mingardo (2016). However, politically it is tough to change this policy, and currently, there are no problems with the parking permit.

## **B.2. Interview municipality of Eindhoven**

The second interview was with Fleur Wouters of the municipality of Eindhoven. She is a traffic engineer at the municipality and is also involved with the parking policy. In this interview, we also discussed the development of the parking policy over the last ten years. Furthermore, we discussed the goal of the municipality and how the parking policy can contribute to this. Finally, also the impact of future developments was discussed.

In 2013 a new parking document was published. The parking policy described in this document was mainly

demand-driven, and the parking standards were relatively high. As a result of these high parking standards, many big projects failed. Therefore, the parking standards were revised; more flexible parking requirements were needed. Especially in the city centre, there was a high demand for housing while the space was limited. Therefore, the question raised new houses could be build without implementing new parking facilities? Therefore, the new parking policy includes discounts on the parking standards when other mobility solutions such as good accessibility to public transport, shared cars, shared mopeds or shared bikes are implemented. It is up to the project developer to prove that there are sufficient alternative solutions for residents, and therefore less parking is needed. However, one problem was that there were no standards for the implementation of alternatives. So for each project, the reduction of parking had to be determined. Therefore, in 2019 the parking document was revised by adding the discount rates when other mobility solutions are implemented.

When looking into visitor parking, it was much harder to lower the parking standards. The visitor parking standards were lowered in the city centre because research showed that much underground parking capacity often was not used. Therefore, parking standards in the city were lowered as visitors can park in these off-street parking facilities. The visitor parking standard was not reduced in the other zones (inner suburbs and outer suburbs). Firstly, because in these areas there is still sufficient space. Secondly, because the municipal college thinks that Eindhoven also has to be accessible by car.

In Eindhoven, the municipal college establishes the parking document. The general policy framework determines the general policy, and the municipal college determines based on this document the parking policy. This framework is named 'Eindhoven op weg'. This framework requires a steering parking policy and aims to increase sustainable mobility. For example, in 2016, a rather left coalition wanted to decrease cars in the city, while now there is a somewhat right coalition that wants the city to be accessible by car. This clearly shows that the parking policy can change as a result of changing political environment.

The parking policy changes as a result of multiple things. First of all, the CROW revises its parking standards when needed. Many municipalities follow and change their parking policy based on these requirements of the CROW. As Eindhoven aims to create a sustainable city, the parking policy thereby focuses on stimulating sustainable mobility and reduced car use. Therefore, in their parking policy, they reduced the parking standards. Furthermore, as discussed previously, the developer can discount the number of parking when other mobility solutions are offered. It is up to the developer to prove that less parking is sufficient. By creating less parking, the municipality hopes that people will reduce their car use in the end. However, this will take many years.

Finally, also future developments were discussed. The primary trend that is expected is the increase of shared mobility. This is already taken into account by the usage of more flexible parking. Developers are responsible for proving that specific solutions result in less parking demand and, therefore, less parking is needed. However, there are differences between developers. Some developers are very willing to reduce parking, while others are old school and want to realise the maximum parking standards. Developers base the number of parking also on the target groups of their projects. Furthermore, shared mobility is an upcoming concept and have to be improved further to realise less parking.

# C

## Conceptual model development

### C.1. Factors influencing residential parking demand

In Table C.1 the results of the literature study are shown. The literature study identified different factors that influence car ownership, car use, and residential parking demand. The results of this study are used to develop a conceptual framework for the visitor parking demand.

Table C.1: Factors influencing residential parking demand

Author	Demographic factors	Geographic factors	Policy factors
Yan et al. (2019)		<ul style="list-style-type: none"> <li>• Walking distance to parking</li> <li>• Distance to non-paid parking</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Kelly & Clinch (2016)			<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Ottosson et al. (2013)	<ul style="list-style-type: none"> <li>• Income</li> </ul>	<ul style="list-style-type: none"> <li>• Distance to downtown</li> <li>• Accessibility to transit</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Hensher & King (2001)			<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Parmar et al. (2020)	<ul style="list-style-type: none"> <li>• Age</li> <li>• Income</li> </ul>	<ul style="list-style-type: none"> <li>• Walking distance to parking-destination</li> <li>• Number of parking spaces available</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Guo et al. (2013)		<ul style="list-style-type: none"> <li>• Parking availability</li> </ul>	
Ruisong et al (2009)	<ul style="list-style-type: none"> <li>• Age</li> <li>• Gender</li> <li>• Income</li> </ul>	<ul style="list-style-type: none"> <li>• Walking distance</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Sen et al (2016)		<ul style="list-style-type: none"> <li>• Transit accessibility</li> </ul>	
Tong et al. (2004)		<ul style="list-style-type: none"> <li>• Parking availability</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Qin et al. (2010)		<ul style="list-style-type: none"> <li>• Transit accessibility</li> </ul>	
Rowe et al (2011)	<ul style="list-style-type: none"> <li>• Household size</li> <li>• Household Income</li> </ul>	<ul style="list-style-type: none"> <li>• City district</li> <li>• Service level of transit</li> <li>• Land use mix</li> </ul>	
Mei et al. (2020)		<ul style="list-style-type: none"> <li>• Land use mix</li> </ul>	
Ghuzlan et al. (2016)	<ul style="list-style-type: none"> <li>• Average car-ownership</li> </ul>	<ul style="list-style-type: none"> <li>• Location (urban zone)</li> <li>• Number of apartments</li> <li>• Average apartment price</li> <li>• Building gross floor area</li> </ul>	

Ostermeijer et al. (2019)		<ul style="list-style-type: none"> <li>• Urban density</li> </ul>	<ul style="list-style-type: none"> <li>• Parking cost</li> </ul>
Litman (2019)	<ul style="list-style-type: none"> <li>• Income</li> <li>• Household size</li> </ul>	<ul style="list-style-type: none"> <li>• City size</li> <li>• Population density</li> <li>• Transit service quality</li> </ul>	
Cervero (2010)		<ul style="list-style-type: none"> <li>• Walking distance to rail station</li> <li>• Parking supply</li> </ul>	
de Gruyter et al. (2020)		<ul style="list-style-type: none"> <li>• Accessibility to transit</li> </ul>	
de Groote et al. (2016)	<ul style="list-style-type: none"> <li>• Income</li> </ul>		<ul style="list-style-type: none"> <li>• Waiting time permit</li> <li>• Parking cost</li> </ul>
Engel-Yan & Passmore (2013)		<ul style="list-style-type: none"> <li>• Housing value</li> <li>• Land use mix</li> <li>• Urban density</li> <li>• Availability of shared cars</li> </ul>	
Rowe et al. (2010)		<ul style="list-style-type: none"> <li>• Transit service level</li> </ul>	
Li & Zhao (2017)	<ul style="list-style-type: none"> <li>• Income</li> <li>• Household size</li> <li>• Household composition</li> </ul>	<ul style="list-style-type: none"> <li>• Land use mix</li> <li>• Neighbourhood type</li> <li>• Tenure type</li> </ul>	
Ding et al. (2017)	<ul style="list-style-type: none"> <li>• Population density</li> <li>• Household income</li> <li>• Household size</li> <li>• Number of children</li> <li>• Age</li> <li>• Education</li> </ul>	<ul style="list-style-type: none"> <li>• Accessibility</li> <li>• Distance to transit</li> </ul>	
Christiansen et al. (2017)		<ul style="list-style-type: none"> <li>• Parking availability</li> <li>• Walking distance parking</li> <li>• Urban density</li> </ul>	<ul style="list-style-type: none"> <li>• Parking restrictions</li> </ul>
Ding et al. (2018)		<ul style="list-style-type: none"> <li>• Residential density</li> <li>• Employment density</li> <li>• Land use mix</li> <li>• Average block size</li> <li>• Distance to CBD</li> </ul>	
Zegras (2010)		<ul style="list-style-type: none"> <li>• Land use mix</li> <li>• Distance to CBD</li> <li>• Distance to metro</li> </ul>	
Hess & Ong (2002)		<ul style="list-style-type: none"> <li>• Land use mix</li> </ul>	
Yao et al. (2016)	<ul style="list-style-type: none"> <li>• Household income</li> <li>• Household size</li> </ul>		<ul style="list-style-type: none"> <li>• Parking fee</li> </ul>
Schwanen et al. (2002)	<ul style="list-style-type: none"> <li>• Gender</li> </ul>		
Chatman (2013)		<ul style="list-style-type: none"> <li>• Year of construction</li> <li>• Housing type</li> <li>• Housing tenure</li> <li>• Density</li> <li>• Accessibility of bus service</li> <li>• Parking availability</li> </ul>	
Acker & Witlox (2010)		<ul style="list-style-type: none"> <li>• Density</li> <li>• Land use mix</li> <li>• Distance to CBD</li> </ul>	

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Albalete & Gragera (2020)			• Parking cost
Willson & Roberts	• Household income • Household size	• Number of bedrooms • Year of construction	

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**C.2. Framework development**

Figure C.1 shows all relations that influence the visitor parking demand. Finally, the simplified figure is given in chapter 3.

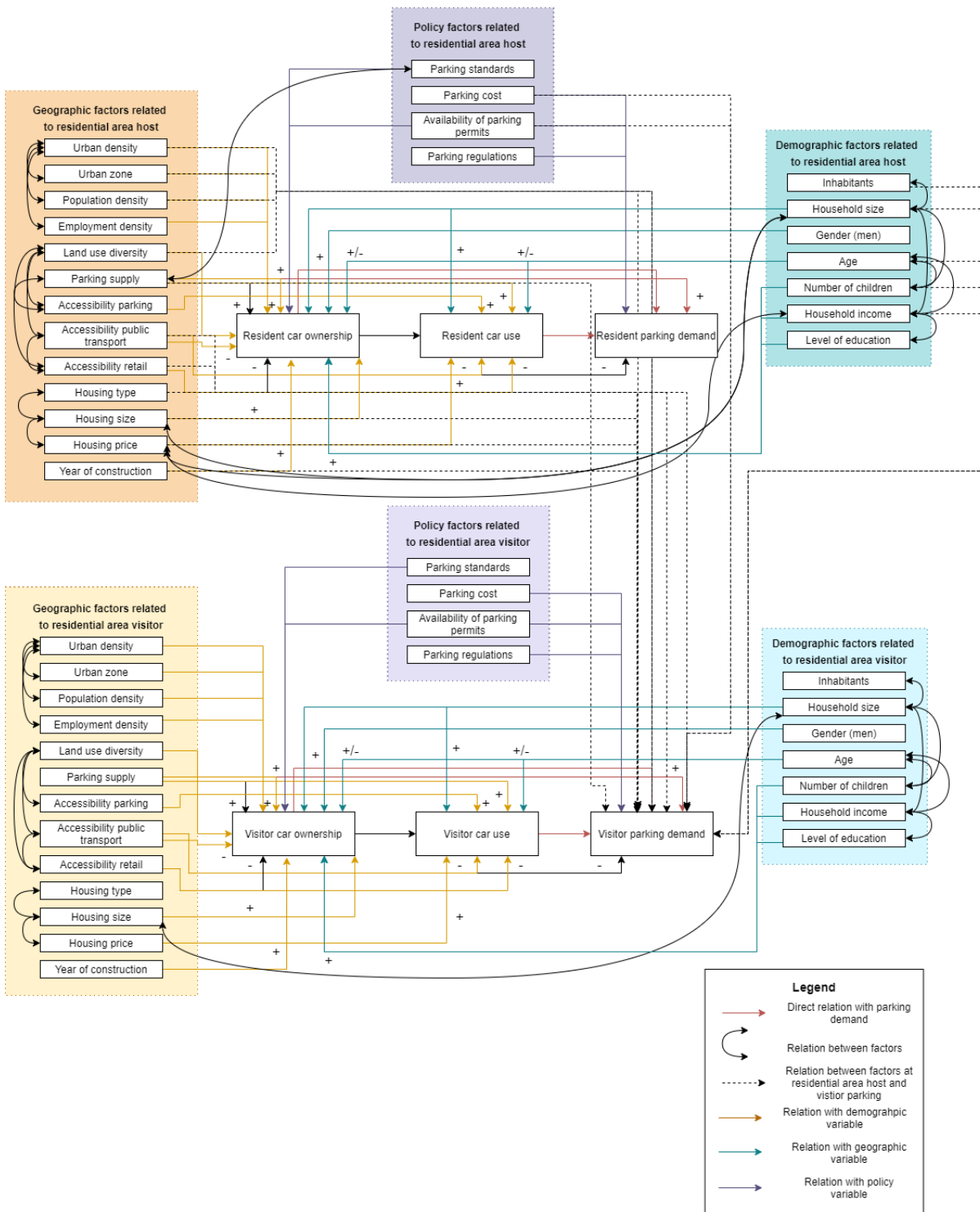


Figure C.1: Factors influencing the total residential parking demand

### C.3. Variables

Table C.2 shows the variables that are included in the regression model. In addition, a short description and the data source of each variable is given. These variables are analysed in chapter 4.

Table C.2: Variables included in the model

Variable name	Description	Source
Parking	Dependent variable, number of registered visitors in 2019 at specific postcode (PC6)	Desyde
Inhabitants	Total number of inhabitants at specific postcode	CBS
Men	Total number of men at specific postcode	CBS
Women	Total number of women at specific postcode	CBS
Inh_014	Number of inhabitants with age between 0 and 14	CBS
Inh_1524	Number of inhabitants with age between 15 and 24	CBS
Inh_2544	Number of inhabitants with age between 25 and 44	CBS
Inh_4664	Number of inhabitants with age between 45 and 64	CBS
Inh_65pl	Number of inhabitants older than 65 years	CBS
Young people and adults	Number of inhabitants with age between 15 and 44	CBS
Middle-aged, children and elderly	Number of inhabitants with age between 0 and 14 and 45 and older	CBS
Households	Number of households	CBS
Hh_1	Number of one-person households	CBS
Hh_1+	Number of households with more than one person	CBS
Avg_hhsize	Average household size	CBS
Income	Median household income (1=low, 2=middle, 3=high)	CBS
Urbanization	Level of urbanization form CBS	CBS
Urban_density	Number of addresses per square km	CBS
Population density	Number of inhabitants per square km	CBS
Surface_040	Number of housing with a surface between 0 and 40 m <sup>2</sup>	BAG
Surface_40-70	Number of housing with a surface between 40 and 70 m <sup>2</sup>	BAG
Surface_70-100	Number of housing with a surface between 70 and 100 m <sup>2</sup>	BAG
Surface1_100-160	Number of housing with a surface between 100 and 160 m <sup>2</sup>	BAG
Surface >160	Number of housing with a surface higher than 160 m <sup>2</sup>	BAG
Housing_number	Number of houses	BAG
Housing_avgsurface	Average surface of houses at specific postcode	BAG
Housing_totalsurface	Total surface of houses at specific postcode	BAG
Housing_0100	Number of houses with a surface lower than 100 m <sup>2</sup>	CBS
Housing_100plus	Number of houses with a surface higher than 100 m <sup>2</sup>	CBS
Houses	Number of houses	CBS
Housing_45	Number of houses build before 1945	CBS
Housing_4564	Number of houses build between 1945 and 1964	CBS
Housing_6574	Number of houses build between 1965 and 1974	CBS
Housing_7584	Number of houses build between 1975 and 1984	CBS
Housing_8594	Number of houses build between 1985 and 1994	CBS
Housing_9504	Number of houses build between 1995 and 2004	CBS
Housing_0514	Number of houses build between 2005 and 2014	CBS
Housing_1524	Number of houses build between 2015 and 2024	CBS
Housing_1+	Number of multiple person housing	CBS
Housing_old	Number of houses build before 1995	CBS
Housing_new	Number of houses build after 1995	CBS
P_rent	Percentage of rental housing	CBS
P_sale	Percentage of owner-occupied housing	CBS
WOZ	Housing value	CBS
Dist_superm	Distance to nearest supermarket	CBS
Dist_highway	Distance to nearest highway	CBS
Parking_permit250m	Number of unique parking areas accessible with parking permit within 250m	Opendata Eindhoven
Parking_permit100m	Number of unique parking areas accessible with parking permit within 100m	Opendata Eindhoven
Parking_public100m	Number of publicly available (paid) parking accessible within 100m (unique)	Openstreetmap
Parking_public250m	Number of publicly available (paid) parking accessible within 250m (unique)	Openstreetmap
Nearest_publicparking	Distance to nearest public parking	Openstreetmap
Bus_400	Number of bus stops accessible within 400m	Openstreetmap
Bus_nearest	Distance to nearest bus stop	Openstreetmap
Train_400	Number of train stations accessible within 400m	Openstreetmap
Train_nearest	Distance to nearest trainstation →distance to city center	Openstreetmap

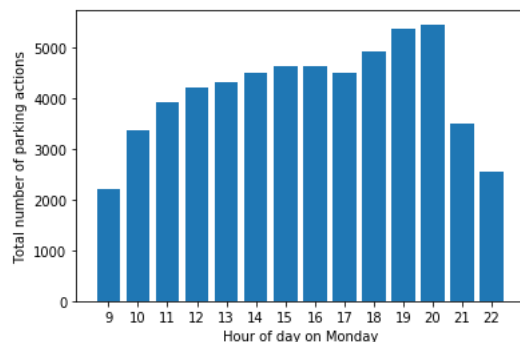
# D

## Results

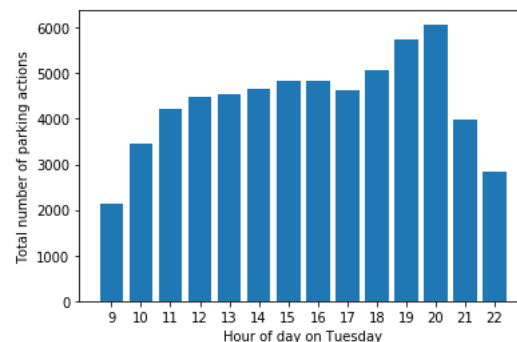
In this appendix, the descriptives of the data are presented. First, graphs related to the number of parking actions are shown. Second, descriptives of the demographic factors are given in sec:demographics followed by a description of the geographic variables in section D.3. After that, the results of the simple linear regression are showed. Finally, the assumptions of the multiple linear regression are tested in section D.5.

### D.1. Parking actions

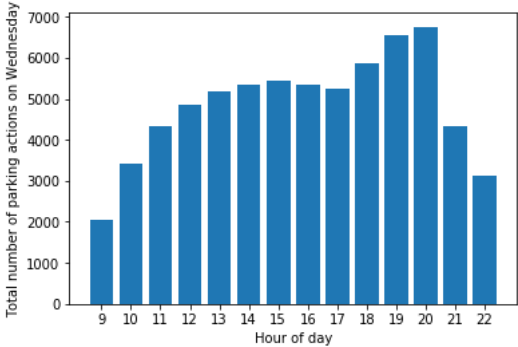
This section presents how the visitor parking actions differ during the day. Only the visitor parking actions during the paid parking times are represented. It can be seen that during weekdays most visitors park during the night between 6 and 8 p.m. On Saturday the number of visitors increases during the day and is highest between 7 and 8 p.m. Sunday however shows a different pattern. On Sundays, most visitors park between 3 and 7 p.m. Furthermore, the spread over the day in different neighbourhoods are shown. In most areas, the parking peak is around 7 p.m. Some areas have peaks around 3 and 4 p.m. (Lakerloopen, Looiakkers, Limbeek-Zuid).



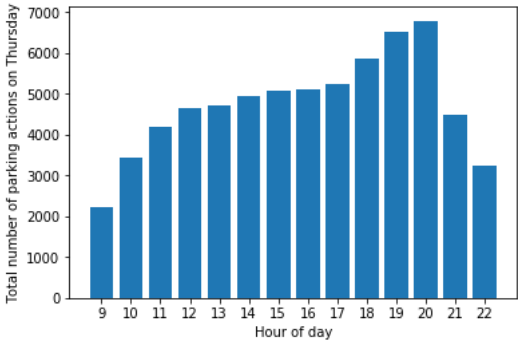
Spread during the day Monday



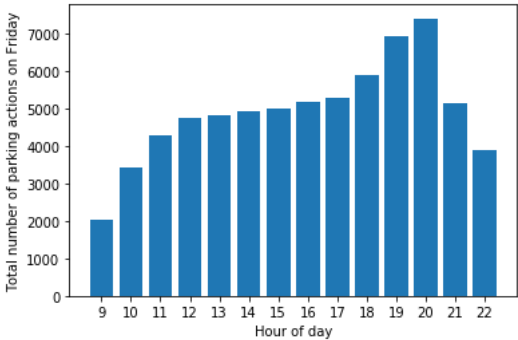
Spread during the day Tuesday



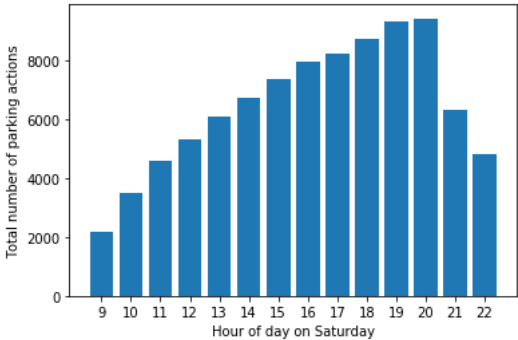
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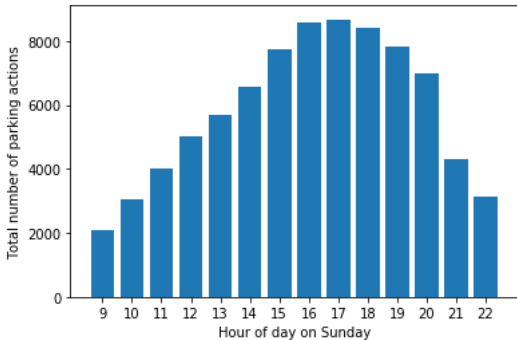
Spread during the day Thursday



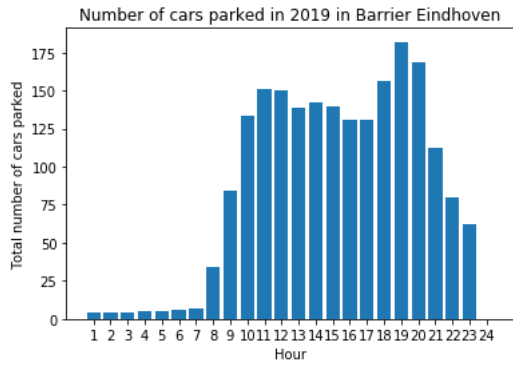
Spread during the day Friday



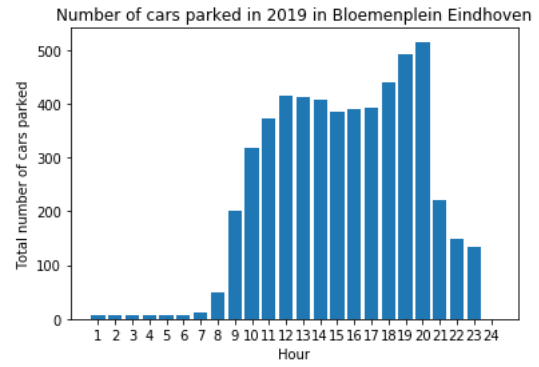
Spread during the day Saturday



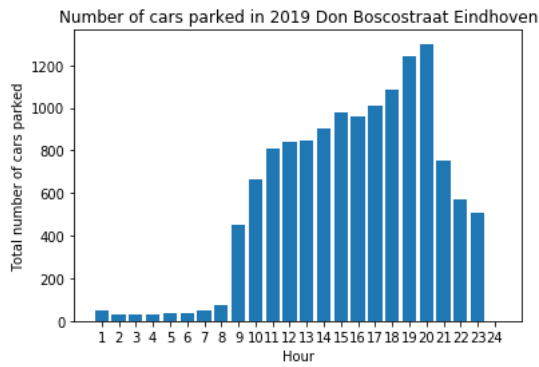
Spread during the day Sunday



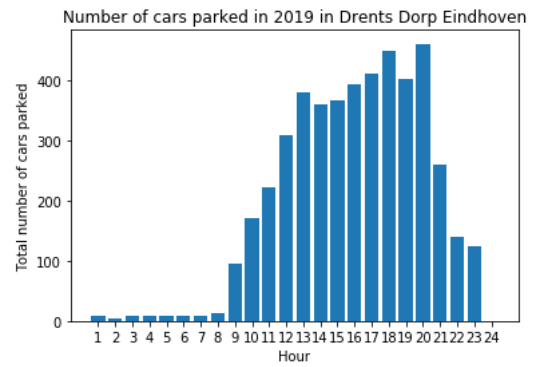
Spread during the day Barrier



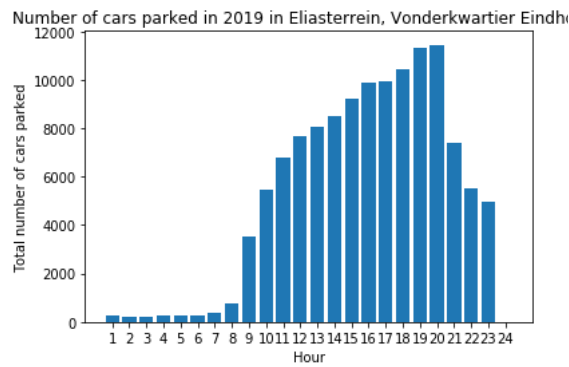
Spread during the day Bloemenplein



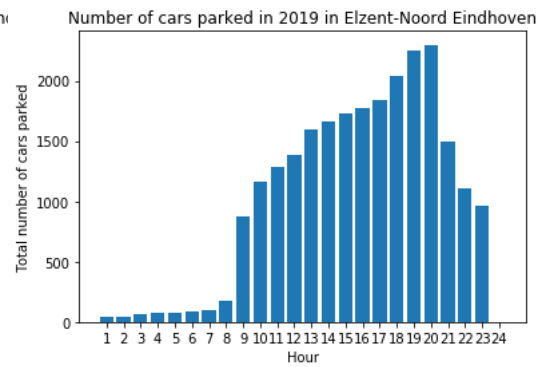
Spread over the day Don Boscostraat



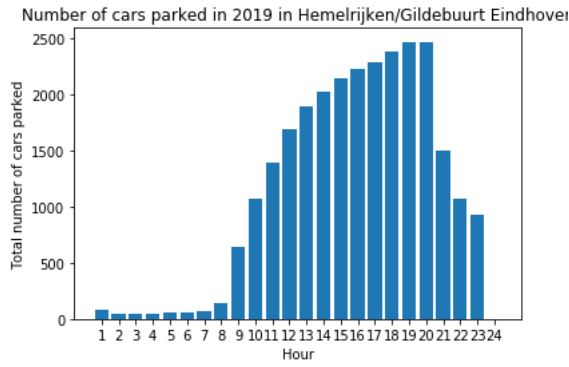
Spread over the day Drents Dorp



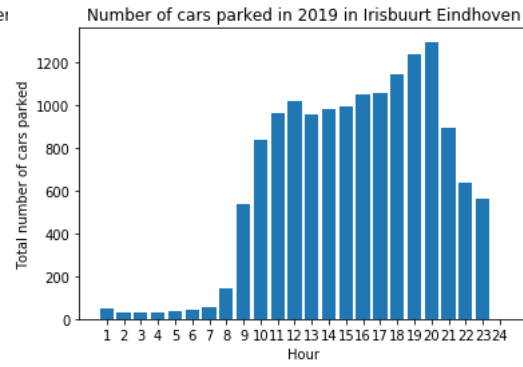
Spread over the day Eliasterrein



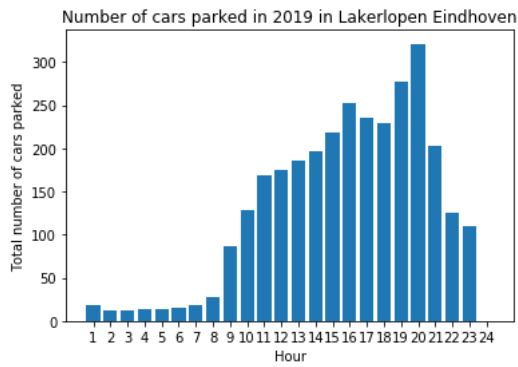
Spread over the day Elzent Noord



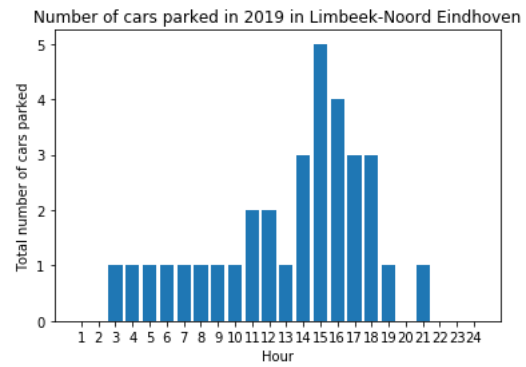
Spread over the day Hemelrijken/Gildenbuurt



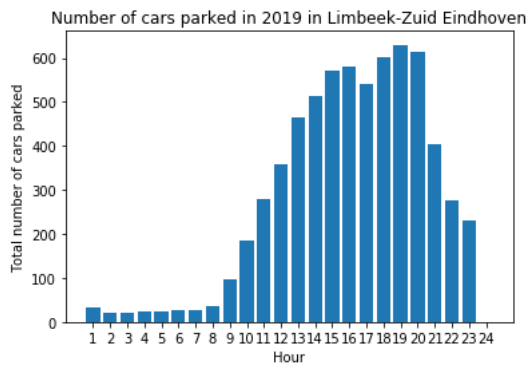
Spread over the day Irisbuurt



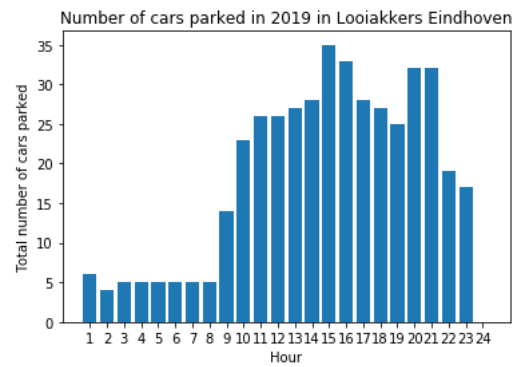
Spread over the day Lakerloopen



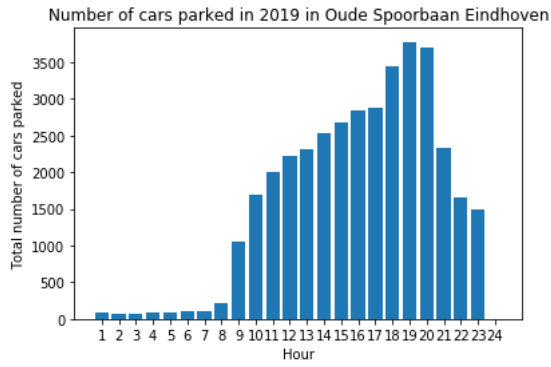
Spread over the day Limbeek-Noord



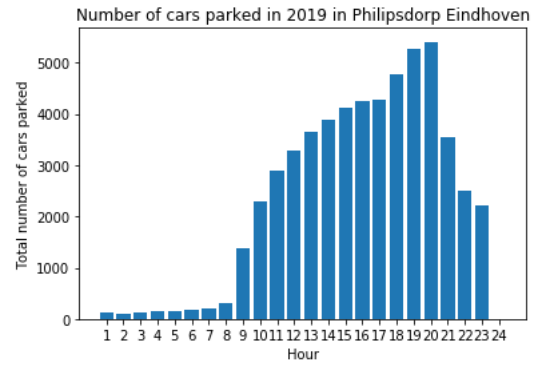
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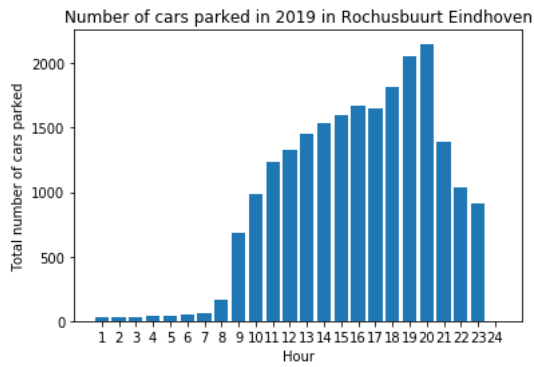
Spread over the day Looiakkers



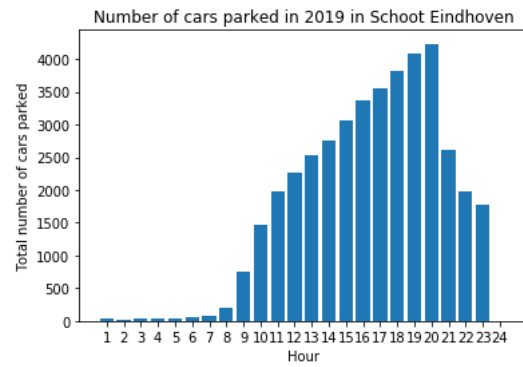
Spread over the day Oude Spoorbaan



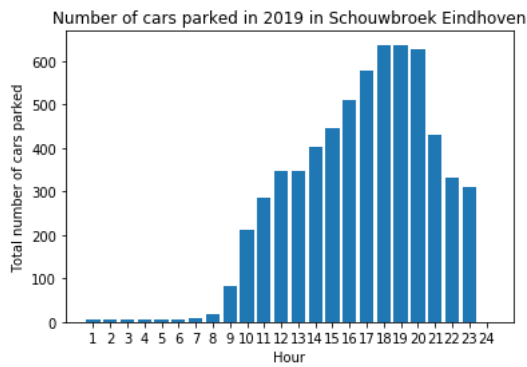
Spread over the day Philipsdorp



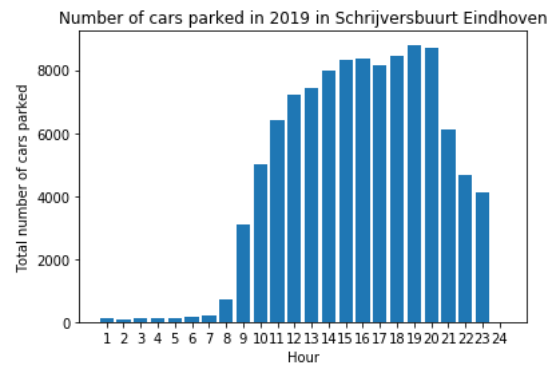
Spread over the day Rochusbuurt



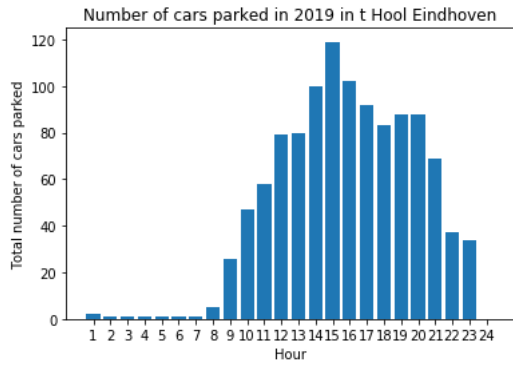
Spread over the day Schoot



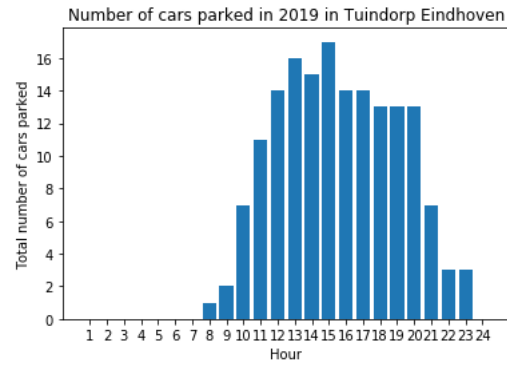
Spread over the day Schouwbroek



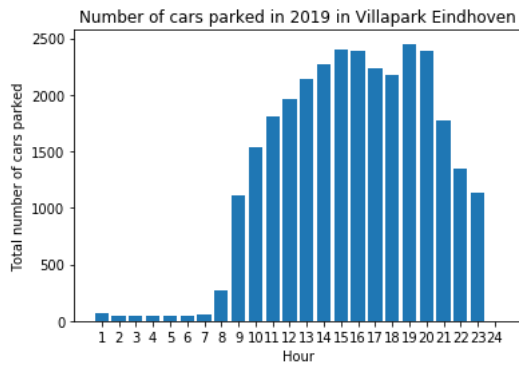
Spread over the day Schrijversbuurt



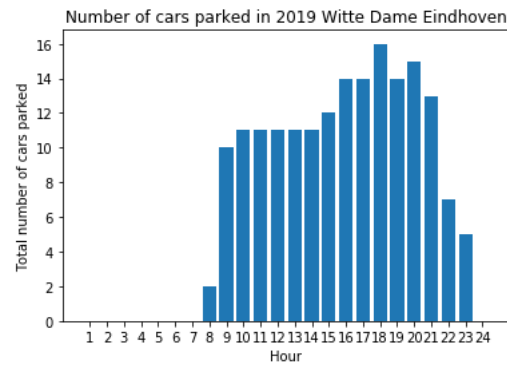
Spread over the day 't Hooi



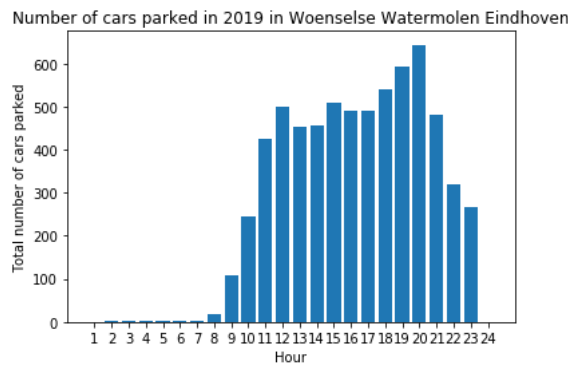
Spread over the day Tuindorp



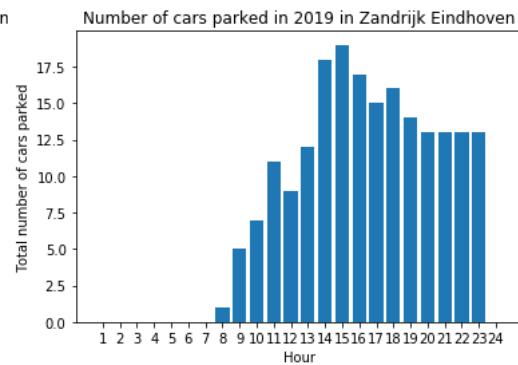
Spread over the day Villapark



Spread over the day Witte Dame



Spread over the day Woenselse Watermolen



Spread over the day Zandrijk

## D.2. Demographics

In Table D.1 shows how the demographic variables are correlated. Furthermore, in Figure D.1 the average household size in each neighbourhood are shown. Figure D.2 shows how the number of households differs per neighbourhood.



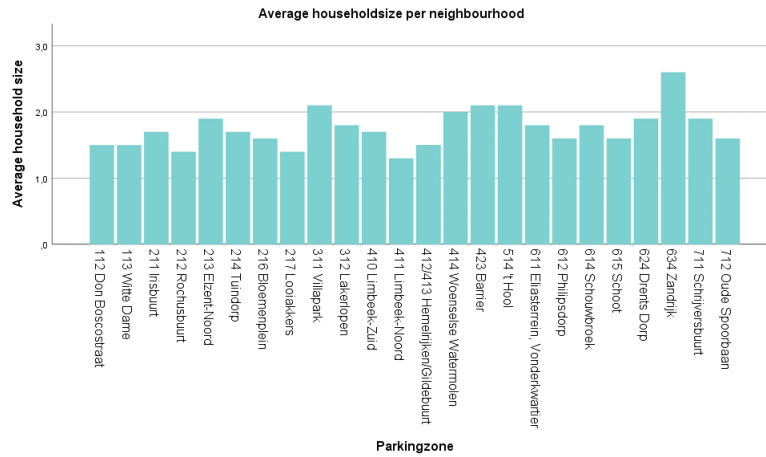


Figure D.1: Average household size per neighbourhood

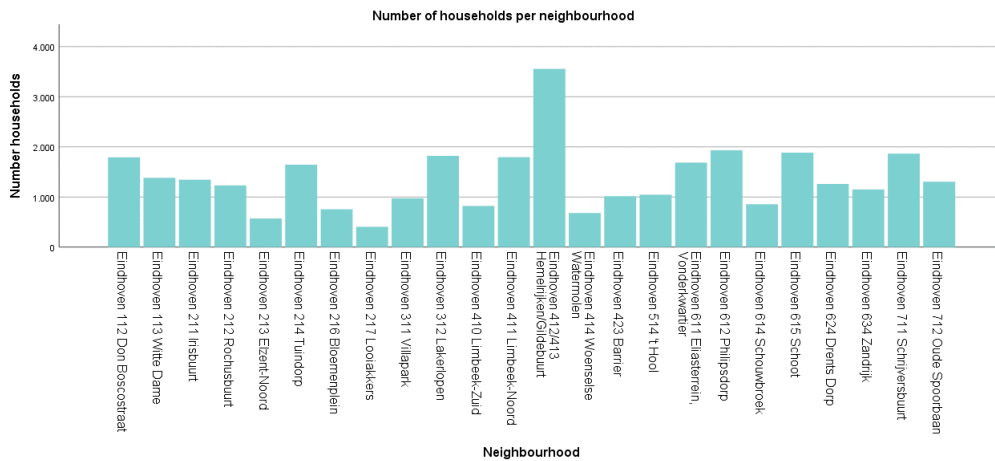


Figure D.2: Number of households per neighbourhood

### D.3. Geographics

In Table D.2 and the correlations between different geographic variables and visitor parking demand are shown. Values with one asterisk (\*) represent the relations significant at a 0.01 level ( $p < 0.01$ ) and values with two asterisks represent relations significant at a 0.05 level ( $p < 0.05$ ).

### D.4. Results simple linear regression

In Table D.4 the results of the simple linear regression models are shown. For all independent variables, a simple linear regression is estimated. The results of these regression models are used to determine which variable to include in the final regression model in case of high correlations. Furthermore, it gives insight into what variables explain the visitor parking demand significantly without the attendance of other variables.

Table D.4: Results simple linear regression models

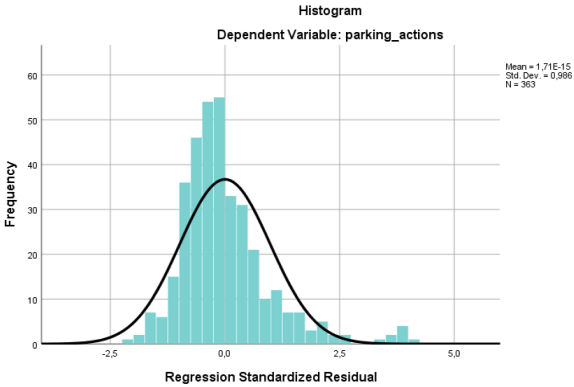
Variable	N	R	R Square	Adjusted R Square	Std. Error of the Estimate	Unstandardized B	Standardized Coefficients Beta	t	Sig.
Inhabitants	455	0.022	0.000	-0.002	11.38444	0.007	0.022	0.469	0.639
Households	451	0.014	0	-0.002	11.4176	-0.006	-0.014	-0.3	0.765
Men	452	0.018	0	-0.002	11.45031	0.009	0.018	0.376	0.707
Women	452	0.034	0.001	-0.001	11.40282	0.021	0.034	0.725	0.469
Inh_0-14	449	0.178	0.032	0.029	11.22994	0.344	0.178	3.818	0
Inh_15-24	450	0.015	0	-0.002	11.40703	-0.13	-0.015	-0.326	0.745
Inh_25-44	451	0.036	0.001	-0.001	11.40982	-0.019	-0.036	-0.767	0.444
Inh_45-64	450	0.193	0.037	0.035	11.20585	0.305	0.193	4.163	0
Inh_65+	450	0.049	0.002	0	11.40699	-0.03	-0.049	-1.033	0.302
Young people and adults	450	0.034	0.001	-0.001	11.40195	-0.13	-0.034	-0.711	0.478
Middle-aged, children and elderly	449	0.222	0.049	0.047	11.12664	0.231	0.222	4.815	0
HH_1	371	0.073	0.005	0.003	11.64493	-0.034	-0.073	-1.409	0.16
Hh_1+	306	0.041	0.002	-0.002	11.72616	-0.066	-0.041	-0.723	0.47
Avg_hhsize	446	0.094	0.009	0.007	11.40553	1.998	0.094	1.987	0.048
Income	418	0.056	0.003	0.001	11.51487	0.921	0.056	1.138	0.256
Urbanisation	460	0.136	0.019	0.016	11.25548	-5.408	-0.136	-2.939	0
Urban density	460	0.171	0.029	0.027	11.1944	0.003	0.171	3.707	0
Population density	460	0.171	0.029	0.027	11.19342	0.001	0.171	3.718	0
Surface_0-40	459	0.089	0.008	0.006	11.328	-0.088	-0.089	-1.9	0.058
Surface_40-70	459	0.096	0.009	0.007	11.31969	-0.14	-0.096	-2.071	0.039
Surface_70-100	459	0.041	0.002	-0.001	11.36327	-0.038	-0.041	-0.87	0.385
Surface_100-160	459	0.157	0.025	0.023	11.23133	0.194	0.157	3.402	0.001
Surface_160+	459	0.11	0.012	0.01	11.30426	0.267	0.11	2.355	0.019
Housing_number	459	0.013	0	-0.002	11.37173	-0.006	-0.013	-0.276	0.783
Housing_avgsurface	459	0.025	0.001	-0.002	11.36903	-0.004	-0.025	-0.541	0.588
Housing_totalsurface	459	0.058	0.003	0.001	11.3535	0	0.058	1.243	0.214
Housing_1+	219	0.103	0.011	0.006	10.98504	-0.031	-0.103	-1.531	0.127
P_rent	413	0.178	0.032	0.029	11.09397	-0.069	-0.178	-3.657	0
P_sale	418	0.19	0.036	0.034	11.08451	0.074	0.19	3.952	0
WOZ	443	0.015	0	-0.002	11.42963	-0.001	-0.015	-0.324	0.746
Dist_superm	451	0.019	0	-0.002	11.41534	0.763	0.019	0.392	0.695
Parkingpermit_250m	460	0.494	0.244	0.242	1.015	9.87897	0.494	12.155	0
Parkingpublic_250m	460	0.039	0.002	-0.001	11.35245	-0.424	-0.039	-0.836	0.404
Nearest_publicparking	460	0.075	0.006	0.003	11.32898	-0.002	-0.075	-1.613	0.107
Bus_400	460	0.023	0.001	-0.002	11.35817	-0.212	-0.023	-0.487	0.626
Bus_nearest	460	0.044	0.002	0	11.34999	0.005	0.044	0.947	0.344
Train_400	460	0.084	0.007	0.005	11.32065	-7.808	-0.084	-1.811	0.071
Train_nearest	460	0.17	0.029	0.027	11.19604	-0.004	-0.17	-3.688	0
Housing_0-100	459	0.104	0.011	0.009	11.31092	-0.055	-0.104	-2.237	0.026
Housing_100+	459	0.21	0.044	0.042	11.11827	0.257	0.21	4.599	0
Housing old	415	0.065	0.004	0.002	11.3284	0.048	0.065	1.329	0.184
Housing new	414	0.103	0.011	0.008	11.27686	-0.056	-0.103	-2.092	0.037

## D.5. Multiple regression model statistics

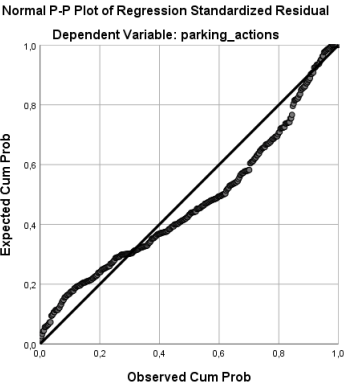
In this section, the statistics of the multiple regression model are shown. First, the assumptions were tested. These are presented in subsection D.5.1. Second, the correlation matrix of all variables is given in subsection D.5.2.

### D.5.1. Assumptions multiple linear regression

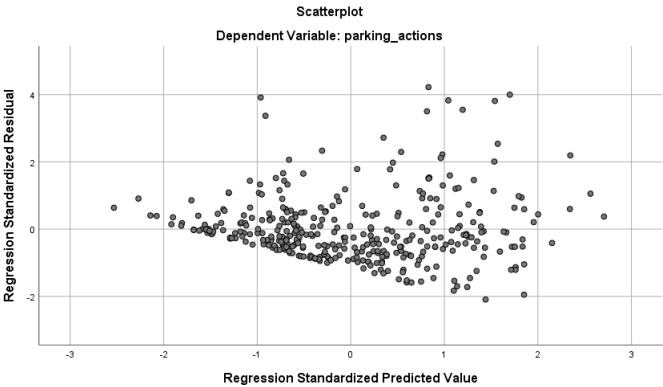
In this section the assumptions for the regression model were tested. In Figure D.3 the normality tests for the models with the normal variable for parking actions is shown. Figure D.4 the normality tests for the model with transformed dependent variable is given. It can be seen that the model with the regular dependent variable does not meet the assumptions on normality and heteroscedasticity, while the model with transformed variables does.



(a) Normality plot residuals

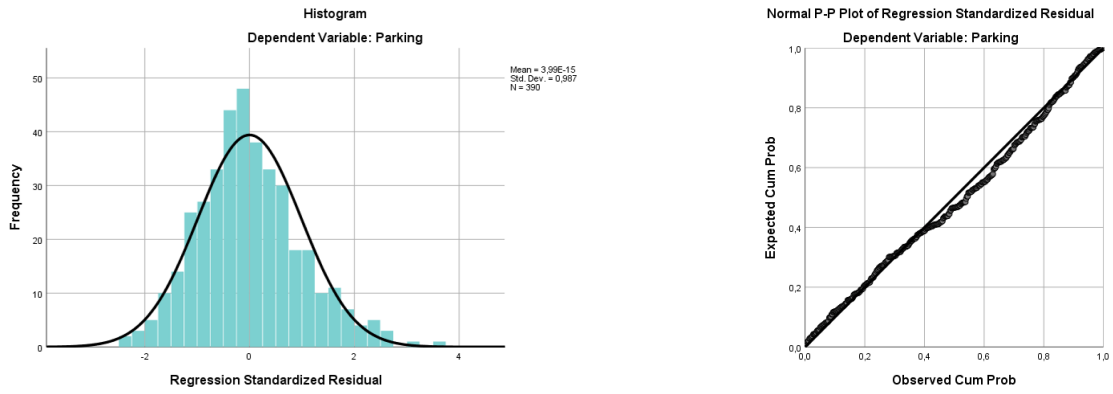


(b) P-plot regression model



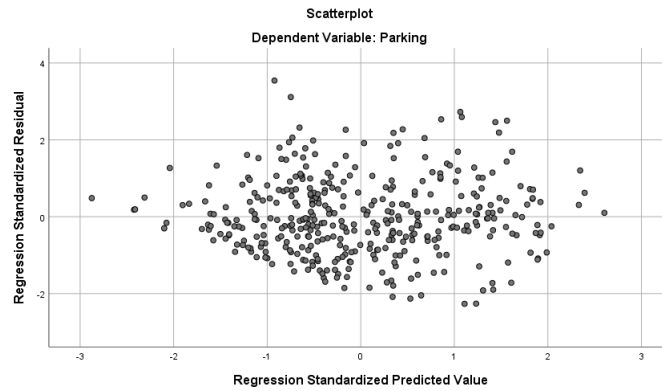
(c) Scatterplot regression model

Figure D.3: Normality and heteroscedasticity plot



(a) Normality plot residuals transformed dependent variable

(b) P-plot regression model transformed dependent variable



(c) Scatterplot regression model transformed dependent variable

Figure D.4: Normality and heteroscedasticity plot with transformed dependent variable

### D.5.2. Correlations multiple linear regression

The correlations matrix is represented in four tables in Table D.5, Table D.6, Table D.7, and Table D.8. These tables show all correlations, including correlations between demographic and geographic variables. Values with one asterisk (\*) represents the relationships significant at a 0.01 level ( $p < 0.01$ ). Values with two asterisks represent relationships significant at a 0.05 level ( $p < 0.05$ ). The bold values are the values with high correlations.

Table D.5: Correlations matrix part I

	Parking	Inhabitants	Men	Women	Inh_014	Inh_1524	Inh_2544	Inh_4564	Inh_65PL	Middle-aged, children, elderly	Young people & adults	Households	Hh_1	Hh_1+
Visitor parking	1	0.022	0.018	0.034	.178**	-0.015	-0.036	.193**	-0.049	-0.034	.222**	-0.014	-0.073	-0.041
Inhabitants	0.022	1	<b>.959**</b>	<b>.945**</b>	.307**	.654**	<b>.782**</b>	.397**	.453**	.840**	.426**	<b>.943**</b>	<b>.863**</b>	<b>.826**</b>
M	0.018	<b>.959**</b>	1	<b>.820**</b>	.309**	.731**	<b>.836**</b>	.400**	.244**	.911**	.428**	<b>.915**</b>	<b>.833**</b>	<b>.788**</b>
Women	0.034	<b>.945**</b>	<b>.820**</b>	1	.269**	.489**	.643**	.351**	.651**	.669**	.375**	<b>.881**</b>	<b>.807**</b>	<b>.799**</b>
Inh_014	.178**	.307**	.309**	.269**	1	0.066	.193**	.399**	-.099*	.166**	<b>.798**</b>	0.070	-0.047	0.040
Inh_1524	-0.015	.654**	<b>.731**</b>	.489**	0.066	1	.498**	.126**	0.006	<b>.789**</b>	.118*	<b>.710**</b>	<b>.733**</b>	.399**
Inh_2544	-0.036	<b>.782**</b>	<b>.836**</b>	.643**	.193**	.498**	1	.167**	-0.023	<b>.925**</b>	.213**	<b>.772**</b>	.676**	<b>.769**</b>
Inh_4564	.193**	.397**	.400**	.351**	.399**	.126**	.167**	1	0.021	.173**	<b>.871**</b>	.227**	0.089	.193**
Inh_65PL	-0.049	.453**	.244**	.651**	-.099*	0.006	-0.023	0.021	1	-0.012	-0.039	.451**	.444**	.422**
Middle-aged, children and elderly	-0.034	<b>.840**</b>	<b>.911**</b>	.669**	.166**	<b>.789**</b>	<b>.925**</b>	.173**	-0.012	1	.202**	<b>.857**</b>	<b>.803**</b>	<b>.721**</b>
Young people & adults	.222**	.426**	.428**	.375**	<b>.798**</b>	.118*	.213**	<b>.871**</b>	-0.039	.202**	1	.187**	0.034	.150**
Households	-0.014	<b>.943**</b>	<b>.915**</b>	<b>.881**</b>	0.070	<b>.710**</b>	<b>.772**</b>	.227**	.451**	.857**	.187**	1	.969**	.815**
Hh_1	-0.073	<b>.863**</b>	<b>.833**</b>	<b>.807**</b>	-0.047	<b>.733**</b>	.676**	0.089	.444**	.803**	0.034	.969**	1	.720**
Hh_1+	-0.041	<b>.826**</b>	<b>.788**</b>	<b>.799**</b>	0.040	.399**	<b>.769**</b>	.193**	.422**	.721**	.150**	<b>.815**</b>	.720**	1
Avg_hhszize	.094*	-.142**	-.132**	-.143**	.561**	-.228**	-.205**	.271**	-.194**	-.246**	.480**	-.355**	-.428**	-.221**
Income	0.056	-.137**	-.123**	-.142**	.223**	-.307**	-.086	.169**	-.107*	-.198**	.232**	-.267**	-.303**	-0.062
Urbanisation	-.136**	.103*	0.082	.102*	.244**	-0.012	0.075	.129**	0.004	0.048	.216**	0.024	-0.035	0.030
Urban_density	.171**	-0.043	-0.038	-0.045	-.215**	0.046	0.006	-0.005	-0.045	0.026	-.119*	0.030	0.026	-0.005
Population_density	.171**	0.029	0.030	0.023	-0.021	0.084	0.073	-0.003	-0.076	0.090	-0.013	0.053	0.026	-0.047
Surface_040	-0.089	.489**	.559**	.360**	-0.016	.634**	.430**	0.033	0.051	.582**	0.013	.555**	.571**	.397**
Surface_40-70	-.096*	.430**	.357**	.479**	-.162**	.167**	.339**	0.015	.425**	.312**	-0.077	.502**	.503**	.422**
Surface_70-100	-0.041	.495**	.404**	.554**	-0.064	.186**	.311**	0.058	.546**	.304**	0.004	.547**	.504**	.496**
Surface_100-160	.157**	.350**	.270**	.402**	.290**	-0.001	.113*	.382**	.340**	0.080	.406**	.254**	.115*	.187**
Surface_>160	.110*	.118*	.117*	.102*	.215**	.130**	-0.089	.280**	0.068	-0.007	.299**	0.012	0.041	0.036
Housing_0_100	-.104*	.688**	.648**	.670**	-.102*	.499**	.522**	0.055	.482**	.589**	-0.019	<b>.777**</b>	<b>.771**</b>	.638**
Housing_100plus	.210**	.405**	.327**	.449**	.396**	0.065	0.067	.520**	.371**	0.076	.554**	.258**	.130*	.203**
Housing_number	-0.013	<b>.805**</b>	<b>.737**</b>	<b>.806**</b>	0.062	.494**	.516**	.258**	.600**	.582**	.203**	<b>.831**</b>	<b>.778**</b>	.682**
Housing_avgsurface	-0.025	-.123**	-.148**	-0.074	.112*	-.107*	-.247**	0.042	0.058	-.222**	0.087	-.226**	-.178**	-.196**
Housing_totalsurface	0.058	.698**	.571**	<b>.777**</b>	.197**	.264**	.291**	.387**	<b>.709**</b>	.322**	.360**	.607**	.530**	.555**
Housing_45	.385**	0.025	0.039	0.010	.130**	.111*	-0.003	.189**	-.149**	0.053	.194**	0.012	0.001	-.142*
Housing_4564	-.114*	.253**	.169**	.321**	-0.046	0.083	.139**	-0.073	.347**	.127**	-0.072	.283**	.274**	.282**
Housing_6574	-0.094	-0.090	-0.088	-0.092	-.179**	-0.081	-0.027	-.156**	0.024	-0.058	-.199**	-0.051	-0.048	-0.069
Housing_7584	-.106*	.112*	0.060	.154**	-.115*	0.023	0.028	-0.077	.243**	0.029	-.113*	.174**	.206**	0.070
Housing_8594	-0.023	.461**	.455**	.421**	0.023	0.072	.663**	.184**	0.048	.501**	.133**	.441**	.357**	.583**
Housing_9504	-0.084	.432**	.412**	.398**	.132**	.258**	.315**	.144**	.273**	.329**	.167**	.425**	.373**	.376**
Housing_0514	-0.061	.634**	.647**	.558**	0.018	.503**	.550**	.143**	.296**	.589**	.103*	.661**	.622**	.679**
Housing_1524	-0.066	.213**	.149**	.267**	-0.040	-0.002	.107*	0.000	.330**	0.064	-0.021	.226**	.201**	.249**
Housing_old	0.065	.400**	.305**	.458**	-0.049	.136**	.300**	.110*	.378**	.251**	0.045	.437**	.398**	.307**
Housing_new	-.103*	<b>.714**</b>	<b>.703**</b>	.650**	0.072	.498**	.582**	.173**	.404**	.608**	.152**	<b>.734**</b>	.676**	<b>.730**</b>
Housing_1+	-0.103	<b>.848**</b>	<b>.794**</b>	<b>.823**</b>	-0.012	.424**	<b>.718**</b>	.203**	.490**	.695**	.135*	<b>.881**</b>	<b>.843**</b>	<b>.873**</b>
P_rent	-.178**	.192**	.153**	.216**	-.345**	.194**	.238**	-.282**	.212**	.255**	-.371**	.321**	.343**	.247**
P_sale	.190**	-.207**	-.169**	-.228**	.352**	-.208**	-.259**	.273**	-.209**	-.276**	.368**	-.341**	-.371**	-.247**
WOZ	.206**	-0.050	-0.055	-0.039	.290**	-.103*	-.180**	.250**	-0.003	-.173**	.319**	-.160**	-.148**	-0.045
Dist_superm	0.019	.144**	.113*	.162**	.314**	-0.022	0.037	.136**	.109*	0.016	.257**	0.051	0.055	.163**
Dist_highway	-0.024	-.130**	-.093*	-.101*	-0.056	-0.070	-0.078	-.093*	-0.005	-0.086	-0.091	-0.087	-0.086	-0.095
Parking_permit250m	.494**	-0.055	-0.033	-0.083	0.051	0.055	-0.030	-0.037	-.132**	0.003	0.003	-0.051	-0.021	-0.085
Parking_permit100m	.445**	-0.060	-0.030	-0.087	0.060	0.024	-0.021	-0.046	-.128**	-0.005	0.002	-0.066	-0.036	-0.092
Parking_public100m	-0.045	-0.030	-0.017	-0.045	-.258**	0.035	0.013	-.147**	0.047	0.025	-.235**	0.049	0.025	0.005
Parking_public250m	-0.039	-0.012	0.008	-0.031	-.230**	0.021	0.080	-.113*	-0.006	0.066	-.198**	0.067	0.010	0.088
Nearest_publicparking	-0.075	0.002	-0.011	0.027	0.020	-0.015	-0.029	0.057	0.018	-0.028	0.048	-0.014	0.019	-0.054
Bus_400	-0.023	0.040	0.032	0.027	-.130**	0.019	0.061	0.042	0.035	0.054	-0.041	0.072	0.017	0.002
Bus_nearest	0.044	-.107*	-0.071	-.124**	.113*	-0.039	-.126**	0.019	-.106*	-.107*	0.073	-.148**	-.133*	-.118*
Train_400	-0.084	.140**	.157**	.106*	-0.063	0.049	.233**	0.015	-0.004	.186**	-0.024	.157**	.137**	.355**
Train_nearest	-.170**	0.020	-0.026	0.066	.175**	-0.077	-.104*	.145**	.095*	-.108*	.189**	-0.057	-0.060	-0.094

Table D.6: Correlations matrix part II

	Avg_hhsz	Income	Urbanisation	Urban_density	Pop_density	Surface_040	Surface_40-70	Surface_70-100	Surface_100-160	Surface_>160	Housing_0100	Housing_100plus	Housing_number	Housing_avgsurface	Housing_totalsurface
Visitor parking	.094*	0.056	-.136**	.171**	.171**	-.089	-.096*	-.041	.157**	-.110*	-.104*	.210**	-.013	-0.025	0.058
Inhabitants	-.142**	-.137**	.103*	-.043	0.029	.489**	.430**	.495**	.350**	.118*	.688**	.405**	<b>.805**</b>	-.123**	.698**
M	-.132**	-.123*	0.082	-.038	0.030	.559**	.357**	.404**	.270**	.117*	.648**	.327**	.737**	-.148**	.571**
Women	-.143**	-.142**	.102*	-.045	0.023	.360**	.479**	.554**	.402**	.102*	.670**	.449**	<b>.806**</b>	-0.074	.777**
Inh_014	.561**	.223**	.244**	-.215**	-.021	-.016	-.162**	-.064	.290**	.215**	-.102*	.396**	0.062	.112*	.197**
Inh_1524	-.228**	-.307**	-.012	0.046	0.084	.634**	.167**	.186**	-.001	.130**	.499**	0.065	.494**	-.107*	.264**
Inh_2544	-.205**	-.086	0.075	0.006	0.073	.430**	.339**	.311**	.113*	-.089	.522**	0.067	.516**	-.247**	.291**
Inh_4564	-.271**	.169**	.129**	-.005	-.003	0.033	0.015	0.058	.382**	.280**	0.055	.520**	.258**	0.042	.387**
Inh_65PL	-.194**	-.107*	0.004	-0.045	-0.076	0.051	.425**	.546**	.340**	0.068	.482**	.371**	.600**	0.058	.709**
Middle-aged, children and elderly	-.246**	-.198**	0.048	0.026	0.090	.582**	.312**	.304**	0.080	-0.007	.589**	0.076	.582**	-.222**	.322**
Young people & adults	.480**	.232**	.216**	-.119*	-0.013	0.013	-0.077	0.004	.406**	.299**	-0.019	.554**	.203**	0.087	.360**
Households	-.355**	-.267**	0.024	0.030	0.053	.555**	.502**	.547**	.254**	0.012	.777**	.258**	<b>.831**</b>	-.226**	.607**
Hh_1	-.428**	-.303**	-.035	0.026	0.026	.571**	.503**	.504**	.115*	0.041	.771**	.130*	.778**	-.178**	.530**
Hh_1+	-.221**	-0.062	0.030	-0.005	-0.047	.397**	.422**	.496**	.187**	0.036	.638**	.203**	.682**	-.196**	.555**
Avg_hhsz	1	.575**	0.051	-.222**	-.214**	-.148**	-.339**	-.321**	0.005	.357**	-.378**	.187**	-.281**	.408**	-0.077
Income	.575**	1	-.033	-.119*	-.197**	-.135**	-.194**	-.187**	0.023	.337**	-.245**	.194**	-.155**	.301**	0.011
Urbanisation	0.051	-0.033	1	-.573**	1	.502**	-.095*	-.028	-.068	.106*	0.087	-0.022	0.075	0.048	-0.063
Urban_density	-.222**	-.119*	-.573**	1	.502**	0.019	0.075	-0.008	0.021	-.152**	0.033	-0.056	0.008	-.164**	-0.073
Population_density	-.214**	-.197**	-.095*	.502**	1	0.037	0.047	-0.033	0.078	-.209**	0.018	-0.028	0.005	-.262**	-0.089
Surface_040	-.148**	-.135**	-.028	0.019	0.037	1	.160**	.177**	-0.011	-0.060	.684**	-0.041	.621**	-.167**	.209**
Surface_40-70	-.339**	-.194**	-0.068	0.075	0.047	.160**	1	.298**	0.023	-0.061	.610**	-0.008	.565**	-.261**	.357**
Surface_70-100	-.321**	-.187**	.106*	-0.008	-0.033	.177**	.298**	1	0.062	-.166**	.755**	-.022	.695**	-.290**	.506**
Surface_100-160	0.005	0.023	0.087	0.021	0.078	-0.011	0.023	0.062	1	-.231**	0.036	<b>.872**</b>	.383**	-.145**	.480**
Surface_>160	.357**	.337**	-.022	-.152**	-.209**	-0.060	-0.061	-.166**	-.231**	1	-.145**	.274**	-.026	.523**	.302**
Housing_0_100	-.378**	-.245**	0.020	0.033	0.018	.684**	.610**	.755**	0.036	-.145**	1	-0.037	<b>.917**</b>	-.343**	.520**
Housing_100plus	.187**	.194**	0.075	-0.056	-0.028	-0.041	-0.008	-0.022	<b>.872**</b>	.274**	-0.037	1	.365**	.119*	.626**
Housing_number	-.281**	-.155**	0.048	0.008	0.005	.621**	.565**	.695**	.383**	-0.026	<b>.917**</b>	.365**	1	-.273**	<b>.734**</b>
Housing_avgsurface	.408**	.301**	-0.063	-.164**	-.262**	-.167**	-.261**	-.290**	-.145**	.523**	-.343**	.119*	-.273**	1	.224**
Housing_totalsurface	-0.077	0.011	0.052	-0.073	-0.089	.209**	.357**	.506**	.480**	.302**	.520**	.626**	<b>.734**</b>	.224**	1
Housing_45	0.047	-.112*	-0.091	.101*	0.041	-0.046	-0.056	-.208**	0.086	.179**	-.159**	.176**	-0.079	0.038	-0.007
Housing_4564	-.102*	-.132**	-0.019	-0.048	0.045	0.095	.184**	.305**	0.078	-.109*	.285**	0.021	.275**	-0.078	.181**
Housing_6574	-.145**	0.070	-0.048	0.057	0.011	-0.007	0.081	-0.005	0.028	-0.057	0.022	-0.002	0.020	-.125*	-0.040
Housing_7584	-.169**	-.134**	-0.021	0.006	-0.017	.151**	.513**	-.046	-0.071	-0.063	.289**	-.102*	.230**	-.151**	0.061
Housing_8594	-.118*	-0.047	-0.028	0.073	0.021	-0.015	.196**	.250**	0.043	-.097*	.200**	-0.007	.186**	-.135**	.132**
Housing_9504	-0.096	-0.007	.297**	-.162**	-0.051	.271**	0.076	.308**	.327**	-0.044	.343**	.302**	.439**	-.122*	.323**
Housing_0514	-.105*	-0.038	-0.025	0.009	-0.025	.701**	.269**	.414**	.145**	0.044	.701**	.166**	.721**	-0.040	.521**
Housing_1524	-0.045	0.045	-0.025	-0.079	-.117*	-0.015	.255**	.298**	0.062	0.006	.245**	0.064	.255**	-0.031	.220**
Housing_old	-.281**	-.245**	-.117*	.130**	-.102*	-.117*	.516**	.360**	-.160**	-0.089	.444**	.114*	.460**	-.264**	.299**
Housing_new	-.136**	-0.021	.129**	-0.087	-0.066	.645**	.264**	.509**	.287**	0.010	<b>.720**</b>	.289**	<b>.789**</b>	-0.095	.576**
Housing_1+	-.272**	-0.086	-0.034	-0.001	-0.081	.541**	.502**	.580**	.216**	-0.032	.820**	.187**	<b>.823**</b>	-.158**	.551**
P_rent	-.582**	-.578**	0.011	.215**	-.115*	.183**	.325**	.312**	0.070	-0.430**	.385**	-.153**	.302**	-.318**	.105*
P_sale	.601**	.589**	-0.013	-.226**	-.102*	-.194**	-.345**	-.320**	-0.064	.417**	-.403**	.151**	-.319**	-.319**	-.121*
WOZ	.529**	.481**	-0.093	-0.015	-0.025	-.184**	-.243**	-.236**	0.096	.538**	-.317**	.308**	-.177**	.565**	.104*
Dist_superm	.275**	.119*	.526**	-.475**	-.291**	0.022	-0.092	0.036	0.092	.172**	-0.001	.179**	0.070	.140**	.143**
Dist_highway	0.003	.188**	-0.103*	0.059	-0.048	-0.048	-0.050	-0.045	-0.096*	-0.012	-0.068	-.101*	-.104*	0.080	-0.097*
Parking_permit250m	0.058	.110*	-.186**	.238**	-.118*	-0.037	-0.065	-0.076	-0.091	.132**	-0.085	-0.023	-0.088	0.032	-0.072
Parking_permit100m	.100*	.124*	-.138**	.122**	.097*	-0.063	-0.086	-0.090	-.094*	.138**	-.114*	-0.023	-.116*	0.057	-0.081
Parking_public100m	-.298**	-.115*	-0.087	.167**	0.072	.106*	0.067	0.081	0.046	-.191**	.125**	-0.050	.096*	-.191**	-0.037
Parking_public250m	-.332**	-.251**	-0.039	.233**	.128**	0.070	0.067	.156**	0.024	-.282**	.148**	-.117*	0.091	-.254**	-0.041
Nearest_publicparking	.096*	0.008	0.050	-.161**	-.110*	-0.014	-0.016	-0.055	0.003	0.082	-0.044	0.044	-0.023	.114*	.108*
Bus_400	-.310**	-0.009	-.151**	.247**	.267**	0.006	.191**	0.067	.106*	-.108*	.109*	0.050	.122**	-.170**	0.080
Bus_nearest	.268**	-0.009	0.085	-.132**	-.110*	-.097*	-.148**	-.155**	-0.078	.131**	-.191**	-0.012	-.183**	.243**	-0.070
Train_400	-.103*	-0.044	0.037	0.041	-0.006	-0.016	0.027	0.037	-0.045	-0.070	0.022	-0.080	-0.012	0.068	-0.045
Train_nearest	.226**	.210**	.224**	-.263**	-.112*	-0.057	0.015	-.125**	0.073	.192**	-.094*	.168**	-0.021	.166**	.120**

Table D.7: Correlations matrix part III

	Housing_45	Housing_4564	Housing_6574	Housing_7584	Housing_8594	Housing_9504	Housing_0514	Housing_1524	Housing_old	Housing_new	Housing_1+	P_rent	P_sale	WOZ
Visitor parking	.385**	-.114*	-0.094	-.106*	-0.023	-0.084	-0.061	-0.066	0.065	-.103*	-0.103	-.178**	.190**	.206**
Inhabitants	0.025	.253**	-0.090	-.112*	.461**	.432**	.634**	.213**	.400**	.714**	<b>.848**</b>	.192**	-.207**	-0.050
M	0.039	.169**	-0.088	0.060	.455**	.412**	.647**	.149**	.305**	<b>.703**</b>	<b>.794**</b>	.153**	-.169**	-0.055
Women	0.010	.321**	-0.092	.154**	.421**	.398**	.558**	.267**	.458**	.650**	.823**	.216**	-.228**	-0.039
Inh_014	.130**	-0.046	-.179**	-.115*	0.023	.132**	0.018	-0.040	0.072	-0.012	-.345**	.352**	.290**	
Inh_1524	.111*	0.083	-0.081	0.023	0.072	.258**	.503**	-0.002	.136**	.498**	.424**	.194**	-.208**	-.103*
Inh_2544	-0.003	.139**	-0.027	0.028	.663**	.315**	.550**	.107*	.300**	.582**	<b>.718**</b>	.238**	-.259**	-.180**
Inh_4564	.189**	-0.073	-.156**	-0.077	.184**	.144**	.143**	0.000	-.110*	.173**	.203**	-.282**	.273**	.250**
Inh_65PL	-.149**	.347**	0.024	.243**	0.048	.273**	.296**	.330**	.378**	.404**	.490**	.212**	-.209**	-0.003
Middle-aged, children and elderly	0.053	.127**	-0.058	0.029	.501**	.329**	.589**	0.064	.251**	.608**	.695**	.255**	-.276**	-.173**
Young people & adults	.194**	-0.072	-.199**	-.113*	.133**	.167**	.103*	-0.021	0.045	.152**	.135*	-.371**	.368**	.319**
Households	0.012	.283**	-0.051	.174**	.441**	.425**	.661**	.226**	.437**	.734**	.881**	.321**	-.341**	-.160**
Hh_1	0.001	.274**	-0.048	.206**	.357**	.373**	.622**	.201**	.398**	.676**	.843**	.343**	-.371**	-.148**
Hh_1+	-.142*	.282**	-0.069	0.070	.583**	.376**	.679**	.249**	.307**	.730**	.873**	.247**	-.247**	-0.045
Avg_hhsize	0.047	-.102*	-.145**	-.169**	-.118*	-0.096	-.105*	-0.045	-.281**	-.136**	-.272**	-.582**	.601**	.529**
Income	-.112*	-.132**	0.070	-.134**	-0.047	-0.007	-0.038	0.045	-.245**	-0.021	-0.086	-.578**	.589**	.481**
Urbanisation	-0.091	-0.019	-0.048	-0.021	-0.028	.297**	-0.025	-0.025	-.117*	.129**	-0.034	0.011	-0.013	-0.093
Urban_density	.101*	-0.048	0.057	0.006	0.073	-.162**	0.009	-0.079	.130**	-0.087	-0.001	.215**	-.226**	-0.015
Population_density	0.041	0.045	0.011	-0.017	0.021	-0.051	-0.025	-.117*	.102*	-0.066	-0.081	.115**	-.102*	-0.025
Surface_040	-0.046	0.095	-0.007	.151**	-0.015	.271**	<b>.701**</b>	-0.015	-.117*	.645**	.541**	.183**	-.194**	-.184**
Surface_40-70	-0.056	.184**	0.081	.513**	.196**	0.076	.268**	.255**	.516**	.264**	.502**	.325**	-.345**	-.243**
Surface_70-100	-.208**	.305**	-0.005	0.046	.250**	.308**	.414**	.298**	.360**	.509**	.580**	.312**	-.320**	-.236**
Surface_100-160	0.086	0.078	0.028	-0.071	0.043	.327**	.145**	0.062	.160**	.287**	.216**	0.070	-0.064	0.096
Surface_>160	.179**	-.109*	-0.057	-0.063	-.097*	-0.044	0.044	0.006	-0.089	0.010	-0.032	-.430**	.417**	.538**
Housing_0_100	-.159**	.285**	0.022	.289**	.200**	.343**	.701**	.245**	.444**	.720**	<b>.820**</b>	.385**	-.403**	-.317**
Housing_100plus	.176**	0.021	-0.002	-.102*	-0.007	.302**	.166**	0.064	.114*	.289**	.187**	-.153**	-.151**	.308**
Housing_number	-0.079	.275**	0.020	.230**	.186**	.439**	<b>.721**</b>	.255**	.460**	<b>.789**</b>	<b>.823**</b>	.302**	-.319**	-.177**
Housing_avgsurface	0.038	-0.078	-.125*	-.151**	-.135**	-.122*	-0.040	-0.031	-.264**	-0.095	-.158*	-.318**	.319**	.565**
Housing_totalsurface	-0.007	.181**	-0.040	0.061	.132**	.323**	.521**	.220**	.299**	.576**	.551**	.105*	-.121*	.104*
Housing_45	1	-.244**	-.247**	-.133**	-.228**	-.153**	-0.089	-0.075	0.093	-.155**	-.181**	-0.049	0.016	.126*
Housing_4564	-.244**	1	-0.059	-0.034	-0.049	-0.063	-.120*	.231**	.475**	0.093	.412**	.148**	-.146**	-.172**
Housing_6574	-.247**	-0.059	1	-0.024	-0.082	-0.062	-0.040	-0.031	0.092	-0.066	-0.024	0.057	-0.024	-.166**
Housing_7584	-.133**	-0.034	-0.024	1	-0.046	-0.048	-0.031	-0.024	.467**	-0.051	.229**	.175**	-.196**	-.179**
Housing_8594	-.228**	-0.049	-0.082	-0.046	1	-0.021	-0.045	0.065	.449**	-0.043	.483**	.149**	-.151**	-.113*
Housing_9504	-.153**	-0.063	-0.062	-0.048	-0.021	1	.202**	0.021	-.215**	.666**	.385**	.172**	-.158**	-0.025
Housing_0514	-0.089	.120*	-0.040	-0.031	-0.045	.202**	1	.142**	-0.030	.846**	.712**	.106*	-.120*	0.019
Housing_1524	-0.075	.231**	-0.031	-0.024	0.065	0.021	.142**	1	.134**	.284**	.355**	0.009	-0.007	0.004
Housing_old	0.093	.475**	0.092	.467**	.449**	-.215**	-0.030	.134**	1	-.108*	.450**	.283**	-.316**	-.310**
Housing_new	-.155**	0.093	-0.066	-0.051	-0.043	.666**	<b>.846**</b>	.284**	-.108*	1	<b>.778**</b>	.168**	-.172**	0.002
Housing_1+	-.181**	.412**	-0.024	.229**	.483**	.385**	<b>.712**</b>	.355**	.450**	.778**	1	.332**	-.359**	-0.114
P_rent	-0.049	.148**	0.057	.175**	.149**	.172**	.106*	0.009	.283**	.168**	.332**	1	-.972**	-.566**
P_sale	0.016	-.146**	-0.024	-.196**	-.151**	-.158**	-.120*	-0.007	-.316**	-.172**	-.359**	-.972**	1	.579**
WOZ	.126*	-.172**	-.166**	-.179**	-.113*	-0.025	0.019	0.004	-.310**	0.002	-0.114	-.566**	.579**	1
Dist_superm	-0.050	0.002	0.000	-.097*	0.058	.151**	0.061	0.027	-.112*	.129**	.168*	-.256**	.264**	.124*
Dist_highway	-.278**	0.011	-.097*	0.041	-0.022	-0.025	-.133**	-0.046	-0.029	-.100*	-.158*	-0.090	0.073	.220**
Parking_permit250m	.209**	-.197**	-0.025	-0.038	-0.028	-0.083	-0.052	-0.102*	-0.054	-0.093	-.148*	-.175**	.178**	.268**
Parking_permit100m	.128**	-.150**	-0.015	-0.039	-0.020	-0.105*	-0.056	-0.077	-0.071	-.101*	-0.130	-.215**	.213**	.239**
Parking_public100m	-.166**	0.004	.240**	.197**	-0.028	0.094	0.055	-0.065	.097*	0.073	0.035	.343**	-.324**	-.270**
Parking_public250m	-0.080	-0.078	0.079	.183**	0.072	0.065	0.057	-0.035	0.084	0.066	0.064	.477**	-.445**	-.368**
Nearest_publicparking	-.105*	0.016	0.021	-0.024	-0.007	-0.051	0.034	-0.002	-0.040	-0.004	-0.045	-0.085	0.068	0.084
Bus_400	-.144**	-0.038	.104*	.156**	0.002	0.047	-0.001	-0.066	.120*	0.024	-0.089	0.095	-.142**	0.037
Bus_nearest	.187**	-0.060	-.157**	-.151**	-.098*	-0.090	-0.044	.151**	-.199**	-0.054	-0.093	-.146**	.162**	0.033
Train_400	-0.062	0.051	-0.029	-0.022	.322**	0.073	-0.019	-0.013	-0.028	0.024	.213**	0.059	-0.061	-0.055
Train_nearest	-.110*	0.045	.140**	-0.034	-0.086	-0.017	-0.050	.097*	0.001	-0.026	-0.089	-.307**	.273**	.215**

Table D.8: Correlation matrix part IV

	Dist_superm	Dist_highway	Parking_permit250m	Parking_permit100m	Parking_public100m	parking_public250m	Nearest_publicparking	Bus_400	Bus_nearest	Train_400	Train_nearest
Visitor parking	0.019	-0.024	.494**	.445**	-0.045	-0.039	-0.075	-0.023	0.044	-0.084	-0.170**
Inhabitants	.144**	-.130**	-0.055	-0.060	-0.030	-0.012	0.002	0.040	-.107**	.140**	0.020
M	.113*	-.093*	-0.033	-0.030	-0.017	0.008	-0.011	0.032	-0.071	.157**	-0.026
Women	.162**	-.101*	-0.063	-0.067	-0.045	-0.031	0.027	0.027	-.124**	.106*	0.066
Inh_014	.314**	-0.056	0.051	0.060	-.258**	-.230**	0.020	-.130**	.113*	-0.063	.175**
Inh_1524	-0.022	-0.070	0.055	0.024	0.035	0.021	-0.015	0.019	-0.039	0.049	-0.077
Inh_2544	0.037	-0.078	-0.030	-0.021	0.013	0.080	-0.029	0.061	-.126**	.233**	-.104*
Inh_4564	.136**	-.093*	-0.037	-0.046	-.147**	-.113*	0.057	0.042	0.019	0.015	.145**
Inh_65PL	.109*	-0.005	-.132**	-.128**	0.047	-0.006	0.018	0.035	-.106*	-0.004	.095*
Middle-aged, children and elderly	0.016	-0.086	0.003	-0.005	0.025	0.066	-0.028	0.054	-.107**	.186**	-.108*
Young people & adults	.257**	-0.091	0.003	0.002	-0.235**	-.198**	0.048	-0.041	0.073	-0.024	-.189**
Households	0.051	-0.067	-0.051	-0.066	0.049	0.067	-0.014	0.072	-.148**	.157**	-0.057
Hh_1	0.055	-0.086	-0.021	-0.036	0.025	0.010	0.019	0.017	-.133*	.137**	-0.060
Hh_1+	.163**	-0.095	-0.085	-0.092	0.005	0.088	-0.054	0.002	-.118*	.355**	-0.094
Avg_hhsiz	.275**	0.003	0.058	.100*	-.298**	-.332**	.096*	-.310**	.268**	-.103*	.226**
Income	.119*	.188**	.110*	.124*	-.115*	-.251**	0.008	-0.009	-0.009	-0.044	.210**
Urbanisation	.526**	-.103*	-.186**	-.138**	-0.087	-0.039	0.050	-.151**	0.085	0.037	.224**
Urban_density	-.475**	0.059	.238**	.122**	.167**	.233**	-.161**	.247**	-.132**	0.041	-.263**
Population_density	-.291**	-0.048	-.118*	.097*	.072	.128*	-.110*	.267**	-.110*	-0.006	-.112*
Surface_040	0.022	-0.048	-0.037	-0.063	.106*	0.070	-0.014	0.006	-.097*	-0.016	-0.057
Surface_40-70	-0.092	-0.050	-0.065	-0.066	0.067	0.067	-0.016	.191**	-.148**	0.027	0.015
Surface_70-100	0.036	-0.045	-0.076	-0.090	0.081	.156**	-0.055	0.067	-.155**	0.037	-.125**
Surface_100-160	0.092	-0.096*	-0.091	-.094*	0.046	0.024	0.003	.106*	-0.078	-0.045	0.073
Surface_>160	.172**	-0.012	.132**	.138**	-.191**	-.282**	0.082	-.108*	.131**	-0.070	.192**
Housing_0_100	-0.001	-0.068	-0.085	-.114*	.125**	.148**	-0.044	.109*	-.191**	0.022	-.094*
Housing_100plus	.179**	-.101*	-0.023	-0.023	-0.050	-.117*	0.044	0.050	-0.012	-0.080	.168**
Housing_number	0.070	-.104*	-0.088	-.116*	.096*	0.091	-0.023	.122**	-.183**	-0.012	-0.021
Housing_avgsurface	.140**	0.080	0.032	0.037	-0.191**	-.254**	.114*	-.170**	-.243**	0.068	.166**
Housing_totalsurface	.143**	-.097*	-0.072	-0.081	-0.037	-0.041	.108*	0.080	-0.070	-0.045	.120**
Housing_45	-0.050	-.278**	.209**	.128**	-.166**	-0.080	-.105*	-.144**	.187**	-0.062	-.110*
Housing_4564	0.002	0.011	-.197**	-.150**	0.004	-0.078	0.016	-0.038	-0.060	0.051	0.045
Housing_6574	0.000	-0.097*	-0.025	-0.015	.240**	0.079	0.021	.104*	-.157**	-0.029	.140**
Housing_7584	-.097*	0.041	-0.038	-0.039	.197**	.183**	-0.024	.156**	-.151**	-0.022	-0.034
Housing_8594	0.058	-0.022	-0.028	-0.020	-0.028	0.072	-0.007	0.002	-.098*	.322**	-0.086
Housing_9504	.151**	-0.025	-0.083	-.105*	0.094	0.065	-0.051	0.047	-0.090	0.073	-0.017
Housing_0514	0.061	-.133**	-0.052	-0.056	0.055	0.057	0.034	-0.001	-0.044	-0.019	-0.050
Housing_1524	0.027	-0.046	-.102*	-0.077	-0.065	-0.002	-0.066	.151**	-0.013	-.097*	0.000
Housing_old	-.112*	-0.029	-0.054	-0.071	.097*	0.084	-0.040	.120*	-.199**	-0.028	0.001
Housing_new	.129**	-.100*	-0.093	-.101*	0.073	0.066	-0.004	0.024	-0.054	0.024	-0.026
Housing_1+	.168*	-.158*	-.148*	-0.130	0.035	0.064	-0.045	-0.089	-0.093	.213**	-0.089
P_rent	-.256**	-0.090	-.175**	-.215**	.343**	.477**	-0.085	0.095	-.146**	0.059	-.307**
P_sale	.264**	0.073	.178**	.213**	-.324**	-.445**	0.068	-.142**	.162**	-0.061	.273**
WOZ	.124*	.220**	.268**	.239**	-.270**	-.368**	0.084	0.037	0.033	-0.055	.215**
Dist_superm	1	-.207**	-0.085	-0.005	-0.260**	-.317**	.108*	-.357**	.222**	0.025	-.183**
Dist_highway	-.207**	1	0.011	0.014	-0.009	-0.053	0.034	-0.008	-0.035	-0.023	-0.007
Parking_permit250m	-0.085	0.011	1	.779**	-0.013	-0.013	-.119*	.119*	-0.016	-0.079	-.189**
Parking_permit100m	-0.005	0.014	.779**	1	-0.017	-0.017	-.121**	0.067	0.044	-0.042	-.191**
Parking_public100m	-.260**	-0.009	-0.017	-0.017	1	.559**	-0.039	.223**	-.264**	.132**	-.303**
Parking_public250m	-.317**	-0.053	-.154**	-.121**	.559**	1	-.129**	-.125**	-.108*	.141**	-.491**
Nearest_publicparking	.108*	0.034	-.119*	-0.077	-0.039	-0.077	1	-0.057	-0.021	-0.066	.164**
Bus_400	-.357**	-0.008	.119*	0.067	.223**	.125**	-0.057	1	-.513**	0.020	0.042
Bus_nearest	.222**	-0.035	-0.016	0.044	-.264**	-.108*	-0.021	-.513**	1	0.059	-0.037
Train_400	0.025	-0.023	-0.079	-0.042	.132**	.141**	-0.066	0.020	0.059	1	-.222**
Train_nearest	.183**	-0.007	-.189**	-.191**	-.303**	-.491**	.164**	.042	-.037	-.222**	1

Table D.2: Correlations matrix geographic variables and visitor parking actions part I

	Parking	Urbanisation	Urban_density	Population_density	Houses	Housing_0100	Housing_100plus	Housing_old	Housing_new	Housing_avgsurface	Housing_totalsurface	P_rent	P_sale
Visitor parking	1												
Urbanisation	-.136**	1											
Urban_density	.171**	-.573**	1										
Population_density	.171**	-.095*	.502**	1									
Houses	-.043	0.029	0.021	0.000	1								
Housing_0_100	-.104*	0.020	0.033	0.018	.820**	1							
Housing_100plus	.210**	0.075	-0.056	-0.028	.254**	-0.037	1						
Housing_old	0.065	-.117*	.130**	.102*	.529**	.444**	.114*	1					
Housing_new	-.103*	.129**	-0.087	-0.066	.780**	.289**	.289**	-.108*	1				
Housing_avgsurface	-0.025	-0.063	-0.164**	-0.262**	-.243**	-.343**	.119*	-0.095	-0.095	1			
Housing_totalsurface	0.058	0.052	-0.073	-0.089	.609**	.520**	.626**	.299**	.576**	.224**	1		
P_rent	-.178**	0.011	.215**	.115*	.308**	.385**	-.153**	.283**	.168**	-.318**	.105*	1	
P_sale	.190**	-0.013	-.226**	-.102*	-.332**	-.403**	.151**	-0.316**	-.172**	.319**	-.121*	-.972**	1
WOZ	-0.015	-.097*	-.188**	-.322**	-.202**	-.248**	0.057	-.285**	-0.044	.809**	.169**	-.385**	.384**
Dist_superm	0.019	.526**	-.475**	-.291**	0.073	-0.001	.179**	-.112*	.129**	.140**	.143**	-.256**	.264**
Dist_highway	-0.024	-.103*	0.059	-0.048	-0.088	-0.068	-.101*	-0.029	-1.00*	0.080	-0.097*	-0.090	0.073
Parking_permit250m	.494**	-.186**	.238**	.118*	-.109*	-0.085	-0.023	-0.054	-0.093	0.032	-0.072	-.175**	.178**
Parking_permit100m	.445**	-.138**	.122**	.097*	-.115*	-.114*	-0.023	-0.071	-1.01*	0.057	-0.081	-.215**	.213**
Parking_public100m	-0.045	-0.087	.167**	0.072	0.081	.125**	-0.050	.097*	0.073	-.191**	-0.037	.343**	-.324**
parking_public250m	-0.039	-0.039	.233**	.128**	.104*	.148**	-.117*	0.084	0.066	-.254**	-0.041	.477**	-.445**
Nearest_publicparking	-0.075	0.050	-.161**	-.110*	-0.034	-0.044	0.044	-0.040	-0.004	.114*	.108*	-0.085	0.068
Bus_400	-0.023	-.151**	.247**	.267**	0.078	.109*	0.050	.120*	0.024	-.170**	0.080	0.095	-.142**
Bus_nearest	0.044	0.085	-.132**	-.110*	-.168**	-.191**	-0.012	-.199**	-0.054	.243**	-0.070	-.146**	.162**
Train_400	-0.084	0.037	0.041	-0.006	.192**	0.022	-0.080	-0.028	0.024	0.068	-0.045	0.059	-0.061
Train_nearest	-.170**	.224**	-.263**	-.112*	-0.049	-.094*	.168**	0.001	-0.026	.166**	.120**	-.307**	.273**

Table D.3: Correlation matrix geographic variables and visitor parking actions part II

	Dist_ superm	Dist_ highway	Parking_ permit250m	Parking_ permit100m	Parking_ public100m	Parking_ public250m	Nearest_ publicparking	Bus_ 400	Bus_ nearest	Train_ 400	Train_ nearest
Visitor parking	0.019	-0.024	.494**	.445**	-0.045	-0.039	-0.075	-0.023	0.044	-0.084	-0.170**
Urbanisation	.526**	-.103*	-.186**	-.138**	-0.087	-0.039	0.050	-.151**	0.085	0.037	.224**
Urban_density	-.475**	0.059	.238**	.122**	.167**	.233**	-.161**	.247**	-.132**	0.041	-.263**
Population_density	-.291**	-0.048	.118*	.097*	0.072	.128**	-.110*	.267**	-.110*	-0.006	-.112*
Houses	0.073	-0.088	-.109*	-.115*	0.081	.104*	-0.034	0.078	-.168**	.192**	-0.049
Housing_0_100	-0.001	-0.068	-0.085	-.114*	.125**	.148**	-0.044	.109*	-.191**	0.022	-0.094*
Housing_100plus	.179**	-.101*	-0.023	-0.023	-0.050	-.117*	0.044	0.050	-0.012	-0.080	.168**
Housing_old	-.112*	-0.029	-0.054	-0.071	.097*	0.084	-0.040	.120*	-.199**	-0.028	0.001
Housing_new	.129**	-.100*	-0.093	-.101*	0.073	0.066	-0.004	0.024	-0.054	0.024	-0.026
Housing_avgsurface	.140**	0.080	0.032	0.057	-.191**	-.254**	.114*	-.170**	.243**	0.068	.166**
Housing_totalsurface	.143**	-.097*	-0.072	-0.081	-0.037	-0.041	.108*	0.080	-0.070	-0.045	.120**
P_rent	-.256**	-0.090	-.175**	-.215**	.343**	.477**	-0.085	0.095	-.146**	0.059	-.307**
P_sale	.264**	0.073	.178**	.213**	-.324**	-.445**	0.068	-.142**	.162**	-0.061	.273**
WOZ	.184**	.132**	0.083	.103*	-.230**	-.304**	0.087	-.198**	.253**	-0.056	.183**
Dist_superm	1	-.207**	-0.085	-0.005	-.260**	-.317**	.108*	-.357**	.222**	0.025	.183**
Dist_highway	-.207**	1	0.011	0.014	-0.009	-0.053	0.034	-0.008	-0.035	-0.023	-0.007
Parking_permit250m	-0.085	0.011	1	.779**	-0.013	-.154**	-.119*	.119*	-0.016	-0.079	-.189**
Parking_permit100m	-0.005	0.014	.779**	1	-0.017	-.121**	-0.077	0.067	0.044	-0.042	-.191**
Parking_public100m	-.260**	-0.009	-0.013	-0.017	1	.559**	-0.039	.223**	-.264**	.132**	-.303**
parking_public250m	-.317**	-0.053	-.154**	-.121**	-.121**	1	-.129**	.125**	-.108*	.141**	-.491**
Nearest_publicparking	.108*	0.034	-.119*	-0.077	-0.039	-.129**	1	-0.057	-0.021	-0.066	.164**
Bus_400	-.357**	-0.008	.119*	0.067	.223**	.125**	-0.057	1	-.513**	0.020	0.042
Bus_nearest	.222**	-0.035	-0.016	0.044	-.264**	-.108*	-0.021	-.513**	1	0.059	-0.037
Train_400	0.025	-0.023	-0.079	-0.042	.132**	.141**	-0.066	0.020	0.059	1	-.222**
Train_nearest	.183**	-0.007	-.189**	-.191**	-.303**	-.491**	.164**	0.042	-0.037	-.222**	1