The impact of transit-oriented development on housing price: A case study in Arnhem-Nijmegen City Region, Netherlands.

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Enschede, The Netherlands, [March, 2018]

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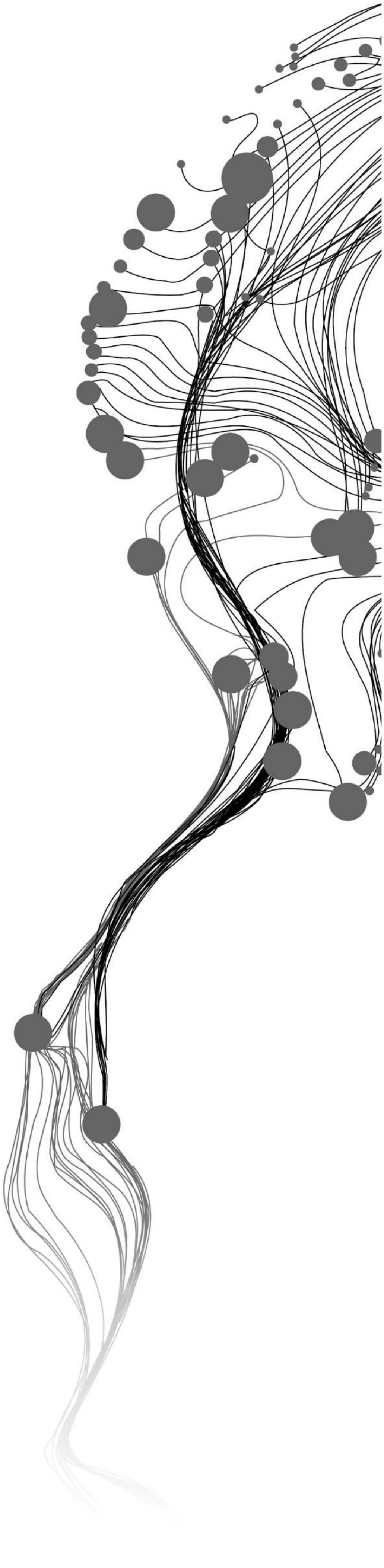

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YIXIN HUANG
Enschede, The Netherlands, [March, 2018]

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning Management

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ABSTRACT

Transit-oriented development (TOD) has become popular in Western Europe over the past few decades with the aim to promote a more sustainable transport system. More and more TOD projects are proposed and implemented in the Netherlands, which not only helps to create more compact and walkable and cyclable environments but also improve mixed land use development around transit stations. Meanwhile, different voices towards the influence of TOD on housing price appears. Regional governments support TOD for the benefit of being accessible to various kind of services, which finally can get capitalized into the house property value nearby. However, residents reckon that TOD would pose negative impacts on property values, traffic, and overall quality of life (Mathur,2013).

In order to address the concerns above, the present study measures the impact of TOD on housing price, in terms of structural, location and TOD-related factors. The Arnhem-Nijmegen city region, in the Netherlands, is used as a case study, because of its network of 22 railway stations that together form a TOD network system. Using hedonic price model to estimate the effect of TOD on housing price, three different models were generated: at the regional level, at the station level and finally taking into account different TOD typologies. Coupled houses (not detached) are analyzed in detail as it is the most representative type of house in the sample.

The results suggest that in general TOD exerts a positive influence on house prices nearby. Moreover, TOD components such as parking supply, economic development, passenger load, user friendliness and land use diversity also show significant influence on housing price. However, at the urban mixed core stations, no relationships were observed between TOD and housing price, because the main function of urban mixed core station is for central business services instead of residential, and less coupled houses are located in the area. However, both urban residential and suburban residential stations (outside the CBD) show positive relationships between TOD factors and housing price. Findings suggest that local government could continue providing financial support to improve the already existing TOD built environment (for instance by increasing the size of the buffer area that has very good accessibility to the transit station)or encourage investment to increase the density of buildings, job opportunities, amenities within the TOD area of influence, as a way to provide more opportunities of housing and jobs thus, potentially allowing for a wider diversity of housing typologies and prices on offer.

Keywords: *Transit-oriented development, property value, hedonic price model, spatial analysis*

ACKNOWLEDGEMENTS

With the thesis finished, my study career in the Netherlands is going to a perfect ending. There are so many thanks to say at the moment!

At first, I would like to take my sincere thanks to my supervisors, Prof. M.F.A.M. van Maarseveen and Dr. A.B. Grigolon for all their supports and guidance during my thesis. Their valuable suggestions always give me lots of inspiration and power in my academic way. I deeply appreciate the confidence they give to me! Besides that, I would also like to thank Dr. Y.J. Singh and R.J. Huang for providing the valuable data. Also I am grateful to Prof. X.J. Li to support my thesis writing in China and give me lots of help during my MSC period.

Then, I am grateful to all of my classmates from UPM, for being with me all the time. My special thank goes to Xiaoshuai, Wenfei for their insightful discussion which helped me a lot to generate my thesis. And also thanks to their accompanies in the Netherlands!

Finally, I would like to express my special thanks to my parents and my love, who give me continuous love and support during my study aboard. Thanks a lot!

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1. INTRODUCTION

The section explains background and justification part of the research, including an explanation of the interaction between land use and transport, the definition of Transit-oriented development (TOD) and its implementations in the Netherlands. Then different voices towards the impact of TOD on housing price between regional governments and residents are explained as the justification part of the research.

1.1. Background and justification

In Europe, more than 1,000 km² are taken up every year for residential, industrial and commercial purposes, transport infrastructure and recreational areas (EC, 2011b). As a result, the spatial distribution of different land use determines trip lengths. For example, low-density and separated land use development with large road areas increase trip lengths and lead to a higher share of car usage. Conversely, high population density with mixed land uses for various social and economic activities create low distance between origins and destinations of urban trips and support a higher public transit share. Public transit provides people with mobility and access to employment, community resources, medical care, and recreational opportunities in the city. It benefits those who are in favor of sustainable transport, as well as those who have no other choice to get around the city. The incorporation of public transportation options also helps a city to reduce sprawl and create a sense of community through transit oriented development(TOD). Therefore, it is very necessary to introduce mass transit like metro, BRT, LRT etc to connect the city suffering high population density and densely land use development. Transit oriented development (TOD) aims at creating more potential transit ridership around transit stations, which can be defined as "development within a specific geographical area around a transit station with a variety of land uses and a multiplicity of landowners" (Salvesen, 1996). The key idea of TOD is that, by intensifying commercial development around stations, mixing land uses, and constructing pedestrian-friendly road networks and urban design, the built environment itself will allow and encourage more efficient travel behavior (Cervero & Kockelman, 1997). More specifically, it deals with "concentrating a mix of moderately dense and pedestrian-friendly developments around transit stations to promote transit ridership, increase walk and bicycle travel and other alternatives to the use of private cars" (Cervero, 2010).

The benefits of TOD are manifold. Bae (2002) states that TOD works as a way of reducing usage of motor vehicles, promoting more compact built environment and increasing mixed land uses. What is more, many planners have seen it as a solution to improve the public transportation system, reduce carbon footprint and improve equity by providing residents with easily reached opportunities to housing, jobs and services (Lund et al., 2004).

Although the concept of TOD originates from the United States, it has become popular in Western Europe over the past few decades with same goals but different implementation strategies. In Europe, TOD projects reach further than single locations in the whole network, which concentrates on realigning cities around railway and away from the automobiles (Pojani & Stead, 2014). Netherlands is one of the Europe countries which implemented TOD at the national level in public transport networks. Moreover, the country is characteristic of dense bicycles, therefore one of the main targets of TOD in the Netherlands is to provide enough, well-integrated and safe parking areas for bikes, cars, and taxis (Diab et al., 2017). Similarly, Hartkoorn (2013) thinks that TOD, with mixed land use patterns around transit stations, not only encourages cycling or walking but also provides a solution for densely populated areas in the Dutch context. Generally speaking, despite some difficulties, people are positive about the future of

TOD in the Netherlands and view it as one of the most efficient urban and regional development policies.

In the opinion of local and regional governments in the Netherlands, TOD is one of the most efficient ways to reduce housing costs while preserving high access levels (Pojani & Stead, 2014). Theoretically, if the market supports transit-oriented development, the support should be reflected in the price people are willing to pay for that development (Bartholomew & Ewing, 2011). The benefit of being accessible to various kind of services can finally get capitalized into the property value nearby the transit station (Simin, 2015). However, these capitalizations are not always turning into higher housing price in the view of residents. Mathur & Ferrell (2013) think that like any new high-density development, TOD is also likely to face community opposition. This opposition primarily stems from the fear of change and manifests itself in the residents' concerns about the TOD's negative impact on property values, traffic, and overall quality of life (Machell, Reinhalter, & Chapple, 2009).

Since the differences in the implementation stage of TOD projects on transit stations would later lead to different performances, which would result in different influence on property value. In the study, different opinions towards the housing price between residents and policy makers are largely affected by the performance of TOD. In theoretical, transit stations with better TOD performance always contribute to higher house price and vice versa. Therefore, the evaluation of TOD performance is very important. American planning community proposed the 5Ds criteria, which are density, distance, diversity, design and destination accessibility, to measure the performance of TOD (Ewing & Cervero, 2001), various indicators have been applied to evaluate TOD performance. For instance, Renne and Wells (2005) have identified 10 indicators that can be used to monitor and measure the impact of TOD, which are transit ridership, quantity of mixed-use development, density of development, quality of streetscape, increase in property value, increase in Tax, public perception, number of mode connections at the station and parking. In the Netherlands, Singh(2015) has also developed proper criteria and indicators to evaluate the TOD performance around railway stations in Arnhem-Nijmegen city region. In conclusion, it is very necessary to include TOD factors to quantify the influence of TOD on surrounding house price.

1.2. Research problem

Many previous researchers have studied the impact of TOD on housing price by assessing the relationship between transit and housing price, associated with being near a metro rail station or LRT station. For example, Daniel (2007) has selected proximity to transit, including straight-line distance to the transit station and network distance to the transit station, as a TOD proxy to explore the influence of light rail transit on station-area property values in Buffalo, New York. Similarly, Mathur (2013) has measured the impact of sub-urban transit-oriented developments on single-family home values in San Jose, CA based on the natural log of distance form single-family house to the TOD. Moreover, Duncan (2011) has studied the impact of transit-oriented development on housing prices in San Diego, CA by measuring TOD development patterns, which could be quantified by different factors, like density of street intersections within 1/4 miles of each house, density of population serving employment within 1/4 miles of each house, area dedicated to park and ride and steepness of the terrain. In conclusion, most of the studies have evaluated the influence of TOD either by selecting distance to the railway station as a TOD proxy or by calculating neighborhood characteristics in a residential area. However, TOD refers to the neighborhood environment of the station and the quality of transport service at the station. Hence, distance to railway station cannot fully explain TOD influence. It works as one of the location factors, which is used to describe the benefits of living near the transit station. As for the neighborhood characteristics mentioned above, which are used to describe the built environment around each house instead of the railway station. Since the impact of TOD should be evaluated at the station level, those neighborhood factors at the house level cannot properly represent the TOD ness of the railway station. Until now, hardly any studies using TOD factors to explore the impact of TOD on house price.

Besides that, lots of studies have investigated the relationships between TOD and housing price in the context of America, which is characteristic with metro cities and low population densities. No relative studies have been found in the Netherlands, which is characteristic with high population densities and cycling intensities. Since the influence of same transit nodes would vary differently among different countries, it is urgent to explore the TOD influence on housing price among different countries.

Moreover, most of the studies have selected one specific type of house to investigate, not all the type of houses. For example, in America, most studies focus on investing the house price of single-family homes (e.g. Duncan (2011); Hess (2007)). However, in the Netherlands, to better taking the advantage of easy accessibility, many new housing projects were built in the 1950s, 1960s and 1970s with the form of multi-story apartment blocks and townhouses to support the transit-oriented development (Smas, 2016). Hence, it is very necessary to explore and compare the variations of housing price among different house types in the Netherlands. In order to solve the three issues mentioned above, the thesis aims at exploring the impact of TOD on housing price through analysing various TOD factors based on the '5Ds' criteria of the built environment – density, design, diversity, destination accessibility and distance to transit (Ewing & Cervero, 2001), What is more, considering the implementation of TOD projects are not likely to be distributed evenly across a set of heterogeneous transit station contexts in a transit system (Higgins & Kanaroglou, 2016). Furthermore, the study also includes TOD typology of transit stations in exploring the impact of TOD on housing price.

1.3. Objective of the study

1.3.1. General objective

The main objective of the study is to assess the influence of transit-oriented development on housing prices. The case study will take the TOD network of Arnhem-Nijmegen city region, Netherlands, which is composed of 22 railway stations.

1.3.2. Specific objectives and questions

1. To assess the relationship between TOD and housing prices.

- What is the effect of distance to a TOD station on housing prices?
- Which other factors related to TOD have an influence on housing prices?
- Which methods have been used to assess the relationship between TOD and housing prices?

2. To quantify the variation of housing prices for different TOD typology.

- To what extent housing prices vary for different TOD typology?
- Which TOD indicators have the most influence in housing price variation in the study area?

1.4. Significance of the study

The result of the study could explain how TOD influence housing price. Specifically, which TOD indicators have more significant positive or negative impacts on housing price than others. Besides that, the study also illustrates the different impact of TOD on housing price under different station typologies. These results can help to develop TOD projects and guide the investment on real estate market around transit stations. For example, if the TOD built environment has a positive impact on house value, then the policy maker may taxes more for the residents nearby to make the TOD area more better. Conversely, if the TOD built environment negatively influences house price, which would attract more people to pay for the houses near transit stations with lower housing price, as a result, more potential transit users will be generated. Moreover, the result also helps to manage railway stations in different TOD typologies, like how to increase house price around railway stations in suburban residential topology to attract more economic investment or decrease house price around railway stations in urban residential topology to reduce the house price gap in the city region.

1.5. Thesis structure

The study is structured as following: Chapter 1 introduces the background and justification of the research and research problem, research objectives etc. Chapter 2 makes a literature review about the main concepts and methods of the topic, which are what is TOD, property value capitalization in the context of TOD, property value capitalization from other factors, TOD typlogy and approaches. After that, conceptual framework of the study, data descriptions and operationalization of factors affecting house price are discussed in Chapter 3. Then, the result of regression models are presented in Chapter 4. Finally, the conclusions, recommendations and limitations of the study are analyzed in Chapter 5.

2. LITERATURE REVIEW

The section makes a literature review about the four underlined concepts and one approach to quantify property value variation. The four main concepts are what is TOD, property value capitalization in the context of TOD, property value capitalization from other factors and TOD typology. One approach is hedonic price model.

2.1. What is TOD?

The concept of Transit oriented development (TOD) is defined by different authors with different objectives. Some definitions are from the sustainable development and environment-friendly society perspective. For example, Duncan (2011) thinks that TOD refers to more compact and walkable environment as well as mixed land use development near a transit station, which dedicates to creating a more sustainable transport system. Other definitions of TOD focusing on the role of promoting transit usage. For instance, Sim (2016) defines that TOD works as a mean of increasing walking and transit ridership, therefore reducing automobile dependence. Besides that, TOD has also been defined as "smart growth" tool which aims to solve the problems like traffic jam, air pollution, etc (Mathur & Ferrell, 2013). Overall, the concept of TOD changes as its purpose or aims change. It is confirmed that TOD has been accepted by more and more countries with the target of creating a more sustainable city by increasing the potential usage of public transport and improving the accessibility to surroundings around the transit stations.

In 2002, based on the nationwide survey of more than 100 TOD projects in America, Cervero et al. (1997) found the following composition of TOD projects: Subway TOD (37.4%), Light Rail TOD (31.3%), Commuter Rail TOD (21.8%), bus TOD (7.8%), ferry TOD (1.7%). Since rail station has its strong image, permanency, and fixity, it appeals more to potential investors. Therefore, most of the studies focus on the TOD of railway station, including this study.

2.2. Property value capitalization in the context of TOD

According to previous studies, most of the researchers have selected proximity to the railway station as a TOD proxy to quantify TOD influence. Besides that, some neighborhood characteristics like pedestrian design and mixed land use are calculated at house level to describe TOD influence by researchers. To sum up, the impact of TOD on property value around transit station could be summarized as distance-related effects, design-related effects and diversity-related effects.

Distance-related effects: The distance from house property to transit stations has mixed impacts on housing prices. For example, Cervero et al. (2004) show that the housing price would increase from 6.4% to 45% if the houses are located between 400m and 800m distance from transit stations. Similary, Daniel(2007) also suggests that system wide, property located within a half-mile radius of rail stations is valued $2.31 higher (using geographical straight-line distance) and $0.99 higher (using network distance) for every foot closer to a light rail station. These positive impacts can be explained by the convenience costs of getting to and from near the transit station are lower comparing to the locations far from the transit station. Conversely, Goetz et al. (2010) show that the distance to light railways has negative impacts on housing prices, which starting at a 16$ discount for every meter close to the tracks. This presumably because of the noise and the vibration associated with rail operations. However, both of the studies mentioned above are in the context of US. In the Netherlands, the cultural preference for cycling over walking implies that the influence area of TOD on housing price should be larger. What is more, people may stick to their bicycles to go out instead of taking railway. Hence, the proximity to railway station may not very significant in the Netherlands.

Design-related effects: Most of the hedonic price studies concentrate on the accessibility benefits of TOD, ignoring pedestrian design which helps to evaluate TOD built environment. Some studies describe pedestrian design by distinguishing "park and ride" transit stations and "walk and ride" transit stations. For example, Kahn (2007) has studied TOD area around transit station across 14 metropolitan areas showing that, over a 10-year period, the prices of homes in park and ride station areas suffer a 1.9% price decrease, while those in walk and ride station areas enjoy a 5.4% increase. Similarly, Bowes & Ihlanfeldt (2001) have investigated the impact of Atlanta MARTA system on the house price, showing that the price of houses located within 800m and 1600m of a park and ride MARTA station experiences a 1.4% decrease, while homes more than 3 miles from a park and ride station show a 4.7% price increase. Other studies identify pedestrian designs by neighborhood characteristics like interconnected street and block sizes. For example, Simin(2015) shows suggests that smaller block with more possible usage of transit, attracting people to pay more for their house properties than large blocks and cul-de-sacs street design.

Diversity-related effects: Diversity requires the TOD area to combine mix land uses like sports, residential, education, commercial together (Chen, 2010). Hence, the main aspect of diversity-related effects largely depend on land use. For example, Li&Brown (1980) investigated the impact of TOD on single-family house price, the result shows that as distance to the commercial use decreases, the housing price increase at about $1,486 for every 10m. Similarly, Mathur (2008) made an analysis of King County, Washington, shows accessibility to retail jobs increasing the price of "low-quality" housing while decreasing the price of "high-quality" housing. The reason is that high degree of mixed land use near transit station area allows the presence of transit users and activities all the times, which not only increases convenience to activities but also shorter daily travel distances. The increase in proximity and convenience would be reflected by housing price in real estate markets.

In conclusion, hardly any studies mentioned above focus on TOD features which refers to neighborhood characteristics of the station and service quality of the station. Hence, those studies cannot fully explain the influence of TOD on housing price. In the thesis, proximity to the railway station(distance-related effects) is excluded from the TOD related factors, but treat it as one of the location factors. Besides that, design-related effects and diversity-related effects are described and calculated at the station level, instead of house level. Moreover, the study also considers density-related effects of TOD built environment like economic development and service quality of the station like passenger load and display of information system, which will be discussed in more details in Chapter 3.5.3.

2.3. Property value capitalization from other factors

Other attributes affecting house price have been studied in the previous studies(e.g., Simin (2015; Berry (1976); Bolitzer & Netusil (2000); Bertolini (1999); Wilhelmsson (2000) etc.), referring to three main attributes, which are structural attributes, neighborhood attributes and location attributes.

Structural attributes are attributes unique to a house. Previous studies have considered structural attributes as descriptions of the basic and physical condition in the house like house quality, age of house, parcel area, living area, number of bedrooms etc. For example, Simin (2015) found that building grade, total finished area, square footage of total basement and number of bedrooms have expected positive signs on house price. Hence, the selection of structural attributes should be as comprehensive as possible in the study.

Neighborhood attributes relate to the social and economic factors such as income, race and owner education level etc. Studies have suggested that different neighborhood attributes have different relationships with housing price. For example, Berry (1976) has made an absolute conclusion that there are housing "discount" for black residents or blacks are actually receiving a "good deal" in the housing market. The reason is that those black residents usually receive less respect from the social and earn less money, so they cannot afford expensive housing. Similarly, low-income family have no choice but live in predominantly poor living condition and cheap housing neighborhood because of the social exclusion (Simin, 2015).All in all, those neighborhood attributes mentioned above are used to describe the economic and social condition of the residential neighborhood. In the thesis, the selection of neighborhood factors refers to the immediate surrounding of the train stations, instead of residential area.

Location attributes include factors that describe the accessibility of a city, such as proximity to entertainment facilities, central business district, highways or open spaces (Pacione, 1984). Existing studies have shown that location factors may have mixed impacts. For example, Bolitzer & Netusil (2000) have measured the distance to nearby open areas and found that house price increases with proximity to open space for the park can provide more green space for residents' daily activities and relax. Bertolini (1999) shows the sales prices of single-family homes would experience 1.7% percent decrease in housing prices with every 10 meters increase of the distance from CBD. The reason is that the CBD areas are commonly more accessible to various activities and associated with high accessibility to jobs, retails and other services. Finally, these benefits are capitalized into higher housing price. Conversely, studies have found that the residential area located along a developed highway would result in discount in the value of properties since highway increases traffic noise pollution (Wilhelmsson, 2000). In the study, different location factors are selected to describe accessibility like proximity to major street and proximity to bus stop, which help to make the result more reasonable. Moreover, proximity to railway station has been treated as one of the location factors, instead TOD related factors. The reason is that the TOD related factors are calculated at the railway station, while the proximity to railway station is calculated at house level.

2.4. TOD typology

The impact of structural factors, location factors and TOD related factors on housing price may not remain same among different transit stations. However, if some transit stations show similar characteristics, then the influence of TOD on housing price may show the same pattern. The assumption for our study is that housing price may have different variations for different urban environments, i.e., different TOD typologies.

In the past, many researchers have studied the performance of station areas using various approaches. One of the most recurring approaches to station area studies is that of developing TOD typologies, where all stations in a study area are categorized into different TOD types, according to the built environment characteristics around the station area. Each type of station area has a kind of specific performance. The main benefit of creating typologies of stations is that it reduces management complexity and allows consistency of actions across large geographical areas and identified areas with similar strengths and constraints (Zemp, Stauffacher, Lang, & Scholz, 2011).

Lots of studies have applied various analysis to explore TOD topology. For example, (Bertolini, 2017) produced a node-place index to classify a number of rail stations in the Netherlands according to their nodal accessibility and place-based characteristics. Finally, four types of stations are produced. Similarly, six node and place related criteria were measured and a 'butterfly model' was suggested and 12 station topologies were developed and existing stations were classified in those topologies(Functions, Landscape, & Metropolis, 2014). Later, (Reusser, Loukopoulos, Stauffacher, & Scholz, 2008)expanded (Bertolini, 2017) model with additional node and place measures, and use it to classify more than 1600 rail stations in Switzerland. In the Netherlands, Huang, Grigolon, Madureira & Brussel (2017) applied a latent class clustering method to classify the 21 railway stations pertaining to the TOD network of the Arnhem-Nijmegen city region into three typologies: urban mixed core, urban residential and suburban residential.

2.5. Approaches to quantify property value variation

The most general approach for assessing the influences of TOD on housing price is regression analysis based on the hedonic model. Hedonic models are based on the intuitive understanding that the value of a piece of real estate is not monolithic nor completely intrinsic to the property itself, but is the result of a multitude of characteristics, many of which come from the context in which the property is situated (Kestens, 2004). Majority studies have applied hedonic regression analysis. For example, Cervero & Duncan (2002) have applied hedonic price model to assess the influences of light rail transit and commuter rail transit on office, commercial and light industrial properties in Santa Clara County, CA. In the hedonic model, the author assumed that all the relationships related to house price are linear. However, there are various relationships rather than only linear relationship in reality. Later, Shyr & Fu (2010) have improved the hedonic model by exploring the new relationships between house price and factors like the log-linear function of house price and square function of the house age, which makes more sense. Similarly, Liang (2011) has investigated the impact of Beijing metropolitan station on property price per square meter of apartment homes using semi-log hedonic price regression model. Later, many studies have found various regression models to explore the relationships. Duncan (2011) has integrated cross-sectional hedonic price model and OLS regression to explore how the Light rail affects the price of condominium in San Diego MSA, CA. Mathur & Ferrell (2013) have applied fixed effect OLS and log-regression analysis in exploring the relationships between light rail and single family home in different time scale.

According to various studies mentioned above, it is clear that the hedonic price regression model has been mature in exploring the impact of TOD on housing price. It could easily isolate the impact of TOD related factors on housing price. Hence, the study also applies hedonic price model to explore the impact of TOD on housing price.

3. METHODOLOGY

3.1. Conceptual framework and definitions

This section illustrates the conceptual framework of the study (Figure 1). The construction of the conceptual framework is based on the literature review about the influence of TOD on housing price. In the thesis, variations in housing price are considered to be influenced by three groups of factors: structural factors and location factors of the house level, TOD-related factors of station level and TOD typologies. These factors will be explained in details below.

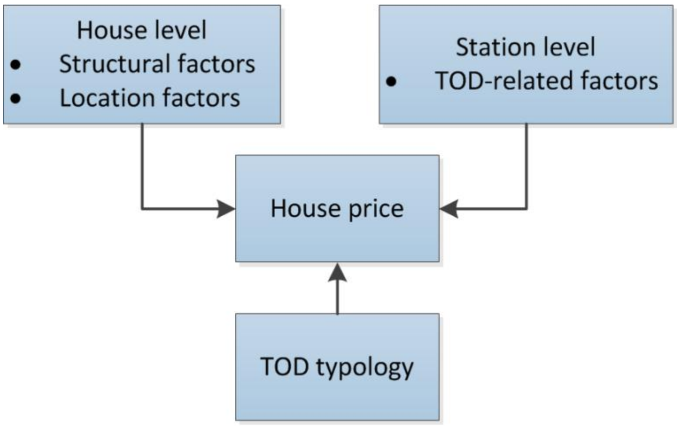

Figure 1: Conceptual framework

House price is considered as the value at which a property is offered for sale. The dataset used in this research records the value of the property at the year the transaction was performed. For instance, if a house was sold in 2003, the purchased value is then recorded for that year and stored in the database. For this study, we have corrected this value caused by inflation so that all houses can be analyzed in the present situation (year 2017).

In the study, other factors affecting property value are narrowed down into two categories: (1) **Structural factors**, which are used to measure the basic condition of the house such as living area, age of the house, number of bedrooms and energy types etc. These are the main attributes of the house itself. (2) **Location factors**, which are used to describe the proximity from each observed house property to the nearest transport infrastructures like the distance to the nearest railway station, distance to the nearest highway and non- transport infrastructures like the distance to the nearest park, the distance to the nearest CBD etc.

TOD-related factors in the study refer to the indicators describe the transit oriented development around railway stations. All of the indicators are calculated at the station level, so those TOD-related factors can also be named as neighborhood factors at station level. The selection and calculation of TOD related factors are according to Singh (2015) work, which will be discussed in details in Chapter 3.5.3.

The effect of different **TOD typologies** on house price will also be explored, as we would like to test whether house prices would vary differently depending on the characteristics of the urban context where the station is located. A previous study has developed TOD typologies for the same study region of Arnhem-Nijmegen (Huang et al. 2017) and its results will be used in our study to explore the influence of different TOD typologies on housing price.

3.2. Research design

This section describes how the data are combined with technical analysis to address the formulated research questions. It mainly includes four parts, which are the introduction of study area and analysis unit, operationalization of factors affecting house price, house price adjustment as well as hedonic price model. Figure 2 shows the methodology flowchart in the study. There are three steps in the flowchart, the first step is to identify analysis unit as well as the factors affecting house price. These are done by qualitative methods like literature review. The second step is to calculate factors affecting house price and generate regression models, which requires quantitative methods through different calculation methods like spatial analysis and regression analysis. The last step is to analyze the result of different regression models, including the conclusion, recommendation of the study.

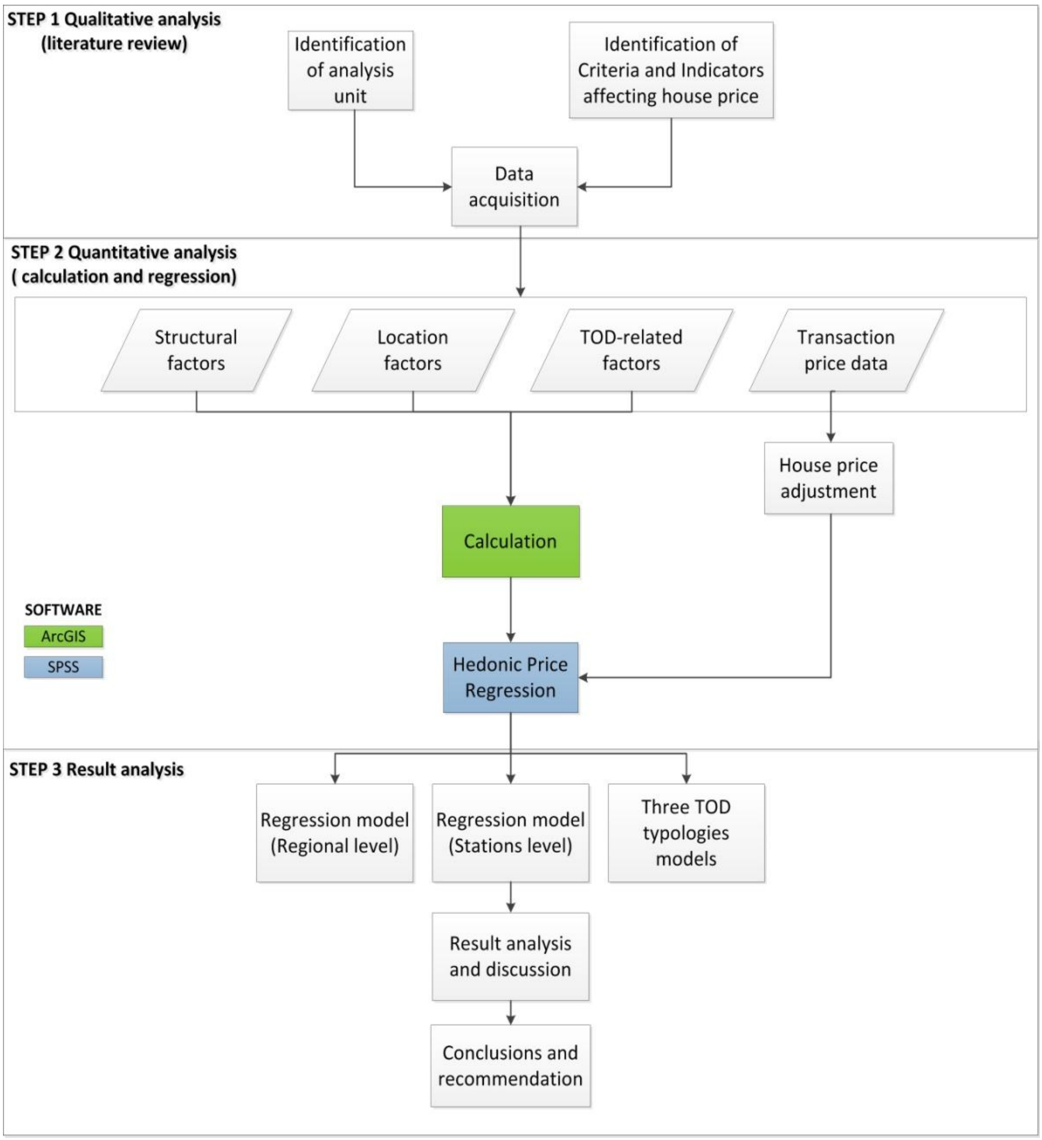

Figure 2: Methodology flowchart

3.3. Study area

Arnhem-Nijmegen city region is located in the east of Netherlands, close to the German border. Figure 3 shows the location of the Arnhem-Nijmegen city region in the Netherlands. The city region has a population of 750,000 and the area is more than 1,000 km², Arnhem and Nijmegen are the two largest cities in the city region. There are totally 22 railway stations in the city region of Arnhem-Nijmegen (Figure 4). These railway lines connect the whole city region, which are operated by several companies. Nijmegen city has five railway stations and Arnhem city has four railway stations. The city region of Arnhem and Nijmegen has been chosen as the study area because these cities are striving to stimulate a transport modal shift from private cars to the public transport like railway or BRT for the daily commuters(Jain et al., 2014). Besides that, according to Residential Real Estate Services (2016), the Gelderland province with its main cities like Arnhem and Nijmegen, have experienced housing price increase due to continued tightening of the housing market and bigger housing shortages. TOD concentrating a mix of moderately dense developments around transit stations contributing to intensive land use and affecting house price nearby. Hence, Arnhem-Nijmegen city region is selected as the study area.

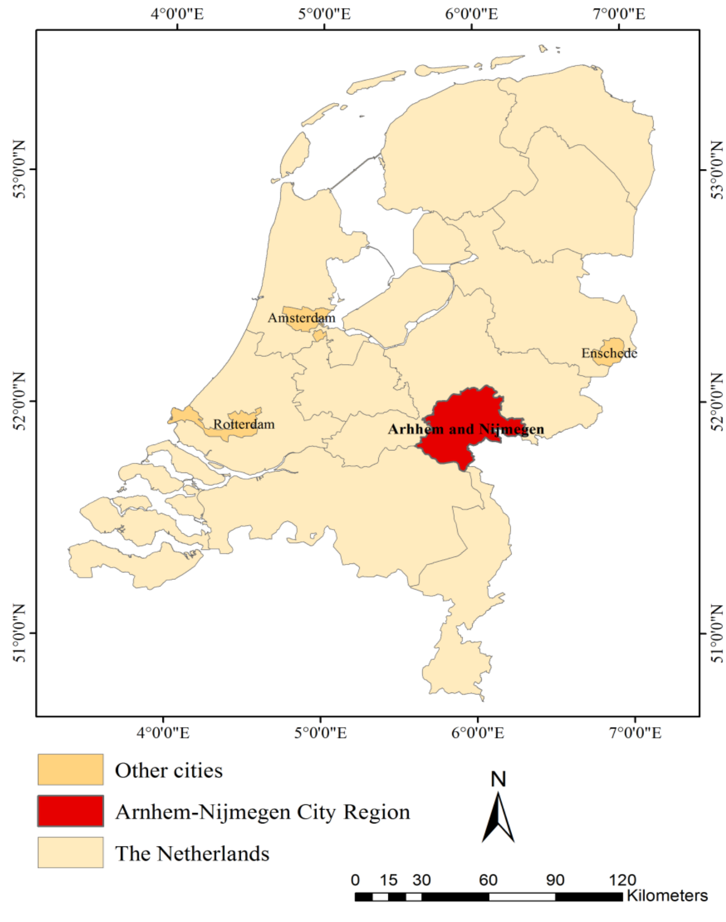

Figure 3: The location of Arnhem-Nijmegen city region in Netherlands

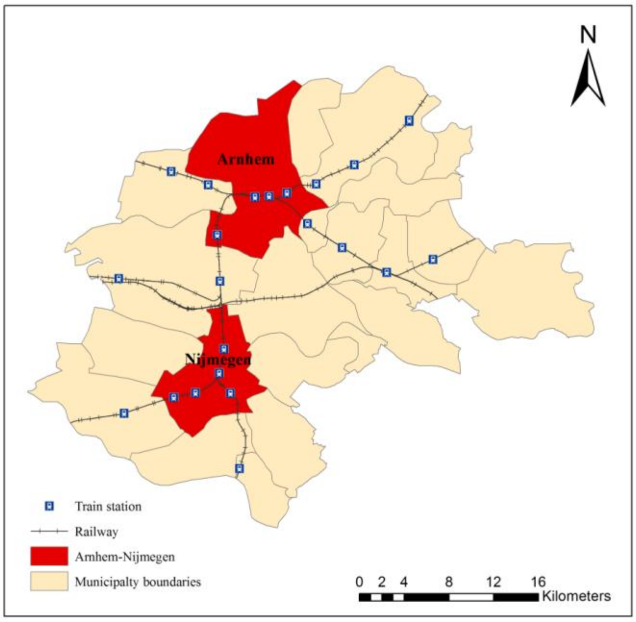

Figure 4: The railway stations of Arnhem-Nijmegen city region

3.4. Data description - Analysis Unit

The analysis unit includes two parts in the study: 1) Unit of TOD area, which defines the TOD influence buffer around railway stations. 2) Unit of house, which defines the most suitable house type to investigate according to the study area.

3.4.1. Unit of TOD area

According to the distance principle that the walking distance from where the residents live to station should be kept within 400 meters (5 minutes)(Chen, 2010). Moreover, the highest development densities should be concentrated within the 400m radius of a transit station, so residents can walk to board transit instead of driving there. However, the situation in the Netherlands is different since the station itself is easily reachable on foot but especially by bike, and contains ample bike parking facilities (Pojani & Stead, 2015). The cultural preference for cycling over walking implies a larger TOD radius. Hence, the TOD influence area is enlarged to 800m buffer from each railway station in the study. It is important to note that the nearness of railway station spacing in Arnhem and Nijmegen city region means that 800m buffer area around stations sometimes overlaps, as is shown in Figure 5. Arnhem Centraal station and Arnhem Velperpoort station have overlapped area. I use ArcGIS to calculate straight line distance from the two railway stations to the overlapped house properties and then assign the house properties to the nearest railway station.

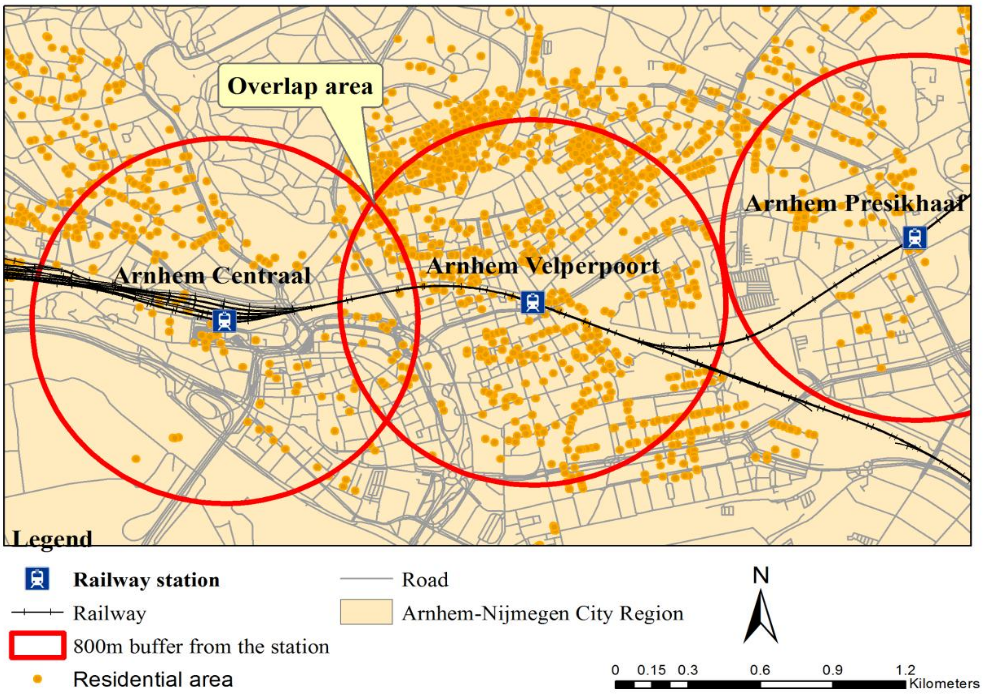

Figure 5: 800m radius buffer areas from railway stations

3.4.2. Unit of house

Housing data for the Arnhem-Nijmegen region was acquired from The Netherlands' Cadastre, Land Registry and Mapping Agency (in short, Kadaster). There are five main types of houses in the Netherlands, including the Arnhem-Nijmegen city region, which are apartment, house on a corner, 2 under 1 roof (semi-detached), coupled house (not detached) and free-standing house (detached).

Table 1 shows some descriptors of the data. From a total of 29,099 houses in the city region, the housing price ranges from €14,000 to €2,7 million, with free standing houses being the most expensive on average, and apartments and coupled houses the cheapest. Coupled houses make up 34% of the sample, and the standard deviation indicates that coupled houses have the smallest value, which explains that the housing price of coupled houses are more concentrated. For these reasons, and because the goal is to explore the influence of distance to transit on housing prices, keeping all housing features the most equal as possible, the present study selects only coupled houses to further exploration.

Table 1: Description of the data by house type

House type	Total (Number)	Total (Percentage)	Price (Euro)	Mean price (Euro)	Standard deviation
Apartment	8435	29%	14,837-1,893,730	173,143	80,235
House on a corner	4635	16%	14,085-1,384,768	228,934	91,068
2 under 1 roof	3217	11%	75,000-1,063,830	294,868	119,847
Coupled house	9918	34%	61,702-914,894	211,176	79,157
Free standing house	2894	10%	38,584-2,765,957	421,362	189,731
Total	29099	100%	14,085-2,765,957	233,223	125,462

The latest transaction housing price data (2017) was used in the study. It is important to note that the transaction year of the house properties are different. Since there exists currency inflation through the years, the record of transaction price of different years needs to be recalculated to adjust to the house price of the year 2017. Besides that, house price also changes with different quarters in one year due to real estate market fluctuation. Consequently, the transaction price data was adjusted to a specific quarter of year 2017. In the study, house price index (HPI), which measures average price changes in repeat sales or refinancing on the same properties was used to adjust the house price. The house price index was acquired from The Netherlands' Cadastre, Land Registry and Mapping Agency (Kadaster) (Appendix A). According to HPI, the transaction prices are adjusted to the second quarter of year 2017.

Figure 7 shows the distribution of average housing price of coupled houses, on each quarter from 2010 to 2017 in Arnhem-Nijmegen city region. The housing price have been readjusted by a home price index. It shows that house price remained stable between 2010 and the second quarter of 2012. After that, the house price fluctuates dramatically in 2013, 2014 and 2015. Finally, it experiences substantial growth from the last quarter of 2015 till 2017. The reason for the house price growth could be due to further economic recovery, high consumer confidence, falling mortgage interest rates and the substantial number of new homes sold all contribute to higher housing price (Lennartz & Vrieselaar, 2017).

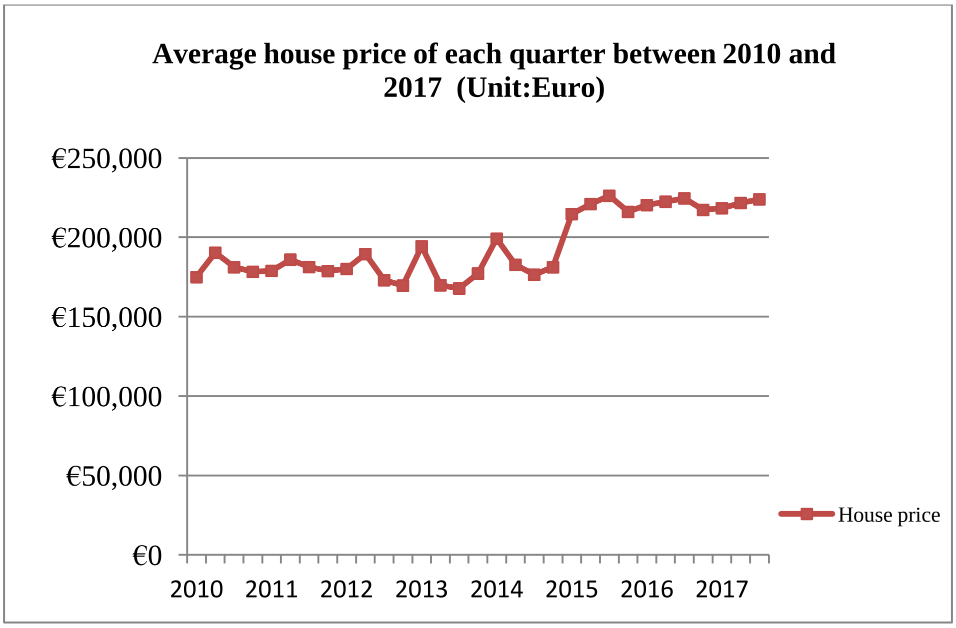

Figure 6: Quarterly based average house price of coupled houses from 2010 to 2017

3.4.3. Description of coupled houses

To better understand the location and price of coupled houses in the city region, Figure 8 shows the distribution of coupled houses with different housing price range in Arnhem-Nijmegen city region. The color scheme ranges from dark green to dark red and represents the housing prices range from low to high. Most of the houses are aggregated near the railway station and a small part of houses are distributed randomly in the city region. Besides that, most of the houses have are an average price range. Only a few houses have higher housing price, which are distributed near the railway stations of Arnhem city and Nijmegen city.

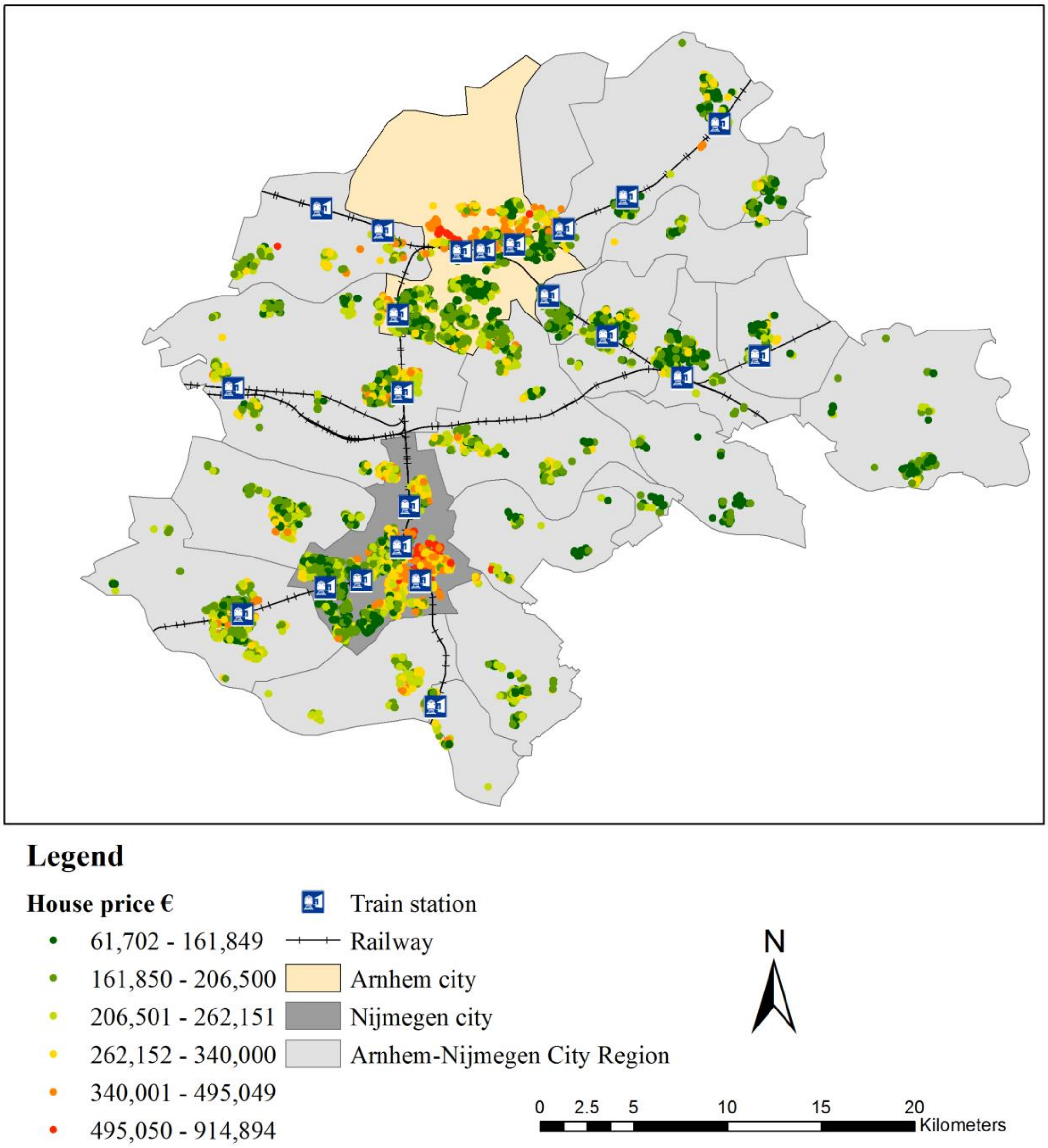

Figure 7: House price distribution in Arnhem-Nijmegen city region

To get a better understanding on the houses aggregation, Figure 9 zooms in to illustrate the house price distribution in Arnhem city (left) and Nijmegen city (right). In Arnhem, houses located next to the north part of the railway have higher price than houses located at the south part of the railway. In Nijmegen, the house price decreases from east to the west of the city. Besides that, most of the houses in both cities have moderate price.

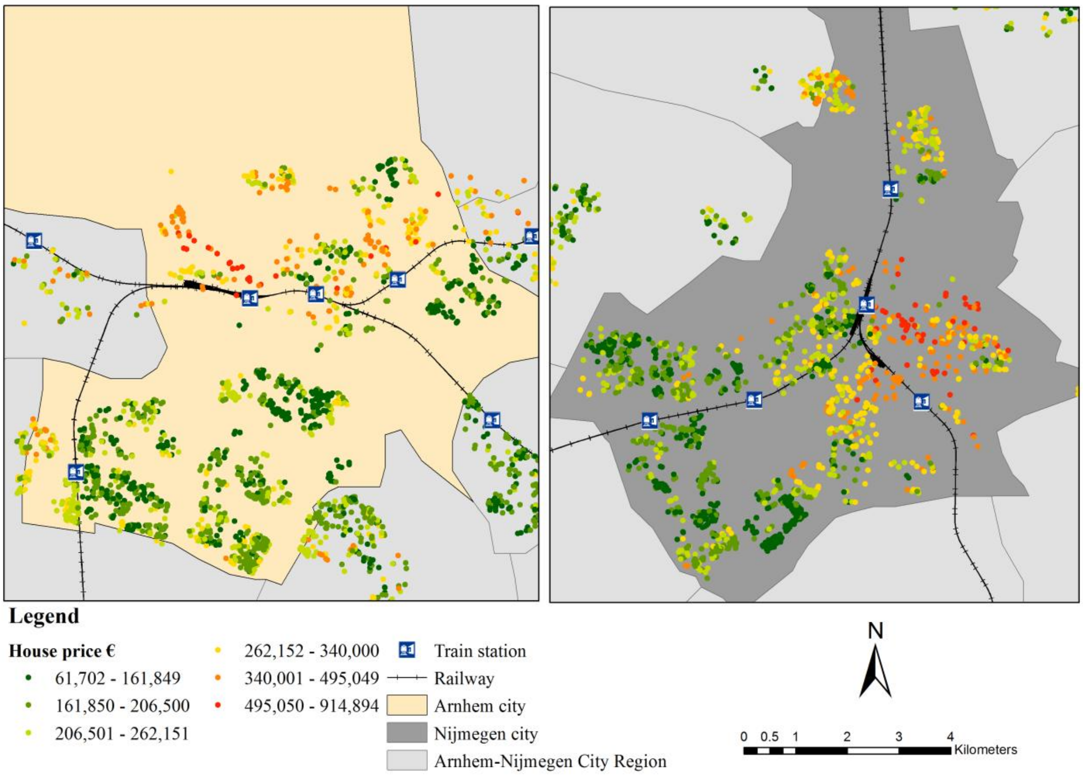

Figure 8: House price distribution in Arnhem city and Nijmegen city

To get further insight on the data, Table 2 shows some descriptive statistics of all variables present in the dataset. Among structural factors, the average parcel area is 165m² whereas the average living area is 122m², meaning on average residents have around 40 m² of garden, porches, garages, etc. The average number of floors is between 2 and 3, and the average energy label is around C level, which indicates the houses are multi stories and the energy efficiency of the houses is relatively good. Besides that, the coupled houses in the region have an average age of 40 years.

As for location factors, the average distance to commercial area, to education institution and to major street are between 500-800 meters, which explains that these daily facilities are not far from the houses and can be reachable by walking or cycling. Bus stops are on average 380 meters away. However, highways, park and railway stations are on average over 2km away. As a result, it takes much time for residents to go out by train. Finally, the average housing price of coupled houses in the whole region is around €211,000, with a fair degree of variation.

Table 2: Statistic data of coupled houses (city region)

Dimension	indicator	Unit	Minimum	Maximum	Mean	Standard deviation
Structural factors	Parcel area	Square meters	24	745	164.94	63.48
	Living area	Square meters	35	565	121.66	39.45
	Number of floors	Number	1	8	2.54	0.66
	Energy label	A-G (1-7)	1	7	3.06	1.50
	Age of the house	Years	1	367	40.84	25.64
Location factors	Distance to commercial area	Meters	0.33	7886.34	509	410.25
	Distance to bus stop	Meters	1.37	2488.32	381	223.12
	Distance to park	Meters	28.69	13847.01	2132.14	2105.36
	Distance to major road	Meters	0.14	6506.72	808.39	727.69
	Distance to highway	Meters	6.40	10665.77	2884.25	2006.67
	Distance to education facility	Meters	40.86	9334.06	603.23	519.44
	Distance to railway station	Meters	89.98	11823.01	2280.21	1594.34
Price		Euro	62396	894342.76	211411.14	79325.65
Total houses		9918				

To further explore the data, scatter plots were generated with the purpose of showing to what extent each variable is affected by variations in housing price. Furthermore, it is a valid exploratory step before performing regression analysis, which will be developed on the next chapter.

Scatter plots of house price in relation to each variable were developed, and all results are on Appendix B. Among structural variables, living area and parcel area show stronger relationships with house price. Figure 10 shows the scatter plot of price in relation to living area, with most of the points concentrated in a certain range of living area from 50m^2 to 190m^2, with the corresponding house price range from 150,000€ to 410,000€. Though some data points are distributed randomly, the uphill pattern from left to right indicates a positive relationship between living area and house price. Besides that, number of floors, age of house and energy label show no obvious relationships with house price. The reason behind is that these variables are discrete variables and the data points are cumulated at certain intervals. Different floors correspond to different house prices. Though it shows no kind of pattern between number of floors and housing price, further regression analysis combined with other variables would still reveal other relationships with house price.

Among location variables, all scatter plots show vague or no relationship with house price. The reason is that location variables are not the main factors affecting house price as structural variables. Hence, the scatter plots of location variables mainly help to observe the distribution of variables and house price. For instance, distance to railway station (figure 12), most of the houses are distributed between 100m and 5000m away from railway station, the corresponding house price range from 100,000€ to 400,000€. A vague trend shows that with increasing the distance to railway station, house price increase for cheaper houses. But for the expensive houses, the trend is the opposite.

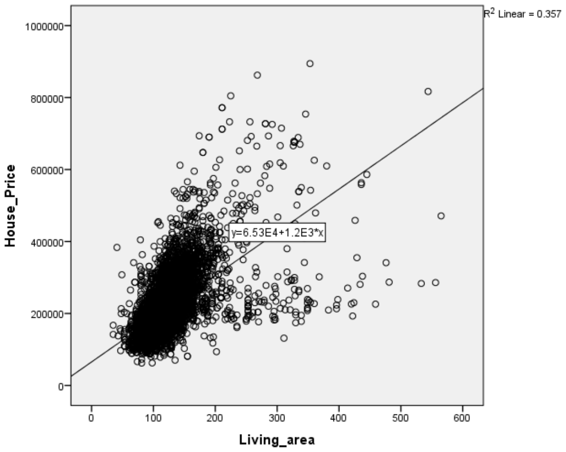

Figure 9: Scatter plot between living area and house price

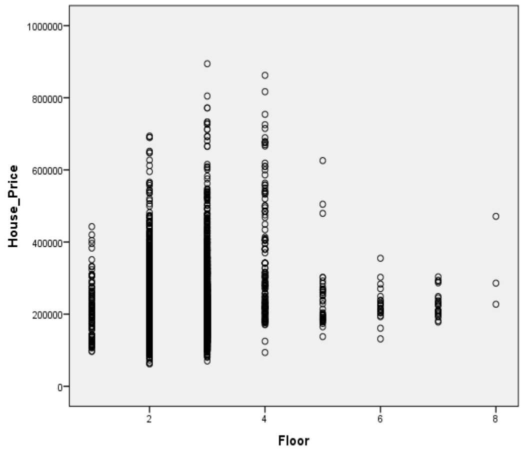

Figure 10: Scatter plot between number of floors and house price

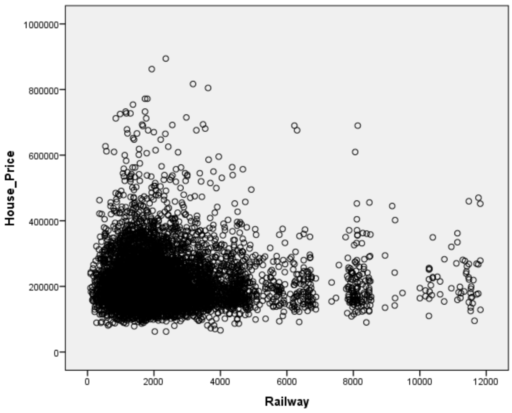

Figure 11: Scatter plot between distance to railway station and house price

3.5. Operationalization of factors affecting house price

From the literature review, it was found that there are several factors affecting house price, such as the house location, low interest rates, diverse growth factors, rental vacancy rates etc. In the study, the selection of factors affecting house price is based on previous studies (e.g. County et al. (2010); Kahn (2007); Bowes & Ihlanfeldt (2001); Simin (2015); Berry (1976); Bertolini (2017); Wilhelmsson (2000)). Finally, three types of factors are selected, which are structural factors, location factors and TOD related factors. In addition, the relationship between house price and different TOD typologies will also be explored, following up on the study by Huang et al. (2018).

3.5.1. Structural factors

Structural factors are used to describe the features of the house, including age, living area, parcel area, number of floors and energy label. Table 3 shows the detailed descriptions of those the selected structural factors. It is important to note that energy label is a unique indicator that may influence house price in the Netherlands. It shows the energy efficiency of homes, by means of a rating from A which means the most energy efficient to G which is the least energy efficient. Since January 2008, it is compulsory in the Netherlands that residential properties for sale have the indication of energy efficiency (Brounen, 2011).The effect of energy label reflects in the sale price that buyers paying more for homes with a green label (labels A, B and C) than a red one (labels D to G), for otherwise comparable homes. The structural data was acquired from Dutch Statistics office (CBS) through Kadaster.

Table 3: Structural factors

Indicators	Description	Data Source
Age	Age of the house	Dutch Statistics Office (CBS)
Parcel area	The total area of the plot	
Living area	The gross house area, including walls. It does not include porches, garages, gardens, etc.	
Floors	Number of floors of the house	
Energy label	Record from A to G, representing the energy efficiency from the best to worst	

3.5.2. Location factors

Location factors are divided into two parts in the study (Table 4). One part measures the distance from each observed house to the nearest transport facilities (e.g. railway station, bus stop, highway or major road). Another part measures the distance to the nearest daily facilities or non-transport facilities such as commercial area, parks and education institutions. Both types of indicators are important location factors influencing house price. For example, if the distance to the highway system is closer than the distance to a railway station, then people may choose their cars to go out. Hence, living closer to a transit station might not result in more "accessibility". And the benefit of being close to a transit station won't necessarily be translated into higher land values. Similarly, being close to a commercial area with various activities may contribute to premium on house price. Land use data was acquired from Dutch Cadastral Office-Basisregistratie Adressen en Gebouwen (BAG) and the network data are acquired from Dutch Cadastral Office.

Table 4: Location factors

Dimension	Indicators	Data Source
Transport facilities	Distance to the nearest railway station	Dutch Cadastral Office-Basisregistratie Adressen en Gebouwen (BAG); Dutch Cadastral Office (Kadaster)
	Distance to the nearest bus stop	
	Distance to the nearest highway	
	Distance to the nearest major road	
Non-transport facilities	Distance to the nearest commercial area	
	Distance to the nearest education institution	
	Distance to the nearest park	

3.5.3. TOD-related factors

Most revised previous studies have explored the impact of TOD on housing price either by describing neighborhood characteristics of each house or by calculating distance from houses to railway stations. However, only distance to transit does not cover all aspects of TOD, as previously discussed. Hence, a more scientific approach is to evaluate the TOD influence according to '5Ds' criteria, by quantifying neighborhood characteristics of stations and service quality of stations. Lots of studies have developed TOD factors based on the '5Ds' criteria to evaluate the influence of TOD. Singh (2015), for instance, has developed criteria and indicators with proper weights to calculate the TOD influence around the railway stations in the city region of Arnhem-Nijmegen. Since the calculation of TOD factors was not the main part of the study, this study adopts Singh (2015)'s TOD factors, which are shown in Table 5. There are in total 8 criteria with different indicators, combined to a TOD index following a weighting scheme. Table 6 shows the resulting TOD index (from 0 to 1, meaning 1 is a perfect TOD environment) for every railway station in the region (excluding Nijmegen Goffert, due to the data unavailability).

Table 5: TOD related factors (Source: Singh, 2015)

No.	Criteria	Weight	Indicators	Weight
1	Density	0.15	Population density	0.67
			Commercial density	0.33
2	Land use Diversity	0.03	Land use diversity Entropy	1
3	Walkability and Cyclability	0.06	Mixed-ness of residential land use with other land uses	0.1
			Total length of walkable/cyclable paths	0.4
			Intersection density	0.2
			Impedance Pedestrian catchment area	0.3
4	Economic development	0.22	Density of business establishments	1
5	Capacity Utilization of Transit	0.19	Passenger load at peak hours	0.67
			Passenger load at off-peak hours	0.33
6	User-friendliness of transit system	0.11	Safety of commuters at the transit stop	0.5
			Information display systems	0.5
7	Access to and from the station	0.15	Frequency of transit service	0.4
			Interchange to different routes of same transit	0.3
			Interchange to other transit modes	0.2
			Access to opportunities within walkable distance from transit station	0.1
8	Parking supply at the station	0.08	Parking supply-demand for cars/four wheelers	0.67
			Parking supply-demand for cycles	0.33
9	TOD index	Combination of 8 indicators mentioned above with different weights.		

Table 6: TOD index values for 21 stations in the City Region

Rank	Station Name	TOD index score
1	Arnhem	0.77
2	Arnhem Velperpoort	0.57
2	Nijmegen	0.57
3	Rheden	0.52
4	Nijmegen Heyendaal	0.45
5	Wijchen	0.42
6	Duiven	0.41
6	Nijmegen Dukenburg	0.41
7	Zevenaar	0.37
8	Elst	0.35
9	Dieren	0.33
9	Velp	0.33
10	Didam	0.31
11	Arnhem Presikhaaf	0.3
12	Arnhem Zuid	0.25
13	Westervoort	0.24
14	Molenhoek-Mook	0.22
15	Oosterbeek	0.21
15	Nijmegen-Lent	0.21
16	Zetten-Andelst	0.18
17	Wolfheze	0.16

TOD index describes the overall condition of the railway station and plays an important role in affecting the housing price. Theoretically, higher TOD index represents better TOD-ness which should have positive effects on housing price comparing with the lower TOD index.

Density includes population density and commercial density. Generally, low density development increases automobile dependence, consumes excessive farmland, and raises the cost of public infrastructure (America Planning Association, 2002). In turn, high density with the possibilities of higher transit utilization. The assumption is that higher density leads to higher housing price.

Land use diversity represents the diversity through the measurement of land use mix entropy within 800m around each railway station. The idea of mix land use is to provide the residents and workers with easy access to some typical daily itinerary, such as employment, housing, schools, shopping, local services etc. The assumption is that higher land use diversity will finally capitalized into higher housing price.

Walkability and Cyclability includes mixed-ness of residential land use with other land uses, the total length of walkable/cyclable paths, intersection density and impedance pedestrian catchment area (IPCA). The design of urban space that makes an area more walkable and cyclable is necessary for TOD. The assumption is that better-developed walkability and cyclability have a positive impact on housing price.

Economic development includes density of business establishments. The assumption is that higher economic development in an area contributes to higher housing price.

Passenger load includes passenger load at both peak hours and off-peak hours. Transit system should have enough free capacity, saturated capacities cannot attract more passengers. The assumption is that lower passenger load leads to higher house price.

User-friendliness of transit system includes safety of commuters at the transit station and the information display systems. A user-friendly transit system is necessary to encourage people to use transit. The assumption is that better user-friendliness of transit system contributes to higher house price.

Access to and from the station includes frequency of transit service, interchange to different routes of same transit, interchange to other transit modes and access to opportunities within walkable distance from transit station. A node with better access that provides high accessibility and increases the interchange of public transports. The assumption is that better access to and from the station leads to higher house price.

Parking supply at the station includes parking supply-demand for cars / four wheelers and cycles. The parking supply encourages more people to use transit for their long commutes. The assumption is that enough parking supply contributes to higher house price.

3.5.4. TOD typology

According to Huang et al. (2018), there are three main types of TOD around railway stations in the Arnhem-Nijmegen region, which are urban mixed core, urban residential and suburban residential. Table 7 shows the developed TOD typologies of railway stations in Arnhem-Nijmegen city region. The urban mixed core stations are characteristic of central business districts, whereas urban residential stations and suburban residential stations are characteristic of residential function in urban and suburban regions, respectively. Figure 6 shows the distribution of stations with different TOD typologies. It indicates that urban mixed core stations and most of the urban residential stations are located in the central part of the city while the suburban residential stations are located at the outskirts of the city. In the present study, the relationship between house prices and TOD typologies will also be explored.

Table 7: TOD typology (Huang et al., 2018) and number of houses in the sample, at each station

Station Typology	Station Name	Coupled houses in the sample
Urban mixed core	Arnhem	25
Urban mixed core	Arnhem Velperpoort	78
Urban mixed core	Nijmegen	158
Urban residential	Nijmegen Heyendaal	41
Urban residential	Wijchen	86
Urban residential	Duiven	186
Urban residential	Nijmegen Dukenburg	103
Urban residential	Elst	83
Urban residential	Arnhem Presikhaaf	42
Urban residential	Arnhem Zuid	221
Suburban residential	Rheden	58
Suburban residential	Zevenaar	28
Suburban residential	Dieren	43
Suburban residential	Velp	44
Suburban residential	Westervoort	53
Suburban residential	Oosterbeek	17
Suburban residential	Nijmegen-Lent	16
Suburban residential	Zetten-Andelst	1
Suburban residential	Wolfheze	3
Suburban residential	Didam	44
Suburban residential	Molenhoek-Mook	48

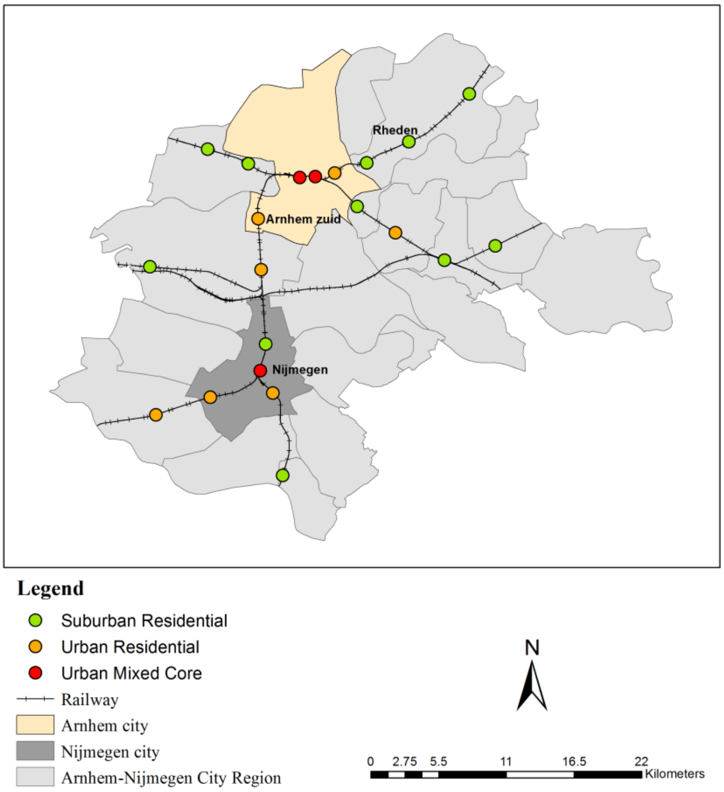

Figure 12: TOD typologies

(Source: Huang et al., 2018)

3.6. Hedonic price model

The hedonic price model assumes that the characteristics affecting housing price can be decomposed, thereby treating each of them separately in order to estimate prices or elasticity for each of them (Rosenkrantz, 1974). In the study, the main aim is to investigate how TOD-related factors affect house price. The hedonic price model could isolate statistically the effect of TOD by predicting the transaction price of houses based on TOD-related factors.

In the study, rather than using a simple linear function form, a logarithmic function form is used. The simple linear function represents the absolute amount of dependent variable change as driven by per unit increase or decrease of independent variables, while the logarithmic function estimates the percentage change of dependent variables according to the unit change of independent variables. Hence, it is easier and more intuitive to compare the different influences on housing price among independent variables through logarithmic function.

The hedonic price regression model with logarithmic form is made use of the following:

$$\mathrm{LnP} = \mathrm{f}(\mathrm{H}, \mathrm{L}, \mathrm{T})$$

Where P is the transaction price of a house, which is a function of the following vectors: H, a vector of structural factors that measure the inherent housing characteristics; L, a vector of location factors that describe the location amenities; T, a vector of TOD-related factors including the measurement of TOD index and the factors constituted of TOD index.

To get better and more critic regression results, the step wise regression method will be used to explore the relationship between house price (dependent variable) and other factors (potential variables). The reason is that step wise regression could manage large amounts of potential variables, fine-tuning the model to choose the best predictor independent variables from the available options and excluded those worse independent variables. More specifically, at each step in the analysis the predictor variable that contributes the most to the prediction equation in terms of increasing the multiple correlation, R, is entered first. When more predictors are added, adjusted r-square levels off. This process continues until none of the excluded predictors contributes significantly to the included predictors(SPSS TUTORIALS).

Three sets of regression models were built with the purpose of analyzing the relationship between housing price and its determinants. Therefore, the dependent variable is the housing price, whereas independent variables are the structural variables, location variables and TOD related variables.

The first type of model is a regression model at the regional level, aiming to investigate how structural factors and location factors affect housing price in the city region. Moreover, the model aims to explore whether the change of house price depends on the distance to a railway station.

The second type of model is a regression model at the station level, in which the research objectives are the coupled houses located within 800m buffer around railway stations. The model is used to estimate how TOD related factors would influence house price within the TOD influence buffer (800m). Besides that, the impact of TOD on housing price was explored by enlarging the TOD influence buffer to 1600m to compare the variations housing price with the results of 800m buffer, considering that in the Netherlands many train travelers reach the station by bicycle

The third model is a series of TOD typology models. According to Huang et al. (2018), TOD environments of railway stations are classified into three typologies, which are urban mixed core stations, urban residential stations and suburban residential stations. Finally, three models are generated to explore how the TOD related factors affect house price in the context of different typologies.

Spatial variables were analyzed using ArcGIS whereas non-spatial variables using SPSS. Table 8 shows the detailed data description and required software.

1) **Structural variables** are all non-spatial variables, most of which are derived directly from the data source without any additional calculation or analysis. Among the structural variables, it is important to note that the energy label ranges from A (most efficient energy) to G(least efficient energy), which are categorical variables. In order to do regression analysis in SPSS, a score (7-1) was used to represent the energy condition (A-G), which helped to change the category variables into scale variables. Besides that, number of floors was calculated by dividing the living area divided by building footprint.

2) **Location variables** are all spatial variables, therefore, all of them were calculated. Network distance was used to calculate all distance-related variables because it can simulate the actual pedestrian route through the network. Besides that, the calculation measures the centroid of the observed house property to the centroid of the facilities. These calculations were all done in ArcGIS.

3) **TOD-related variables** were adopted from Singh(2015) and was already discussed in section 3.5.3.

4) **TOD typologies** were adopted from Huang et al (2018) and was already discussed in section 3.5.4

Table 8: Data descriptions

Dimension	Variable name	Description	Software
Dependent variable	Lnprice	Natural logarithm of transaction price of the houses adjusted to 2017	Calculated using SPSS
Structural variables	Area_P	Parcel area of the building	Calculated using ArcGIS and Excel
	Area_L	Living area of the building	
	Floor	Number of floors of the building	
	EL	The score (1-7) represents the condition of the energy of the building. Score 7 represents the best energy condition, score 1 represents the poorest energy condition.	
	Age	Age of the building	
Location variables	Com_area	Network distance to the nearest commercial area	Calculated using ArcGIS
	Bus_stop	Network distance to the nearest bus stop	
	Park	Network distance to the nearest park	
	Major_R	Network distance to the nearest major street	
	Highway	Network distance to the nearest highway	
	Edu	Network distance to the nearest education institution	
	Rail_Sta	Network distance to the nearest railway station	Calculated using ArcGIS;

4. RESULTS

In this section, three types of models are generated, which are regression model in regional level, regression model in station level and regression model of different TOD typologies.

As a first step, to explore to what extend proximity to TOD (distance to railway station) influences housing price, a regression analysis between distance to railway station and house price was done, considering all types of houses in the region. Table 9 shows the regression results of distance to railway station and house price of five different type of houses.
Standardized coefficients show that for all house types a negative relationship between housing price and distance to railway station, meaning house prices increases when distance to railway decreases. In addition, the influence of distance to railway station on housing price varies for different house types. The free-standing house has the largest negative impact on housing price while the coupled houses and house on a corner shows smaller influence on housing price. Thus, in general, proximity to TOD influences housing prices. However, coupled houses estimates are not significant at the 1% statistical level, and the R square of the model (0.000) is quite low, meaning that are other influential variables influencing housing price. Hence, it is very important to further explore coupled houses.

Table 9: Regression result for all type of houses

House type	**Independent variable**	**Unstandardized Coefficients**	**Standardized Coefficients**	**Sig.**	**R^2**
Apartment (A)	Distance to railway station	-3.987E-5	-.115	.000	.013
House on a corner (H)		-7.634E-6	-.037	.027	.001
2 under 1 roof (K)		-2.030E-5	-.116	.000	.013
Coupled house (T)		-1.519E-6	-.008	.485	.000
Free standing house (V)		-2.571E-5	-.151	.000	.023

4.1. Regression model in regional level

Regression model in regional level is used to investigate how the influential factors (e.g. structural factors, location factors) affect house price. Moreover, it helps to explore whether the change of house price depends on the distance from railway station combining with other variables. The research objectives are all the coupled houses in the city region

Table 10: Regression results of regional level

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.001	.234***	.644	1.552
	Area_L	.004	.530***	.494	2.024
	Floor	-.070	-.145***	.576	1.736
	Age	.003	.240***	.394	2.540
	EL	.070	.327***	.387	2.583
	constant	11.184			
Model Statistics	N=8039; Adjusted r^2=0.448; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

Table 10 shows the result of step wise regression analysis, the adjusted R^2 is equal to 0.448 which explains about 44.8% percent of variance in housing price could be explained by those independent variables. The values of Variance Inflation Factor (VIF) are all between 1 and 5, which indicates that there is some multicollinearity among variables but not severe (if more than 5.0, it is considered severe). The coefficients for structural variables are statistically significant at p=0.01 level and all have expected signs. For example, house price increases with the living area and parcel area while decreases with the height of the house. Besides that, energy label also shows a strong positive relationship to house price which explains that house with better energy efficiency has higher house price. In the model, location variables have been excluded from step wise regression, which means that there are no obvious relationships between house price and location factors in the whole region. Specifically, the change of house price does not depend on the proximity to railway station.

The regional model suggests that structural factors have strong relationships with house price while no significant signs are explored between house price and location factors in Arnhem-Nijmegen city region. The model doesn't include TOD related factors because the influence of TOD area should be kept within a certain distance around railway stations. In the study, the TOD related factors are considered and calculated for an 800m buffer around railway stations instead of the whole city region. Hence, the second model, which is a regression model at the station level aims to explore how TOD related factors would affect house price within the TOD influence area.

4.2. Regression models in station level

Regression model at the station level was developed to explore how structural, location, but also TOD related factors would influence house price within 800m buffer around railway stations. In theory, different TOD related factors have different impacts on housing price. Hence, two types of regression models are generated at stations level. The first model is regression model considering the TOD index. TOD index represents the TOD ness of each railway station, which is used to describe and evaluate the overall performance of TOD around railway stations. By analyzing the relationship between house price and TOD index, we can easily know how the overall performance of railway stations affect house price. The second model is a regression model with components of TOD index. Since TOD index is constituted by many factors, it cannot fully explain the influence of a specific factor on housing price. Hence, the second model was used to explore to what extent these specific factors that make up the TOD index would affect housing price.

Table 11 and Table 12 shows the result of step wise regression. Both models have good overall fits with R square above 0.65. VIF values are all between 1 and 5, which indicates acceptable multicollinearity among variables. Further details of the two models are discussed below.

4.2.1. Regression model with TOD index

Table 11 suggests that all structural variables, some of the location variables and TOD index are significant at the 1% statistical level.

Table 11: Regression result of 800m buffer (TOD index)

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.002	.311***	.619	1.615
	Area_L	.004	.480***	.424	2.356
	Floor	-.041	-.078***	.545	1.834
	Age	.002	.206***	.294	3.407
	EL	.078	.355***	.360	2.781
Location variables	Park	-2.154E-5	-.103***	.639	1.564
	Major_R	-5.241E-5	-.085***	.711	1.407
	Highway	4.320E-5	.170***	.739	1.354
	Edu	7.126E-5	.087***	.448	2.233
	Com_area	.000	-.102***	.499	2.004
	Rail_Sta	4.551E-5	.049***	.866	1.155
TOD related variables	TOD_ind	.603	.213***	.554	1.806
	constant	10.835			
Model statistics	N=1379; Adjusted r²=0.652; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_Div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

Among structural variables, living area shows the highest coefficient value. For every square meter increase in living area, the property value increases by about 1%. Positive relations are also found for age of the house, parcel area and energy label. Older houses because of its unique characteristics and better geographical location would attract more buyers with higher house price. The higher score of energy label represents better energy efficiency, which helps to reduce energy consumption and contribute premiums on housing price. Oppositely, the negative coefficients for number of floors of the house indicate that house price would decrease for higher floors. The reason is that higher floor is sometimes associated with moving inconvenience and evacuation problems, and is especially disruptive for the elderly and people with disabilities.

Among location variables, proximity to highway followed by proximity to park are the most robust independent variables with two largest coefficients. More specifically, house price would increase for closer to park and decrease for closer to the highway system. The reason is that park could provide good view and enough open space for residents nearby to relax themselves. However, highway always associated with kinds of noise and pollution problems, which would cause an unlivable environment for residents around. Besides that, proximity to railway station shows a negative relationship to house price with the smallest coefficient value. For example, house price would decrease about 4.9% for a standardized deviation (about 388m) closer to a railway station, which means that 1km further from railway station would increase house value about 12.6%. The positive relationship between house price and proximity to railway station is opposite from the first analysis (all type of house), which shows negative signs. In the first analysis, proximity to railway station is the only independent variable, which cannot fully explain the reality with quite low R^2. After considering other influential variables, the regression result would more conform to the reality. Hence, for the coupled houses, house price would increase for the farther distance from the railway station. The main reason is that houses next to the railway station always have smaller living area comparing with the houses far away from the railway station. Besides that, railway usually causes vibration and noise problems to residents nearby, which would seriously affect residents' daily living. As a result, housing price are cheaper next to the railway station.

As for the TOD index, the log result suggests a significant price premium for houses located around stations with higher TOD index. More specifically, a 0.1 increase of TOD index incurs a 16.3% increase in house price, which explains that better TOD ness stations would increase housing price, which is a logical and expected result.

All in all, TOD index and proximity to railway station both show positive relationships to housing price. Moreover, the coefficient value of TOD index (0.213) is higher than the value of proximity to railway station (0.049), which means that TOD index would influence house price more comparing with proximity to railway station.

4.2.2. Regression model with components of TOD index

Table 12 suggests that all structural variables, four location variables and five TOD related variables are significant at 1% statistic level.

Table 12: Regression result of 800m buffer (components of TOD index)

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.002	.289***	.589	1.699
	Area_L	.004	.471***	.424	2.359
	Floor	-.039	-.075***	.549	1.823
	Age	.002	.193***	.282	3.550
	EL	.072	.328***	.359	2.788
Location variables	Park	-1.948E-5	-.094***	.605	1.653
	Highway	7.883E-5	.310***	.454	2.201
	Edu	9.772E-5	.119***	.423	2.362
	Com_area	-9.375E-5	-.075***	.497	2.013
TOD related variables	Park_sup	.379	.223***	.394	2.536
	Eco_dev	.214	.142***	.353	2.834
	Pass_load	-.098	-.076***	.562	1.780
	User_fri	.181	.155***	.231	4.334
	Land_div	.310	.165***	.204	4.891
	constant	10.473			
Model statistics	N=1379; Adjusted r^2=0.688; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

The contribution of structural variables to house prices is highly significant and similar to the first model. For example, the estimates of the log-linear function imply that the score of energy label from B to A is associated with a price increase of about 20.2%.

Among location variables, proximity to highway and proximity to education show positive signs, which indicates that house price would increase for the farther distance from the highway system and education institution. Conversely, proximity to park and proximity to commercial area have negative relationships with house price. For example, the coefficient on proximity to park indicates that house price declines 4.4%

for each km away from the park. Proximity to railway station shows no relationship with housing price in the model.

As for the TOD related variables, **parking supply** has the strongest positive relationship with house price. For example, house price would increase about 22.3% for each SD (about 0.21) increase in parking supply. Parking supply aims at providing enough parking space for cars and cycles, which are very attractive for passengers who drive or cycle to the railway station. Generally speaking, the construction of parking supply is according to the passenger's flow. Large parking space indicates large passenger flow, reflecting more people live or work nearby. Hence, the house price would increase for the attractive station. The economic development, user friendliness and land use diversity also show positive signs. High score of **economic development** means more business establishments are built within the TOD influence buffer, which not only contributes to more job opportunities but also makes the area more competitive. As a result, people would choose to live nearby for the potential job opportunities and the real estate agent would plan to invest in the attractive place. Hence, the house price would increase. **User friendliness** shows positive influence on housing price. User friendliness evaluates the service quality at transit stations. For example, if the transit station could guarantee the safety of passengers then more people would choose train to go out, especially at night. Similarly, better service level refers to the install of information display system, which could provide detailed train information for passengers. Finally, more safety environment and better service level together contribute to higher housing price nearby. **Land use diversity** has a positive influence on housing price. High score of land use diversity represents more mixed land use, which could provide kinds of infrastructures in the TOD influence buffer such as education, health, sport, office etc. These basic infrastructures provide conveniences for peoples' daily life and in turn would increase housing price. Conversely, **passenger load** shows a negative relationship with housing prices. If the passenger load increases by 0.1, house value would decrease about 2.7%. Higher passenger load ensure better utilization of transit capacity. However, if the passenger load is too high, then the train would be considered too crowded and people may switch to other transport mode. Generally speaking, stations with higher passenger load are always central business area or densely populated area which main function is not for living because of noisy problems so that the house price would decrease. In the model, other TOD related factors like density, walkability and cyclability and access to and from the station have been eliminated, indicating that these variables have weaker effect on house price.

The results of the two models suggest that TOD index has a strong relationship with house price within the TOD influence area (800m). More specifically, better TOD ness would increase house price. Besides that, some of the TOD related factors show expected positive or negative signs. The results confirm our assumptions.

To further explore the role of TOD influence area, the 800m buffer was enlarged to 1600m to explore whether any relationships between TOD related factors and house price would be captured in larger distance. This is especially relevant in the Dutch context where a large percentage of train travelers reach the station by bicycle.

Table 13 shows the regression results of 1600m buffer of a model with structural factors, location factors and the TOD index, while Table 14 presents the estimates of a model with structure factors, location factors and the components of TOD index, for 1600m buffer. The adjusted R^2 values are respectively 0.504 and 0.536, which explains the model fits the data relatively well. The VIF values are all between 1 and 5, which indicates acceptable multicollinearity among variables. Both models suggest that, when the TOD influence buffer is enlarged to 1600m, higher TOD index implies in higher housing prices, just like the result for 800m. Besides that, walkability and cyclability, user friendliness and land use diversity show relationships with house price. More specifically, walkability and cyclability shows negative signs with housing price, which indicates that higher score of walkability and cyclability would decrease house price. Conversely, better user friendliness and more land use diverse would increase house price. However, it is important to note that the coefficients of TOD related factors in 1600m buffer are smaller than 800m buffer, indicating a weaker relation. Take TOD index for example, the coefficients of TOD index in 800m buffer is 0.213 compared with the coefficient in 1600m buffer (0.118), both at 1% statistical level, which indicates that the influence of TOD index on housing price in 800m buffer is stronger than 1600m buffer. In conclusion, the influence of TOD on housing price is reduced as the distance increases from the railway stations.

Table 13: Regression result of 1600m buffer (TOD index)

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.001	.225***	.674	1.484
	Area_L	.005	.554***	.551	1.815
	Floor	-.041	-.074***	.652	1.534
	Age	.003	.269***	.344	2.910
	EL	.065	.293***	.383	2.608
TOD related variables	TOD_ind	.282	.118***	.812	1.232
	constant	10.967			
Model statistics	N=7135; Adjusted r^2=0.504; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_Div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

Table 14: Regression result of 1600m buffer (components of TOD index)

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.001	.225***	.652	1.533
	Area_L	.005	.557***	.545	1.836
	Floor	-.041	-.074***	.653	1.531
	Age	.002	.195***	.325	3.076
	EL	.064	.289***	.383	2.611
Location variables	Com_area	2.005E-5	.024**	.999	1.001
TOD related variables	Walk_cycl	-.245	-.148***	.752	1.330
	User_fri	.176	.162***	.481	2.079
	Land_div	.166	.099***	.471	2.125
	constant	11.123			
Model statistics	N=7135; Adjusted r^2=0.536; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

4.3. Regression model of different TOD topologies

Since the influence of TOD related factors of different railway stations have different impacts on house price, a model including different TOD topologies was done to test whether house prices would vary differently depending on the characteristics of the urban context where the station is located. According to Huang et al. (2018), railway stations in Arnhem-Nijmegen city region were classified into three typologies, which are urban mixed core station, urban residential station and suburban residential station. Three models were developed for each typology, as results are discussed in detail below.

4.3.1. House price at urban mixed core

Table 15 provides the result of a step wise regression model including structural variables, location variables and TOD related variables, only considering the urban mixed core stations. In the model, structural variables mostly have intuitive and significant coefficients. The positive coefficient of living area indicates that each SD square meters (about $77m^2$) increase in the living area, the property value increases by about 47.6%. The positive signs are also shown in parcel area, age of the house and energy label.

Among location variables, results suggest that with the increment of distance to bus stop, distance to park and distance to railway station, the house price would increase. More specifically, the coefficient of distance to railway station shows that the house price would decrease about 8.8% for each SD (about 347m) increase to railway station. The main reason is that most of the houses located far from the railway stations always have larger living area and getting away from the noise problems associated with the train. Conversely, farther distance to major street would decrease house price.

Finally, all the TOD related factors have been excluded after step wise regression, which may suggest that on one hand, other variables have stronger relations with house price, and on the other hand, because only urban mixed core stations are considered, they belong to the same homogeneous environment like high street and building density, mixed land use, etc. To get insights on whether the location of the houses relative to the stations would uncover trends, the station Nijmegen Central Station was taken as an example of an urban mixed core station. Figure 13 illustrates the coupled houses around the station, with the corresponding house prices and living area.

Table 15: Regression result of urban mixed core stations

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.002	.212***	.610	1.641
	Area_L	.003	.476***	.483	2.072
	Age	.004	.292***	.516	1.938
	EL	.044	.155***	.585	1.708
Location variables	Bus_stop	.000	.110***	.808	1.238
	Park	.000	.243***	.748	1.337
	Major_R	-.001	-.308***	.608	1.644
	Rail_Sta	.000	.088**	.524	1.910
	Constant	11.226			
Model Statistics	N=261; Adjusted r^2=0.774; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_Div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

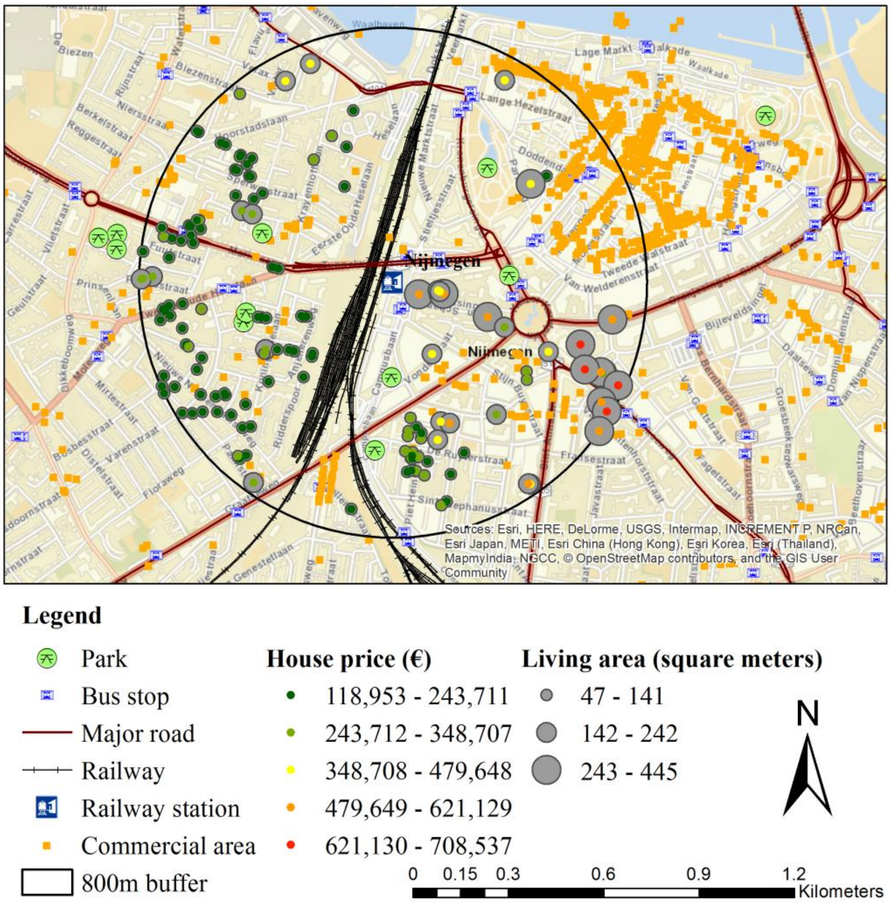

Figure 13: House price distribution of Nijmegen railway station

A sample of 158 coupled houses was analyzed on the 800m buffer around the Nijmegen railway station. House prices range from €118,953 to €708,537. As we can see from figure 13, the green, yellow and red points represent the houses which have low house price, medium house price and high house price, respectively. Besides that, the grey circle from small to large represents the living area from 47m² to 445m². In general, houses with larger living area have higher house price. The pattern shows the same findings with the regression model. Besides that, houses located on the right side of the railway show the pattern that house price increase with increasing distance from railway station. An important reason is that there are a large area of commercial zones in the right side of the railway, which would influence house price nearby. However, on the left sign, most houses have lower prices, and clear relation with distance from the station is not noticeable.

4.3.2. House price at urban residential

Table 16 shows the result of a step wise regression model including structural variables, location variables and TOD related variables, only considering the urban residential stations. In the model, structural variables mostly have expected signs with 99% level of confidence. More specifically, house price increase for increasing living area, parcel area and better energy efficiency. Conversely, house price would decrease for higher floors.

Among location variables, proximity to highway positively impact house price while proximity to park negatively influence house price. The coefficient on proximity to railway station also shows a positive sign. For example, 1 km increase of distance to railway station would increase the house price about 11.4%.

Finally, among TOD-related variables, walkability and cyclability and access to and from the station are the most statistically significant independent variables and both negatively influence property value. For instance, every SD (0.11) increase in the walkability and cyclability, the property value decreases by about 43%. Besides that, the coefficient on economic development indicates that house price increases for better economic development within the 800m buffer. These signs suggest that TOD related factors have influence on house price in urban residential area. To get insights on whether the location of the houses relative to the stations would uncover trends, the Arnhem Zuid Station was taken as an example of an urban residential station. Figure 14 illustrates the coupled houses around the station, with the corresponding house prices and living area.

Table 16: Regression result of urban residential stations

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.001	.286***	.476	2.103
	Area_L	.004	.377***	.491	2.038
	Floor	-.046	-.083***	.630	1.588
	EL	.040	.176***	.773	1.293
Location variables	Park	.000	-.314***	.562	1.779
	Highway	4.407E-5	.182***	.793	1.262
	Rail_Sta	6.655E-5	.094***	.821	1.217
TOD-related variables	Access_to	-1.191	-.310***	.490	2.042
	Walk_cycl	-.697	-.265***	.490	2.043
	Eco_dev	.343	.092***	.559	1.788
	Constant	12.318			
Model Statistics	N=562; Adjusted r^2=0.786; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_Div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

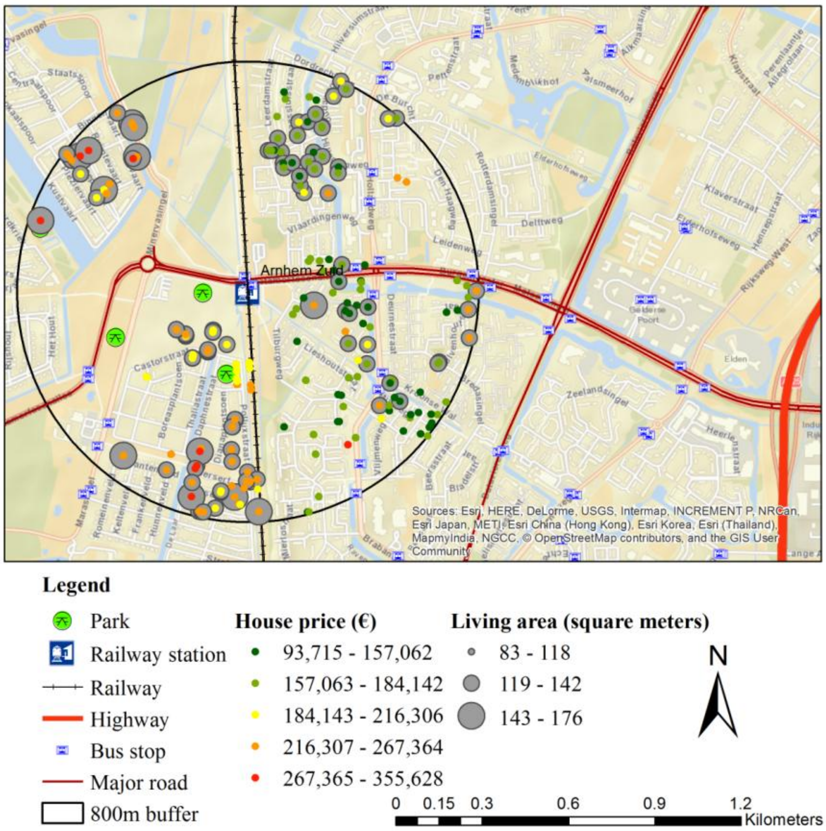

Figure 14: House price distribution of Arnhem zuid railway station

A sample of 221 coupled houses was analysed on the 800m buffer around the Arnhem Zuid railway station. The housing price range from €93,715 to €355,628. As we can see from figure 14, houses located on the left side of the railway have higher housing price than the houses located on the right side of the railway. Overall, houses with larger living area have higher housing price. However, some houses located next to the railway station have relative small living area but higher house price. The reason is that these houses have better accessibility to the parks, which contribute premiums on housing price. Moreover, houses located in the northwest are the most expensive ones, the reason behind is that these houses are surrounded by the lake and have better living environment. Besides that, houses located on the left side of the railway show the pattern that house price increase with increasing distance from railway station, which also supports the findings in Table 16.

4.3.3. House price at suburban residential

Table 17 shows the result of a step wise regression model including structural variables, location variables and TOD related variables, only considering the suburban residential stations. In the model, location variables have been excluded after the step wise regression, which indicates that no relationships between location variables and house price have been found.

Among structural variables, housing price increase for increasing living area, parcel area and better energy efficiency. The log result of energy label show that a level increasing, say from level B to level A, incurs a 23.8% increase in price. Conversely, number of floors negatively influences house price.

Among TOD related variables, house price would increase for lower passenger load, higher percentage of parking supply, better economic development and user friendliness. Besides that, the coefficient of passenger load is larger than the parking supply, which indicates the passenger load has more impact on housing price. In conclusion, four TOD related factors show relationships with house price in the suburban residential area. To get insights on whether the location of the houses relative to the stations would uncover trends, the Rheden Station was taken as an example of a suburban residential station. Figure 14 illustrates the coupled houses around the station, with the corresponding house prices and living area.

Table 17: Regression result of suburban residential stations

Dimension	Independent variable	Unstandardized Coefficients Beta	Standardized Coefficients Beta	Tolerance	VIF
Structural variables	Area_P	.002	.430***	.648	1.543
	Area_L	.003	.431***	.357	2.801
	EL	.060	.313***	.912	1.097
	Floor	-.052	-.144***	.453	2.206
TOD related variables	Pass_load	-.377	-.223***	.671	1.489
	User_fri	.163	.111***	.656	1.524
	Eco_dev	.086	.098**	.618	1.618
	Park_sup	.406	.218***	.478	2.092
	Constant	11.151			
Model Statistics	N=355; Adjusted r^2=0.548; Dependent variable: Lnprice Predictors: Area_P, Area_L, Floor, Age, EL; Bus_stop, Com_area, Major_R, Edu, Highway, Rail_Sta, Park; TOD_ind, Density, Land_Div, Walk_cycl, Eco_dev, Pass_load, User_fri, Access_to, Park_sup;				

Notes: *P<0.10, significance at the 0,10 level;** P<0.05, significance at the 0.05 level; ***P<0.01, significance at the 0.01 level.

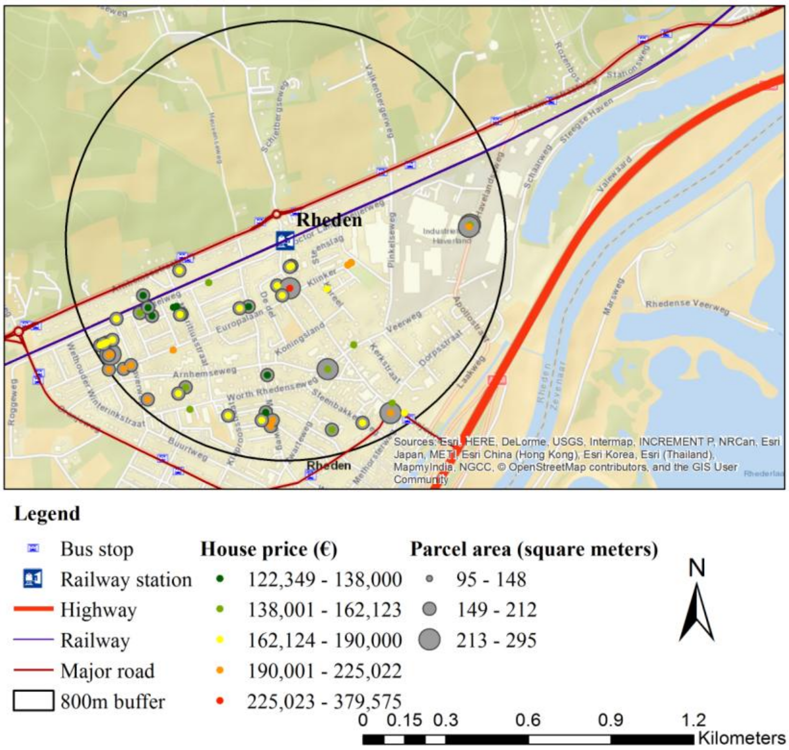

Figure 15: House price distribution of Rheden railway station

A sample of 58 coupled houses was analyzed on the 800m buffer around the Rheden railway station. The housing price range from €122,349 to €379,575. As we can see from figure 15, all the houses are located in the south part of the railway. The north part of the railway is non-built up area. Overall, the houses with larger parcel area have higher house price. The distribution of house price is random. However, most of the houses with higher house price are not far from the major road and highway system.

4.3.4. Summary of the three TOD typologies

In conclusion, models for the three TOD typologies have suggested that the distance to railway station has a positive effect on housing price at urban mixed core stations and urban residential stations. No relationship is found between distance to railway and house price in suburban residential stations. As for the TOD related factors, house price in residential areas is affected by TOD related factors more. However, TOD related factors wouldn't affect house price in the urban mixed core area. Detailed explanations and descriptions of the role of TOD on housing price in urban mixed core, urban residential and suburban residential are discussed below. Figure 16 shows the mean value of TOD factors among different TOD typologies. This analysis has the intention to help us better understand the performance of different TOD components among the three TOD typologies.

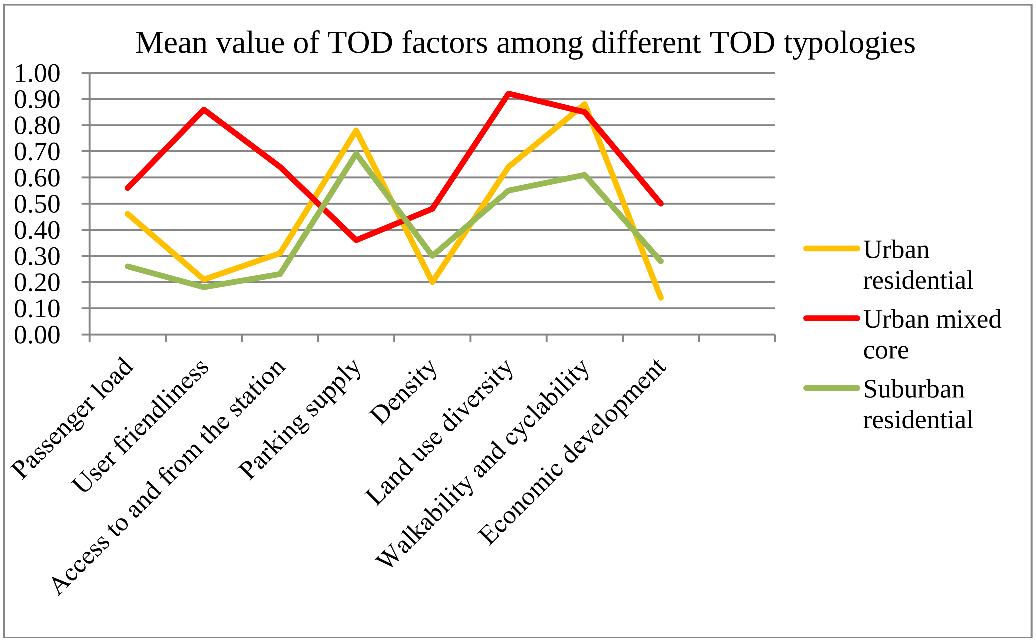

Figure 16: Mean value of TOD factors among different TOD typologies

In the urban mixed core area, though TOD performance shows no influence on housing price nearby, it would not depress housing price. According to figure 16, the overall TOD performance of urban mixed core is much better than the other two TOD typologies, except for parking supply. The average value of passenger load, user friendliness as well as economic development are quite high comparing with others, which suggest that urban mixed core area is characteristic of large passenger demand, better service quality of railway stations and more developed economy. These features conform to the characteristics of central business districts (CBD). Hence, the main functions of urban mixed core areas are for office and entertainment instead of living (indeed, only 261 coupled houses located nearby). Moreover, the lower value of parking supply in CBD area aims at avoiding people using car. In a future study, maybe more relationships between TOD factors and commercial property value would be found in urban mixed core areas.

In the suburban residential area, regression analysis shows that four TOD factors have an effect on housing price, which are passenger load, user-friendliness, economic development and parking supply. Passenger load negatively influences housing price because most people work in the central part of the city and live in surrounding areas. Hence, lower passenger load implies stations outside the urban core, which is better for living. Parking supply positively influences housing price. The reason is that park and ride area encourages people who live in the suburban area to reach the CBD by train. Similarly, figure 17 shows the road distribution in some of the suburban residential areas, which indicates that most of the road are major road or motorway. Hence, motor vehicles are the main transport mode for people to go out or commute between railway stations and their homes. As a result, enough parking supply provides conveniences for residents nearby. And finally, these benefits are reflected in housing price. Better economic development positively influences housing prices as it not only improves job opportunities but also promotes investing, which contribute to higher housing price. User friendliness also shows a positive relationship with housing price at suburban residential stations, which indicates that better service quality is necessary for both TOD development and housing price.

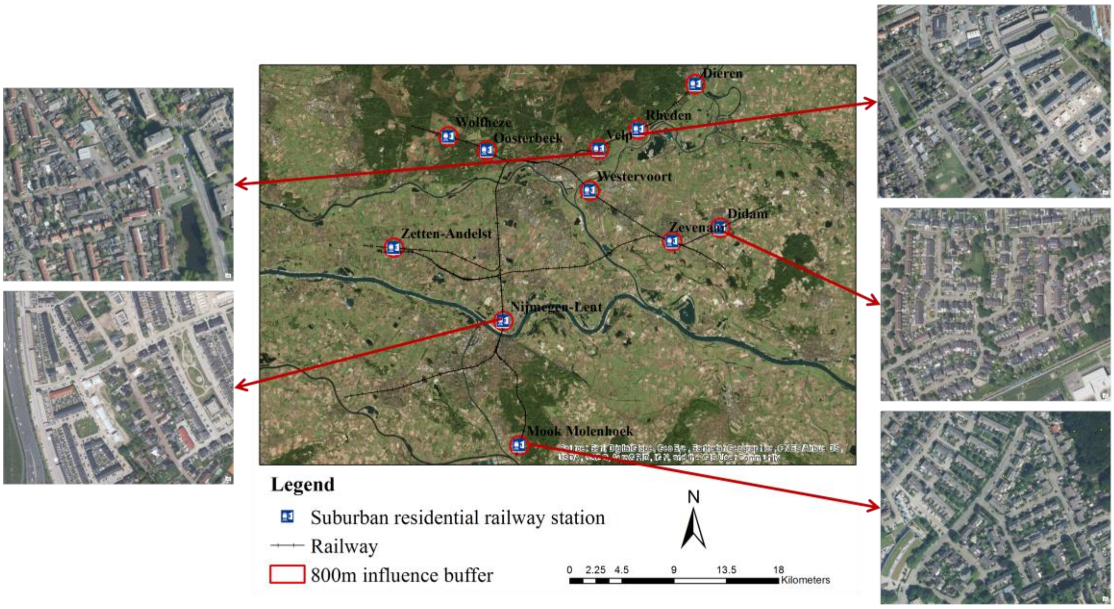

Figure 17: Road pattern of suburban residential railway stations

In the urban residential area, three TOD factors show relationships with housing price, which are walkability and cyclability, access to and from the station and economic development. First, walkability and cyclability have negative effects on housing price. It is important to note that the total length of the walkable/cyclable path and impedance pedestrian catchment area (IPCA) are the two main components which take up two largest weights comparing with other components of walkability and cyclability. Hence, the main analysis is based on the two main components. According to figure 16, the mean value of walkability and cyclability of the urban residential area is higher than the other two TOD typologies, which suggests that urban residential area has a better design of non-motorized transport infrastructure. By zooming into the TOD influence buffer of the urban residential area (figure 18 to figure 24), figure 19, figure 22, figure 23 and figure 24 are railway stations with a large area of parks, which have been highlighted in the red frame. It is easy to find that many of the walk path and cycle path are distributed in the parks. While the roads next to the coupled houses are major streets or motorways, which supports motor vehicles. Similarly, though no parks are founded in figure 18 and figure 20, a large area of open space is built near the two railway stations with orderly walk path for pedestrians and cycle ways for cyclists. Only figure 21 shows that the sidewalks and motorways are crossly distributed near the coupled houses. As a result, it seems that many roads near coupled houses are composed of major streets or motorways, whereas sidewalks or cyclists lanes are mostly located inside the green spaces. Hence, the coupled houses near the park have higher housing price because of its welcoming environment, which has already been proved in Table 16. Conversely, coupled houses located far away from the park have lower prices. The IPCA represents the ratio of areas that can be covered by walking within a specific walking time from a rail station. Higher values of IPCA means that more area can be reachable by walking. However, due to the disrupting of the sidewalks by parks or open spaces and the uneven distribution of walking path, the IPCA coverage is unbalanced, e.g. Arnhem Zuid railway station (Figure 25). As a result, many of the coupled houses cannot be reached on foot within a specific time, therefore the housing price would be depressed.

Second, access to and from the station also shows negative relationships with housing price. From figure 16, we know that the average score of access to and from the station of urban residential (0.31) is between the score of suburban residential (0.23) and mixed core residential (0.35). Since the frequency of transit service and interchange to different routes of same transit are the two main components which take up the largest weights comparing with other components of access to and from the station. The higher frequency of transit service means more trains operating in per hour at railway stations, which would cause the vibration problem and noise pollution on the surrounding houses. Hence, these disadvantages would depress housing price nearby. Besides that, it seems that higher the interchange possibilities has a negative effect on housing price, which also can be explained by the noise pollution caused by more trains. Finally, economic development reveals positive influence on housing price also for urban residential stations.

Figure 18: Arnhem Zuid railway station

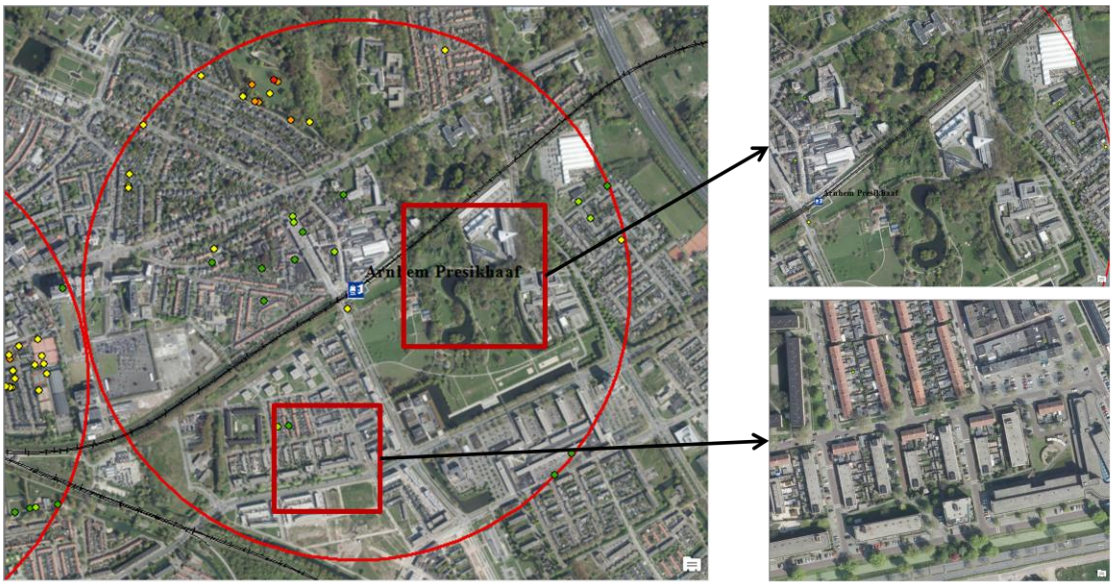

Figure 19: Arnhem Presikhaaf railway station

Figure 20: Nijmegen Dukenburg railway station

Figure 21: Duiven railway station

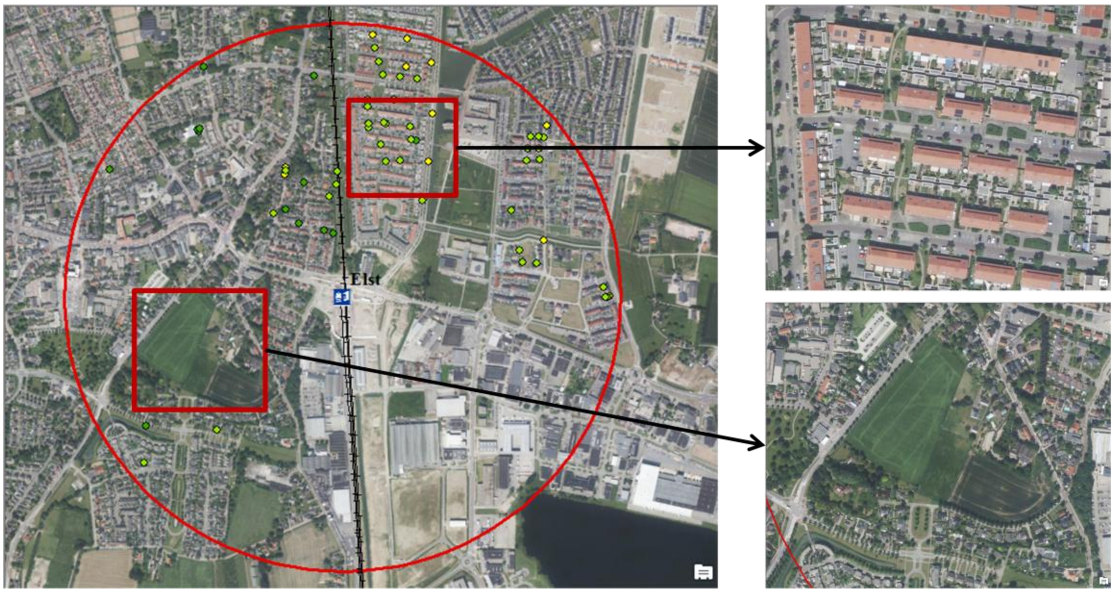

Figure 22: Duiven railway station

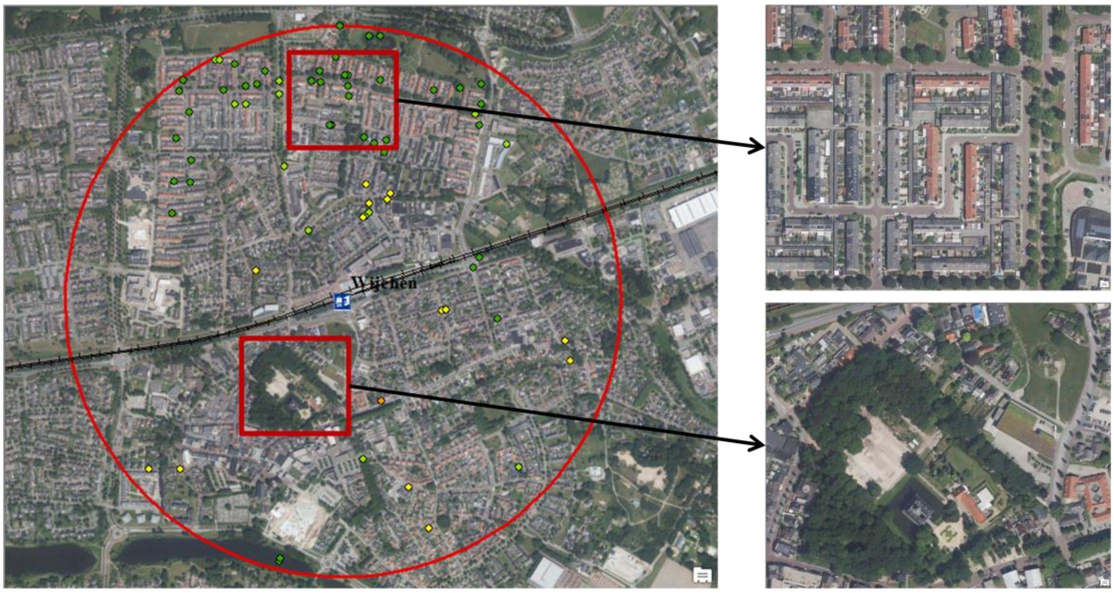

Figure 23: Wijchen railway station

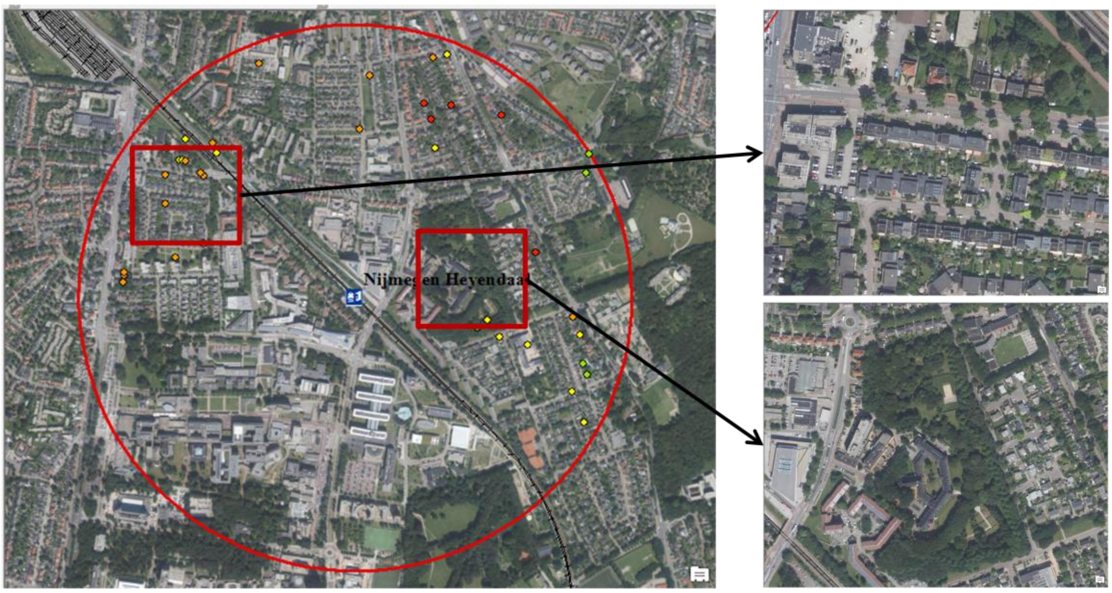

Figure 24: Nijmegen Heyendaal railway station

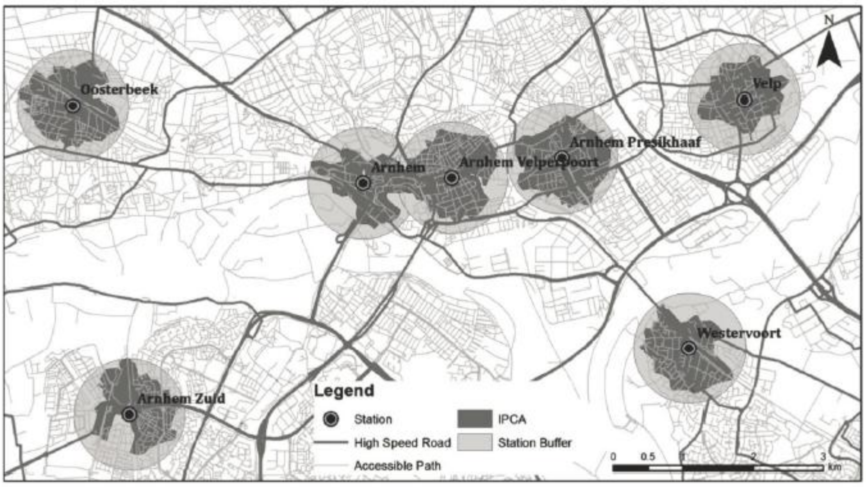

Figure 25: IPCA for areas around various stations in the city region

Source: Singh (2015)

5. CONCLUSIONS

5.1. Conclusions

The main objective of the study was to assess the influence of transit-oriented development on housing prices. A literature review and analysis of the local context supported the selection of select influential factors on housing price variation. The selected factors were classified into structural factors, location factors and TOD related factors. First, regression analysis between housing price and distance to railway stations was done to quantify the variations of housing price among different type of houses. Coupled houses were selected for further investigation because they make up the largest sample of houses. Then, hedonic price models were developed to quantify the influence of TOD on housing price. Four different models were built: (1) regional level, (2) 800m TOD buffer area (station level), (3) 1600m TOD buffer area, (4) TOD typology. Below, conclusions are derived for each model.

First, the regression model in regional level was used to explore housing price variation at the regional level. The relationships among structural factors, location factors and housing price for all the coupled houses were analyzed. It is important to note that the TOD factors because they are only relevant when analyzed the immediate vicinity of station areas (named as TOD buffer in this thesis), were excluded of this model since the area is too large to capture any relationships. The regression model in regional level suggests that among all the coupled houses in Arnhem-Nijmegen city region, only structural factors affect housing price. No relationships have been found between location factors and housing price. The reason is that the area is too large to capture any distance related factors. The model helps to better understand the overall house conditions and house price in the city region.

Second, the regression model in station level suggests that among all the coupled houses located within TOD influence buffer (800m), housing prices increase for areas with high TOD index (i.e. the more oriented an area is towards transit). This is in conformity to our assumption, that higher TOD index represents better TOD performance, which not only includes better services provided by the railway station but also better neighborhood environment around railway stations, thus reflected into higher housing prices. Besides that, among other TOD factors, parking supply, economic development, passenger load, user friendliness as well as land use diversity also have influences on housing price. The model using a 1600m TOD buffer suggests that the influence of TOD on housing price is weaker as the distance increases from the railway stations.

As for the model analyzing housing prices in relation to three TOD typologies, regression results suggest that TOD factors have no effect on housing price in the urban mixed core area. However, both urban residential area and suburban residential area show different relationships between TOD factors and housing price. More specifically, in the suburban residential area, user friendliness, economic development and parking supply positively influence housing price. However, passenger load negatively influences housing price. In the urban residential area, access to and from the station and walkability and cyclability show negative signs with housing price while economic development shows positive signs with housing price.

5.2. Recommendations

All in all, the study provides strong evidence that TOD positively influences the price of surrounding coupled houses, specifically, the better performance of TOD, the higher the housing price. The findings help the local governments address the residents concern about the negative housing price effect of TODs. Residents don't need to worry about the devaluation of the housing price. In the long run, the government should spare no effort to improve the TOD built environment and service quality of railway stations.

According to the findings of this thesis, some detailed actions and recommendations for the local government are summarized as follows:

- The local government should enlarge the TOD influence buffer by increasing the size of the buffer area that has good accessibility to the transit station, which not only helps to increase the housing price but also generate more potential ridership around the railway station.
- Build more parking facilities for cars and bicycles near the transit station to make sure enough spaces for passengers who ride or drive to the transit station. Besides that, the government could release shared bicycles in the parking area for the passengers to commute between a transit station and their homes. This action not only improves the accessibility to stations but also make full use of the parking facilities. As a result, coupled houses would be more welcomed and valuable by people for better accessibility.
- Make sure the construction of basic infrastructures as rich as possible around railway stations. The detailed actions, like encouraging manufacturers or entrepreneurs to build companies or personal studios near the transit station by giving subsidies or reducing tax every year. And the government could help to build public infrastructures like school or hospital within the TOD influence buffer. The objective is to increase the density of buildings, job opportunities and amenities within the TOD influence area, thus potentially allowing for a wider diversity of housing typologies and prices on offer.
- Strictly control passenger load at peak hours and off-peak hours by increasing trains' frequencies at peak hours and decreasing trains' frequencies at off-peak hours. Besides that, improving competitiveness among other transport modes, like BRT or LRT, also helps to share the traffic flow. These actions could reduce the effect of noise pollution on surroundings and evacuate the passenger flow at the railway station, and the housing price would turn to higher for the quieter and less crowded living environment.
- Since service quality of transit station is very important, some actions aim at improving service level need to be taken. For example, the transit stations should arrange one or two security guard, especially at night, to make sure the commuters safety. Besides that, every station should properly install information display system to help the passengers better know the exact train information. These actions aim at creating a better environment for people waiting for trains at railway station, which could be reflected in higher housing price for the conveniences.

5.3. Limitations and future research

The study tries to measure the impact of TOD on housing price of coupled houses using a series of models, controlling for the influences of other property value factors. This study has limitations:

First, the study only focuses on analyzing the impact of TOD on coupled houses, not other type of houses. According to previous studies, the impact of TOD on housing price varies for different house types. Hence, the results cannot represent the whole house situation in Arnhem-Nijmegen city region.

Second, the study area is not the whole Netherlands, but a city region. Each city of the Netherlands has its own characteristics and different TOD implementation strategies. Hence, the result cannot explain the general TOD influence on housing prices in the Netherlands.

Third, TOD factors in the thesis only refer to neighborhood factors and quality factors of transport service. Other types of factors used to describe TOD-ness are ignored, such as directions of each station, which is also very important for evaluating TOD.

Fourth, this study does not fully control the effects of other non-TOD factors like social economic data (e.g. average income of each family, crime rate of the neighborhood).

According to the limitations mentioned above, several suggestions are proposed for future studies. First, the analysis of other type of houses (not only coupled houses) would enrich the study content, but would also make the study more meaningful since residents are living in different types of houses. Second, exploring the impact of TOD on housing price on different (Dutch) cities would allow comparing the differences, which in turn would aid to developing policies and strategies by the local governments. Third, improving the evaluation of TOD influence by taking into account more TOD-related factors would potentially contribute to better model results. Moreover, including social and economic factors would also potentially lead to more realistic results.

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APPENDIX

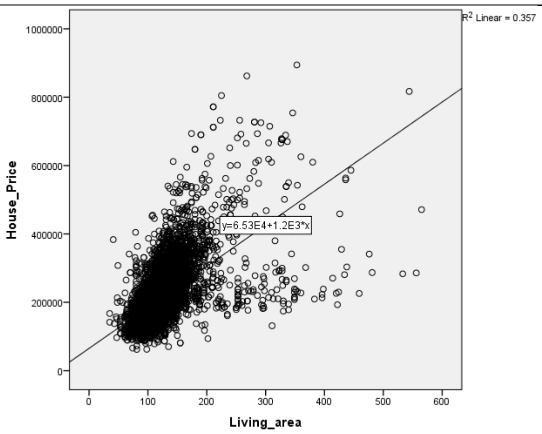
Appendix-A House Price Index in the Netherlands

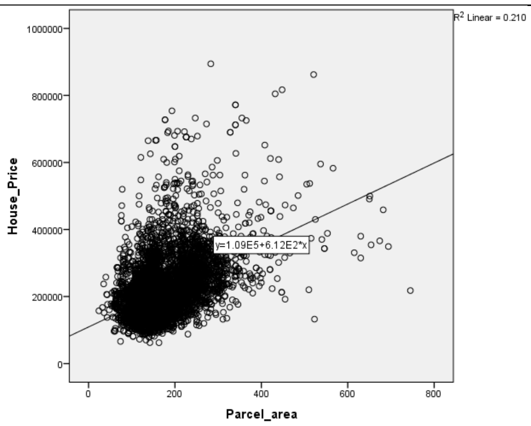
Subjects	Price index purchase prices					
	Price index of existing own homes					
Regions	Nederland	Groningen (PV)	Zuid-Holland (PV)	Noord-Brabant (PV)	Amsterdam	Rotterdam
Periods	*2010 = 100*					
1995	37.6	38.1	38.9	36.2	30.0	37.1
2000	71.1	62.3	69.7	69.9	68.7	67.0
2005	94.4	94.5	95.4	94.8	81.9	93.3
2011	97.6	96.9	98.3	96.8	99.7	99.3
2012	91.3	90.7	91.9	89.9	94.0	94.4
2013 1st quarter	86.5	87.9	87.2	84.6	88.3	89.3
2013 2nd quarter	84.7	85.5	85.7	83.1	89.8	87.4
2013 3rd quarter	85.1	85.5	86.1	83.0	89.5	90.2
2013 4th quarter	84.8	84.4	86.2	82.7	88.7	89.6
2013	85.3	85.8	86.3	83.4	89.1	89.1
2014 1st quarter	85.2	84.3	86.2	82.9	90.6	89.1
2014 2nd quarter	85.8	85.4	87.2	83.5	93.0	91.0
2014 3rd quarter	86.6	85.4	87.9	84.3	95.1	91.1
2014 4th quarter	86.6	85.5	88.1	84.1	96.0	90.9
2014	86.1	85.2	87.4	83.7	93.7	90.5
2015 1st quarter	87.3	86.6	88.5	84.6	99.6	92.6
2015 2nd quarter	87.9	87.6	89.3	85.2	100.5	94.0
2015 3rd quarter	89.1	87.7	90.6	86.1	104.5	95.7
2015 4th quarter	89.7	88.0	91.4	86.5	106.5	95.9
2015	88.5	87.5	90.0	85.6	102.8	94.5
2016 1st quarter	90.8	88.9	92.3	87.6	110.2	97.3
2016 2nd quarter	91.8	89.7	93.6	88.0	115.3	99.3
2016 3rd quarter	94.1	93.7	95.7	89.6	119.3	102.8
2016 4th quarter	95.1	94.0	97.0	90.5	121.9	105.7
2016	93.0	91.6	94.6	88.9	116.7	101.3
2017 1st quarter	97.0	94.4	99.1	91.9	127.5	108.4
2017 2nd quarter	98.9	95.4	101.1	93.6	130.8	112.6

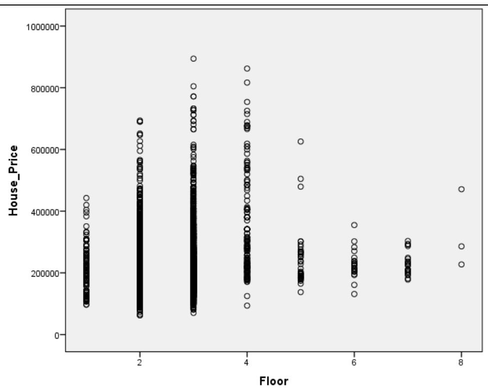
Statistics Netherlands, Kadaster 21-8-2017

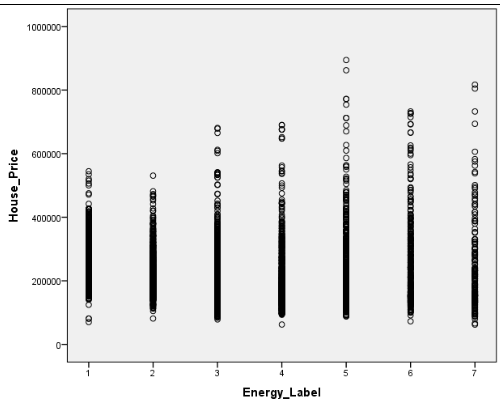
Appendix-B Scatter plot of structural factors and location factors

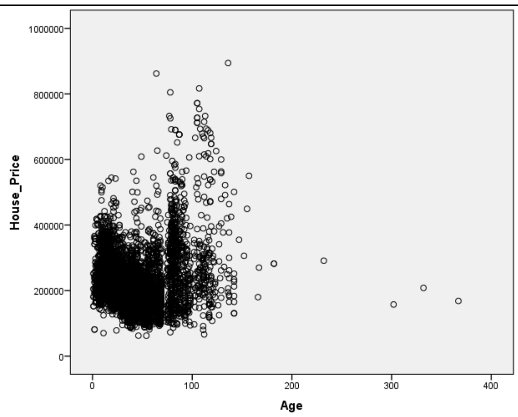
Structural factors



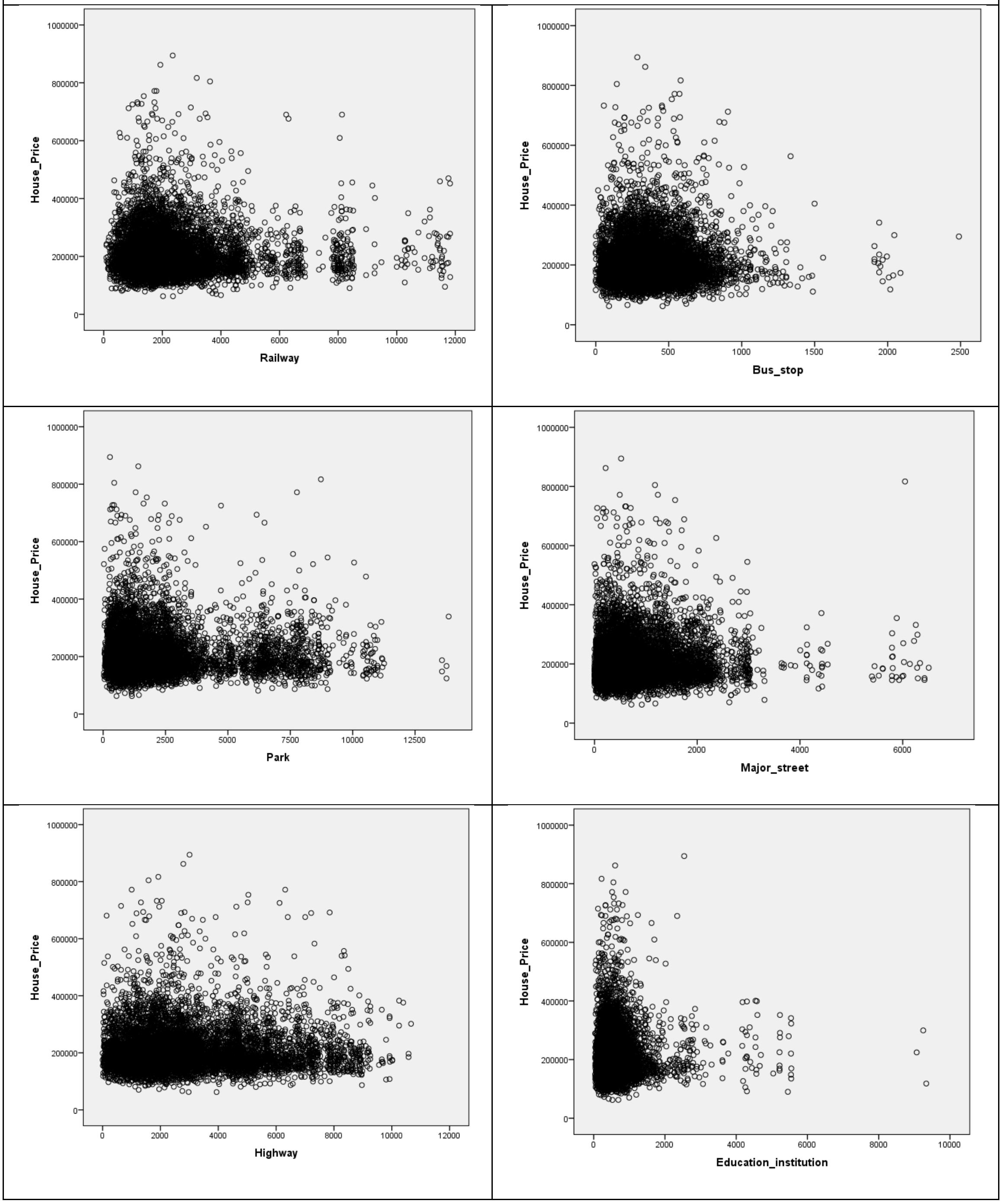


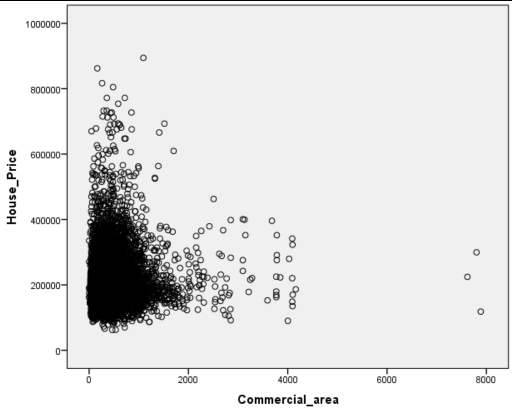






Location factors




House_Price
Commercial_area
1000000
800000
600000
400000
200000
0
0
2000
4000
6000
8000