MSc Economics – Public Policy

Master thesis

The Impact of Density on Residential Property Values: Evidence from Dutch ‘VINEX’ Locations

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Preface

I am pleased to present my master thesis ‘The Impact of Density on Residential Property Values: Evidence from Dutch ‘VINEX’ Locations’. This research is written as part of the masters’ degree program Economics – Public Policy at the Vrije Universiteit Amsterdam. I would briefly thank my supervisor Dr. Eric Koomen from the Vrije Universiteit’s Department of Spatial Economics for the extensive guidance and support during my thesis process. I would also like to thank Daan van Gent and Niels Hoefsloot for contributing to my research and offering me the opportunity to combine my master thesis with an internship at Decisio.

Abstract

The Netherlands is facing a major housing shortage, because of which the government aims at large-scale housing development in the coming years. This housing challenge underlines the importance of efficient spatial planning and has led to urban densification becoming central to urban planning. It is believed that compact urban structures are desirable, which is evidenced by the main response of the government by developing suburban VINEX locations across the Netherlands. We add to existing literature on costs and benefits of urban densification by investigating the impact of localised density on residential property values in VINEX locations. To do so, we have formulated the following research question: *'What is the impact of localized urban density on residential property values in VINEX locations?'*. To answer the research question, we apply a hedonic pricing model and employ multiple indicators of urban density, that relate to building density as well as residential density. Our results show that the impact of density on residential property prices in VINEX locations strongly depends on the density indicator being investigated: with respect to the building density indicators, we find positive price effects for the floor space index, building height and mixed-use index and a negative price effect for the open space index. With respect to the residential density indicators, we find a negative price effect for the number of residential units within a radius of 100 and 500 meters. Our results suggest that variation in residential environments is attractive, but as densification is multi-faceted and complex, advocating for certain residential environments based on our findings is too simplistic. It is therefore important to place the results in the broader context of densification and to see the results as an addition to existing literature in the Dutch context of how residents in new suburban development locations value localized density.

Key words: Hedonic price method, Density, Residential property values, VINEX locations

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1. Introduction

In the past century, urbanization has become an important development in global society. Attractivity of urban areas resulted in people moving from rural to urban areas (Henderson et al., 2021), enabling the existence of primate cities and wide-spread agglomerations (e.g., Tokyo, Shanghai, New York Metropolitan area, Greater London etc.). Urban areas are characterized with concentration of employment, man-made amenities, natural advantages, and agglomeration benefits, contributing to its attractiveness (Gaigné et al., 2022). In 1950, 30 percent of world's population lived in urban areas, while in 2014 this percentage was equal to 54 percent (Fesselmeyer et al., 2018). The expectation is that the urbanization process continues, ending up with a world's urban population equal to 68% in 2050 (United Nations, 2018).

In the Netherlands, urbanization also has been the trajectory for decades. Currently, most of the Dutch population lives in urban areas, resulting in a degree of urbanization exceeding 70 percent (Manders & Kool, 2015). The proportion of people living in urban areas will continue to grow as the Netherlands currently faces multiple demographic developments: (i) total population growth and (ii) household dilution (Manders & Kool, 2015; Central Agency for Statistics, 2022). Total population growth is reflected in rising life expectancy, natural domestic population growth and international migration (e.g., migrant workers, refugees, and international students). According to Central Agency for Statistics (2022), the Dutch population will increase from 17.8 million to 19 million by 2035, up to levels between 19 million and 22.4 million by 2070. The number of households will increase as well, from 8.1 million to 8.9 million in 2035 (Central Agency for Statistics, 2022). Indeed, forecasts are uncertain, but increasing trends prevail (Manders & Kool, 2015).

These demographic developments increase pressure on the housing market, as the demand for housing increases. More housing is needed, causing a mismatch between housing demand and housing supply. If the housing market does not clear on time, house prices will increase or stabilize at high price levels. This development is currently visible in the Netherlands, where house prices have risen extremely in the past ten years, and especially in the period 2018-2022 (Eijsink & van Dijk, 2023), creating a housing affordability crisis for many societal groups (e.g., single-households, low and-middle income groups, and young individuals). It is estimated that the shortage of housing in 2031 will be equal to 2.3% of the housing stock (Ministry of the Interior and Kingdom Relations, 2021). As housing is an important basic need, it has become clear that action must be taken, to balance the housing market. Consequently, the Dutch government has recently drawn up the 'National Housing- and Construction Agenda', describing present housing challenges, with its policy measures. One important measure is that the national government aims to have more control over housing construction and is committed to expanding the housing supply by building 900,000 new houses by 2030 by agreeing on housing deals (e.g., percentage of new owner-occupied and rental homes, percentage of new social housing, and agreements about the location and design of public space etc.) with provinces, municipalities and other involved institutions, and by accelerating housing construction processes and procedures (Ministry of Housing, and Spatial Planning, 2021).

The challenge does not only lie in achieving the objective of building 900,000 houses by 2030, but also in the way in which the stock expanding process must be fitted into existing spatial planning and where most of the new houses need to be built (Ministry of Housing, and Spatial Planning, 2021). Obviously, there is little discussion about the necessity of expanding the housing stock in urban areas, implying many construction projects must be clustered in a relatively small area (Hamers et al., 2023), especially in the Randstad area, containing the four biggest cities of the Netherlands: Amsterdam, Rotterdam, The Hague, and Utrecht. Demand for housing in urban areas highly exceeds demand for housing in rural areas, making it desirable to construct most houses at those locations. Dutch policy debate has mainly aimed at developing and creating ‘compact city’ structures, rather than unrestricted urban growth with lower densities, which increases pressure on undeveloped land near urban areas (Nabilek et al., 2012; Ministry of Housing, and Spatial Planning, 2021). The concept of the ‘compact city’ includes high-density development and mixing spatial functions in urban districts, focusing on efficient public transport systems. Such an urban structure is opposed to unrestricted urban growth, causing urban sprawl. Urban sprawl, which is associated with lower densities, is highly criticized: it increases the pressure on multiple landforms, including agricultural land, open space, and natural areas (Gaigné et al., 2012). This may be undesirable for a country like the Netherlands, where land is already regarded as a scarce commodity. Besides that, where dense urban structures strengthen spatial production externalities, including productivity and innovation (agglomeration economies), urban sprawl might attenuate this. Agglomeration economies arise when people and firms cluster in space. Examples are input/output sharing, knowledge spill overs and labour market pooling (Brueckner, 1999; van Duijn & Rouwendal, 2013). In addition, urban sprawl is associated with strong automobile dependence and longer commutes, contributing to more traffic congestion and air pollution.

That Dutch policy in recent decades has been aimed at developing compact city structures is evident from the development of suburban VINEX locations, scattered across the country adjacent to major cities (Lörzing et al., 2006). VINEX is an abbreviation for ‘Fourth Memorandum on Extra Spatial Planning’ (in Dutch: ‘**Vi**erde **N**ota Ruimtelijke ordening **Ex**tra’) and is a policy briefing note of the Dutch ministry of Housing, Spatial Planning, and the Environment at the time in 1991. In fact, VINEX locations have mainly been developed in the period 1995-2005, because of covenants between the Dutch government and provinces and municipalities, but current construction projects adjacent to previously developed areas are also seen as VINEX locations in daily use (Lörzing et al., 2006). The concept of VINEX was rolled out to meet the demographic developments the Netherlands was dealing with (e.g., population growth), as well as preventing skewed living by different groups. It includes the development of new houses and districts, close to existing city centres, because of which other land use types are protected, commuting of residents that is limited and existing shopping centres and amenities are strengthened (Ministry of Housing, Spatial Planning, and Environment, 1996). With the advent of VINEX locations, compact concentrations of houses and facilities arose. Despite the compact character of VINEX locations, there are considerable differences in the structure and design among the VINEX locations, originating from differences in residential and building density. In general, VINEX locations are characterized by a high proportion of low-rise buildings (e.g., semi-detached, detached, and terraced properties), but in various locations the proportion of low-rise buildings is much lower (e.g., more apartment type properties). In addition, there are locations that have a more non-urban character, with lower densities. These differences in structure imply differences in localized density (Lörzing et al., 2006).

As previously mentioned, developing compact structures comes with positive externalities, including abundance of amenities and existence of spatial agglomeration economies (Ostermeijer et al., 2022; PBL, 2015). On the other hand, compact structures increase exposure to negative externalities as well, including overcrowding, loss of greenery and open space, lack of privacy, pollution, and traffic congestion (Ahlfeldt & Pietrostefani, 2017). It is these positive and negative effects of density that households value differently, originating from preferences for certain neighbourhood and district characteristics, and it is assumed that these effects translate into house price capitalization (Hilber, 2017). Given that the Dutch government will continue to focus on developing new residential construction locations in the coming years, to offer a solution to the housing construction challenge the Netherlands is facing, empirical evidence on economics of density might be desirable. As previous literature on economics of density is context-specific, we aim to extent existing knowledge by investigating resident's preferences for localized density of the vicinity, building on the positive and negative effects of compact urban structures that might be capitalized into residential property values.

Specifically, in this paper, the research goal is to investigate the impact of urban density at the localized level on residential property values in VINEX locations. Multiple attempts have been made that aimed to explore the relation between urban density and residential property values (Fesselmeyer et al., 2018; Ahlfeldt & Pietrostefani, 2019; Kulish et al., 2011; Lee, 2016; Matthews & Turnbull, 2007; Bramley et al., 2010; Koster & Rouwendal, 2010) and are mainly based on complete city structures, rather than certain parts of urbanised areas. By focusing only on VINEX locations, it is possible to see how such suburban development locations are valued by residents, which may contribute to the discussion on costs and benefits of densification of future development locations. To investigate our research goal, we have formulated the following research question:

'What is the impact of localized urban density on residential property values in VINEX locations?'.

In addition, multiple sub-questions are central that help us answering the research question: the first sub-question describes what the characteristics of residential real estate are. The second sub-question describes what urban structures are in urban economic theory. The third sub-question describes what value-determining drivers of residential real estate are. The fourth sub-question describes how urban density is measured. Finally, the fifth sub-question describes empirical evidence on the relation between density and residential property values. In our study, we apply a hedonic pricing model and use multiple indicators of urban density, describing the morphological character of the neighbourhood and district. With our study, we attempt to contribute on existing research in multiple ways. First, the scope of our study differs from previous studies. Where most studies mainly focussed to one area, and mostly on one city or region, or a few neighbourhoods, we will focus on a unique Dutch housing development plan, namely suburban VINEX locations which are scattered throughout the Netherlands. This allows us to observe more variation in density and make it possible to see how such suburban development locations are valued by residents, which may be usable for future housing development programs. Secondly, we include an exhaustive set of control variables which emerges in academic work as important determinants of house prices, allowing us to observe more explanatory variables that are relevant in investigating the impact of urban density on residential property prices. Thirdly, to our knowledge, previous studies mostly included the number of residential units per unit area, and floor area ratio (FAR) as indicators of density. We involve a broader interpretation of the concept of density, by including multiple indicators that are related to building density as well as residential density.

This paper applies the following structure: Chapter 2 discusses the literature review, including characteristics of residential real estate, urban structures in economic theory, value-determining drivers of house prices, urban density indicators, and academic literature of the relation between density and residential property values. In Chapter 3, the study area is presented. Chapter 4 contains our methodology, followed by our main results in Chapter 5. Chapter 6 contains the robustness checks, followed by the discussion in Chapter 7 and the conclusion in Chapter 8. At the end of this paper, used references and the Appendix can be found.

2. Literature review

2.1 Characteristics of residential real estate

Real estate is a commodity, that distinguishes itself from other commodities, based on four main characteristics. Firstly, real estate is a durable commodity– meaning that buildings have a long lifespan (e.g., canal houses in the city centre of Amsterdam), allowing properties to be owned by different consumers over time (Rouwendal et al., 2021). Secondly, real estate is considered as very expensive and moving costs are high. Using a mortgage is often part of real estate financing. This does not apply to large real estate investors, but especially for private households, to smooth the share of consumption to housing. Thirdly, real estate is immobile – meaning it is impossible to move real estate over space. Indeed, there are some exceptions (e.g., boat houses in Amsterdam and mobile homes in the United States), but immobility generally prevails. Fourthly, and the most important characteristic that makes real estate distinguishable from other commodities, is heterogeneity, rather than homogeneity. Real estate is considered as a heterogenous commodity, consisting of multiple attributes. In the case of residential real estate, it is possible to distinguish four dimensions that contribute to real estate being considered as a heterogenous commodity: (i) physical characteristics, (ii) physical environmental characteristics, (iii) social environmental characteristics and (iv) functional environmental characteristics (Visser & van Dam, 2006).

Physical characteristics relate to the physical condition of the property, for example housing type (e.g., semi-detached, terraced, apartment etc.), number of rooms, number of floors, presence of garage, garden, central heating system, solar panels, and the design of the property. Physical environmental characteristics relate to the physical condition of the vicinity. Examples are the amount of open space and greenery (e.g., public parks) and the density of the environment (e.g., dwelling and building density). Social environmental characteristics relate to social-economic aspects, for example the unemployment rate in the vicinity, average income per resident and percentage of rental and owner-occupied houses. Finally, functional environmental characteristics relate to facilities in the vicinity. For instance, the presence of urban amenities (e.g., shopping malls, restaurants, bars, and universities), accessibility to public transport (e.g., accessibility to train station), infrastructure (e.g., accessibility to highways and traffic junctions) and the presence of a dense labour market (number of jobs).

Major differences in property characteristics mainly occur when comparing properties located in different cities and municipalities, rather than comparing properties in the same district or neighbourhood (Visser & van Dam, 2006).

2.2 Urban structures in economic theory

Much academic research that has been conducted in economics of density is based on the monocentric city model, developed by Alonso, Mills, and Muth (Brueckner, 1999). The model incorporates household behaviour, relying on standard microeconomic theory. The monocentric city model assumes a city or urban area where the population is fixed, with individuals with a certain income. These individuals live around the central business district (CBD). Each individual commutes from home to the CBD for work. The monocentric city model describes the urban structure around the employment centre, based on utility maximizing consumers: consumers derive utility (u) from consuming two different goods: housing services (h), and composite goods (q). The model assumes that every individual aims to maximize their utility (Equation (1)), subject to a budget constraint, as in Equation (2). This budget constraint includes the wage or income (y), price of housing (p), costs of transport per unit distance (t) and distance to the employment centre (x), referred as the CBD. Solving the model results in Equation (3), wherein $\partial p(x)$ is the house price function, and ∂x the change in distance to the CBD (Brueckner, 1999). The complete mathematical derivation of the model can be found in Appendix A.

$$u = u\ (q, h) \tag{1}$$

$$q + p\ (x)\ h = y - tx \tag{2}$$

$$\frac{\partial p(x)}{\partial x} = -\frac{t}{h} \tag{3}$$

Noteworthy, the ratio between transport costs and housing services consumption is always negative: one cannot have negative transport costs and housing services consumption. Equation (3) is known as Muth's condition and implies that a consumer can only find a situation in which the optimal residential location is chosen if the house price function is downward sloping in distance to the CBD. In other words, the price of housing and land rents becomes cheaper if the distance to the city centre increases. This condition can be rewritten as a 'marginal cost = marginal benefit' condition, and directly describes the trade-off consumers face in choosing the optimal residential location: high housing costs and low transport costs close to the CBD, or low housing costs and high transport costs far away from the CBD. If one considers a small change in the distance to the CBD, additional transport costs are equal to t, while saved housing costs are equal to $-\frac{\partial p(x)}{\partial x}$. Figure 1A shows the market equilibrium in the monocentric city model, with the house price function and the slope. As can be seen, the house price function is not only downward sloping in distance to the CBD, but the function becomes flatter as well. This stems from the fact that if one moves further away from the CBD, housing services consumption increases, yielding a flatter house price function.

Insights from the house price function have important implications for other urban characteristics, including the number of dwellings, dwelling size, building height, population distribution and urban density. As the price of housing is expensive close to the CBD, real estate planners have the incentive to increase the amount of capital per unit of land (e.g., multi-story buildings), increasing building heights, making high-rise buildings attractive from an economic point-of-view. Consequently, the number of dwellings is high, but the dwelling size is small. As the number of dwellings are higher close to the CBD, the highest share of the population is located closer to the CBD. Finally, as the distance to the CBD increases, urban density decreases (Kulish et al., 2011).

In market equilibrium, the slope of the price function is everywhere equal to $-\frac{t}{h}\,(x)$, and every consumer reach the same utility level, no matter where that consumer is located (Figure 1A). Muth, Alonso and Mill argue thereafter that the house price function can be considered a bid rent function. A bid rent function gives the maximum price a consumer can afford to pay for land at a particular location while reaching a particular utility level (McCann, 2013). It represents the marginal willingness to pay of a consumer for a specific location. Given that consumers reach the same utility level in equilibrium, and that consumers differ in preferences, steepness of bid rent curves differ across consumers. Consequently, consumer types outbid each other from areas of the city, creating patterns of concentric rings. This pattern can be seen in Figure 1B, where the bid rent function of retailers exceeds the one from manufactures and manufactures the one from residents (Kulish et al., 2011).

Figure 1A: Market equilibrium in monocentric city model (Kulish et al., 2011)

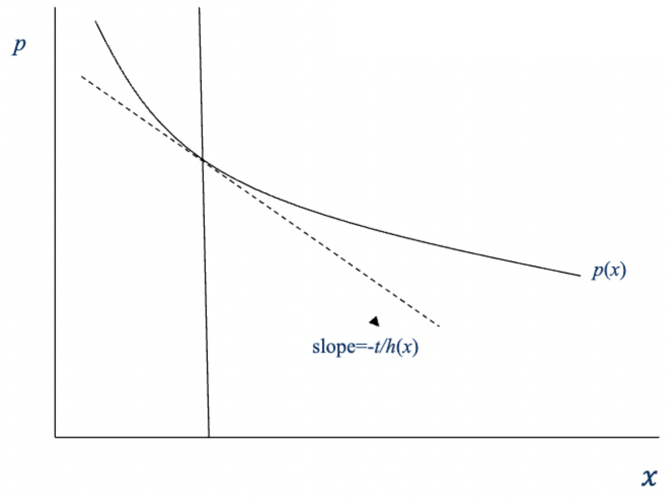
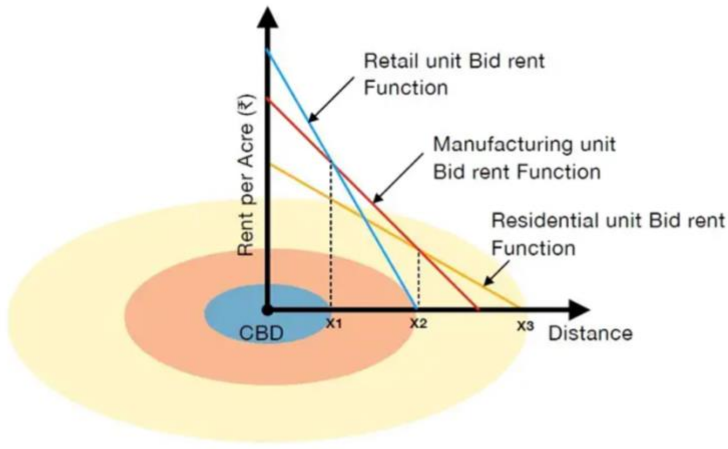


Figure 1B: Bid rent functions



2.3 Value-determining drivers of house prices

As residential real estate is a heterogenous commodity, multiple value-determining drivers of prices exist. Before continuing to which factors explain the price of housing, it is important to mention there is a difference between (i) the market value and (ii) the transaction price of a property. The market value is the expected selling price in the competitive market at a given reference day, while the transaction price is the realized price of market transaction, between a buyer and a seller. Generally, there is a direct link between the market value and the transaction price: a higher market value is associated with a higher transaction price and vice-versa. However, the transaction price is not always equal to the market value: it may exceed the market value, but it may be lower as well. The extent to which the transaction value deviates from the market value depends on the buyers' assessment, resulting from the preference and willingness to pay (WTP) for the attributes and property. Certain preferences and a high willingness to pay for certain housing attributes increase the transaction price (Koster & Rouwendal, 2020).

The market value and transaction price of residential real estate is determined by two important drivers: (i) property characteristics (Visser & van Dam, 2006) and (ii) market forces and conditions (Eijsink & van Dijk, 2023). Residential real estate is made up of property attributes and the plot where it stands on. Differences in characteristics among properties imply differences in residential property market values. Within the property characteristics, a distinction can be made between four categories, as already mentioned in Section 2.1: physical characteristics, physical environmental characteristics, social environmental characteristics, and physical environmental characteristics. In determining the market value, especially physical and functional environmental characteristics explain a major part of the market value. Specifically, physical characteristics seem to explain more than 50% of the market value (Visser & van Dam, 2006).

The other important driver explaining market values and transaction prices refer to market forces and conditions, including housing demand, housing supply, growth potential of housing supply, and price setting. Like other commodities, the residential real estate market is subject to classical economic interaction between housing demand and- supply: with increasing housing demand and a decreasing housing supply, real estate prices will generally increase. Reversed, with decreasing housing demand and an increasing housing supply, real estate prices will decrease (Ministry of the Interior and Kingdom Relations. (2021).

Real estate markets can be volatile, originating from periods of economic downturns ('crashes', e.g., the financial crisis starting in 2007) and periods of economic expansion (''bubbles', the period after the financial crisis). Periods of economic downturn are characterized by lower of negative absorption of real estate and slowing-down real estate construction, where in periods of economic expansion absorption becomes positive and real estate construction increases. As mentioned in Chapter 1, housing affordability is a major concern in the Netherlands, as residential real estate prices have been skyrocketing since mid-2013, and especially in last few years (Eijsink & van Dijk, 2023). Three important factors explain a major part of the rising prices in the past decade: (i) high level of private equity, (ii) declining mortgage interest rates, and (iii) lagging residential real estate construction (Eijsink & van Dijk, 2023). According to CBS (2023), private equity of the average Dutch resident has increased over the years, increasing financing resources. With the adjustments to the ECB-interest rates from the European Central Bank (ECB) after the financial crisis, mortgage interest rates gradually declined over time (European Central Bank, 2023). Consequently, consumers were able to borrow relatively cheaply and often agree with lenders on higher mortgages. Increasing private equity and declining mortgage interest rates lead to consumers being able to pay more for a property. These two factors drive up demand for housing and ultimately increase residential property prices (Eijsink & van Dijk, 2023). The moment new construction of real estate is low, housing supply does not adjust, and prices keep increasing. In the past year, mortgage interest rates have increased, increasing the financing costs for consumers, slowing down the price increase and caused even slightly falling property prices (van der Heijden et al., 2023). This slightly reduces market tightness, but housing affordability issues remain present. Generally, growth potential of housing supply has a dampening effect on market values, as housing supply adjust. Consequently, the housing market moves more towards equilibrium.

In general, price setting strategies are also considered to influence the transaction price. Obviously, the seller of the property has a preferred transaction price in mind that he or she wants to have for the property, to be satisfied. This preferred transaction price is referred to as the list price. According to Koster & Rouwendal (2021), with conventional bargaining, there is a positive relationship between the list price and the transaction price: increasing the list price with 1 percent is associated with about 1 percent increase in the transaction price, indicating that bargaining and price setting influence the transaction price.

2.4 Measuring urban density

Measuring urban density is quite complex, as it is a variable measure: there is no unambiguous definition of urban density, which emerges from the different possible density indicators as shown in Table 1. In the Netherlands, urban density is often defined as residential density (Harbers et al., 2022). In particular, the number of residential units per area unit, often an area with a radius of 100 meters. This indicator is relevant and interesting for the housing market, but it does not include commercial real estate (e.g., office buildings, retail stores, hotels, malls, warehouses, and garages). As commercial real estate is an important aspect of the spatial landscape, especially in urban areas, the number of residential units per unit area is a somewhat limited indicator of urban density (Harbers et al., 2022).

Other indicators that emerge in the literature and are used as an indicator of urban density are (i) floor space index (FSI), (ii) ground space index (GSI), (iii) open space index (OSI), (iv) average building height, represented as the number of building layers (L) and the mixed-use index (MXI). The

FSI is the ratio between the total floor area of the building and the size of the plot. The GSI is the ratio between the total floor area of the footprint of the building and the size of the plot. The OSI is equal to the value of 1 minus the GSI, divided by the FSI. The difference between the GSI and OSI lies in the spatiality: floors are also included in the open space index. The number of building layers, L, is the ratio between the ground floor space and the footprint of the building and comes down to the ratio between the FSI and the GSI. Finally, the mixed-use index describes the share of residential floor area relative to the gross total floor area and provides information about diversity of the environment (Harbers et al., 2022; Koster & Rouwendal, 2010; Fesselmeyer et al., 2018; Lee, 2016; Bramley et al., 2010).

All density indicators relate to the physical-spatial appearance of an area and can be used to describe the morphological and environmental structure. Figure 3 show equations 4-8, describing the density indicators, where Figure 2 show a visual representation of the FSI, GSI and OSI. As these indicators are considered to have certain similarities, Figure 2 show how different combinations of the FSI, GSI, OSR and L, yield different urban structures. As an example, both buildings in Figure 2 have a similar FSI value, equal to 1. However, the GSI, OSR and L are different, creating a difference in structure. The building on the left-hand side in Figure 2 takes up less space, but is taller, while the building on the right-hand side takes up more space but is less tall. These indicators are therefore a good representation of the spatial density of an area.

Table 1: Density indicators

Main indicator	Sub indicator		Reference
Residential density	(i)	Residential units per unit area	Harbers et al. (2022); Koster & Rouwendal (2010); Bramley et al. (2010)
Building density	(i)	floor space index (FSI)	Harbers et al. (2022); Lee (2016); Fesselmeyer et al. (2018)
	(ii)	ground space index (GSI)	Harbers et al. (2022); Lee (2016)
	(iii)	open space index (OSI)	Harbers et al. (2022); Irwin (2002)
	(iv)	average building height (L)	Harbers et al. (2022); Lee et al. (2016)
	(v)	mixed land use index (MXI)	Harbers et al. (2022); Koster & Rouwendal (2010)

Figure 2: Schematic representation of FSI, GSI, L and OSI (Tare, 2018)

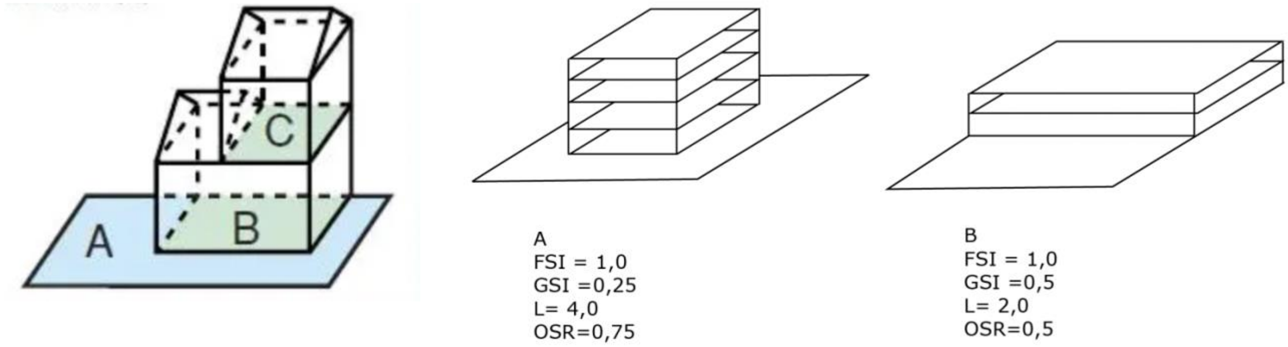


Figure 3: Formulas building density indicators

$$Floor\ space\ index = \frac{Total\ floor\ area\ of\ building}{Plot\ size} = \frac{(B+C)}{A} \tag{4}$$

$$Ground\ space\ index = \frac{Total\ floor\ area\ of\ footprint\ building}{Plot\ size} = \frac{B}{A} \tag{5}$$

$$Open\ space\ index = \frac{Undeveloped\ area}{Gross\ floor\ area} = \frac{1-GSI}{FSI} = \frac{A-B}{B+C} \tag{6}$$

$$Building\ height\ (building\ layers) = \frac{FSI}{GSI} = \frac{(B+C)}{B} \tag{7}$$

$$Mixed\ use\ index = \frac{Gross\ residential\ floor\ area}{Gross\ total\ floor\ area} \tag{8}$$

2.5 Empirical evidence on density and residential property values

Several studies have investigated the effect of urban density, based on multiple density indicators, on residential property values (Fesselmeyer et al., 2018; Kulish et al., 2011; Lee, 2016; Matthews & Turnbull, 2007; Bramley et al., 2010; Koster & Rouwendal., 2010). An important contribution is made by Fesselmeyer et al. (2018), who use data on private residential property transactions and a variety of property characteristics (property type, floor, area, etc.), to estimate the effect of project density on house price for private apartments in Singapore. Fesselmeyer et al. (2018) apply a hedonic price approach with instrumental variable regression, with plot ratio allowance as instrument, and showed that project density has a negative effect on house price: a 10% increase in project density is accompanied with a decrease in house prices of between 1.3% and 2.0%. By applying instrumental variable regression, the problem of endogeneity of the variable of interest is mitigated. Endogeneity is the situation when the explanatory variable is correlated with the error term, containing unobserved characteristics. The results of Fesselmeyer et al. (2018) are somewhat in contrast with economic theory (monocentric city model), describing that high densities are associated with high house prices. Important to note, Fesselmeyer et al. (2018) argue that the results are not immediately generalizable to other urban cities or areas, as preferences differ among residents.

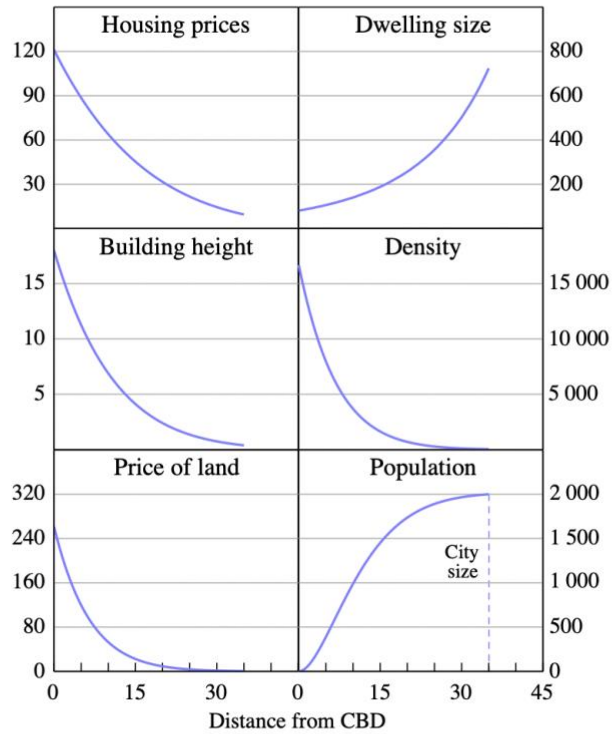
Another important research is performed by Kulish et al. (2011) who use a different approach, to identify the effect of density on house prices, including setting up a calibrated model, matched with features of large Australian cities. While the model omits many real-life characteristics, Kulish et al. (2011) find a positive relation between density and house prices. In addition, Kulish et al. (2011) incorporates other relevant urban characteristics, showing that dwelling size is increasing in distance to the CBD, while building height and price of land are decreasing in distance to the CBD. The results and important model parameters are shown in Figure 4.

Another study, performed by Lee (2016), investigates the effect of housing density on sales prices in Seoul, to identify whether there is a price premium for higher housing density. The main empirical strategy consists of hedonic price regressions, including data on density, location, market, and other control variables. Lee (2016) finds that the floor area ratio (FAR), building coverage ratio (BCR) and dwelling density have a negative effect on house prices. The negative found price effect of the floor area ratio from Lee (2016) does not correspond to Buitelaar et al. (2020), who showed that the willingness to pay for living in apartment type properties in the Netherlands increases over time.

A similar study was performed by Matthews & Turnbull (2007), but the main goal in this study was to investigate whether the physical layout and the street pattern of neighbourhoods in Seattle (USA) affect house prices. Using a hedonic price regression, Matthews & Turnbull (2007) find that grid-like street patterns have a positive price impact. The study by Bramley et al. (2010) focused on the relation between dwelling density and house prices in different city-regions in England, and find a negative relationship, implying preferences for less dense neighbourhoods.

Another important contribution was made by Koster & Rouwendal (2010), who investigate the impact of mixed land use on house prices. Using hedonic pricing models, with data on house transaction price, with related housing characteristics, Koster & Rouwendal (2010) show that some household types are willing to pay a price premium for a diversified environment, in terms of commercial, residential, and industrial land within the district or neighbourhood. The results indicate that a diversified district or neighbourhood is positive correlated with house prices, but also that there is substantial heterogeneity among residents. Apartment occupiers are willing to pay a lot more for a diversified area than households living in detached, semi-detached, and terraced properties.

Figure 4: Results from the calibrated model by Kulish et al. (2011)



Important model parameters:

- *Population size = 2 million*
- *50% of area suitable for housing*
- *Price of land at city fringe = price of land agriculture*
- *Commuting costs is 60% of wage rate*
- *Remainder spent on housing and other goods*
- *Cobb-Douglas preferences*
- *Land and capital input factors for housing*

Notes: bottom-right figure represents the cumulative city population. House price is measured in dollars per square meter, land price in thousands of dollars per hectare, dwelling size in square meters, building height in number of floors and density in individuals per square kilometre.

3. Study area

Our study area in this research contains a variety of VINEX locations, distributed across the Netherlands. Figure 5 show the distribution of the VINEX locations across the Netherlands. We have based our map upon spatial geodata from Ministry of Housing, Spatial Planning, and the Environment (2020) and PDOK ('Publieke Dienstverlening Op de Kaart'), including spatial data on the distribution of the VINEX locations, water bodies, and province borders. Using QGIS, we were able to visualize the distribution of the VINEX locations in the Netherlands.

As can be seen in Figure 5, VINEX locations are distributed across the country, with a district in almost every province. There is one exception, as the province of Zeeland does not contain any VINEX locations. Most districts are in the Randstad area, around the cities of Amsterdam, Rotterdam, The Hague, and Utrecht. In addition, many districts are located close to the 'Brabantse Stedenrij', the area in the middle of the province of Noord-Brabant, and adjacent to urban areas. There are relatively less VINEX locations located in the provinces of Groningen, Friesland, and Drenthe.

The spatial dimension concerns the Netherlands and is in our study of great importance. The VINEX locations are distributed across the Netherlands, indicating that many districts and neighbourhoods differ in terms of public transport facilities, accessibility and presence to amenities, distance to main ports (e.g., Amsterdam Airport Schiphol, harbour of Rotterdam), and nature areas.

Figure 5: Suburban VINEX locations in the Netherlands

Note: All VINEX locations shown in this image relate to suburban residential development

4. Methodology

4.1 Hedonic price method

Hedonic price functions assume a house can be regarded as a heterogenous good, consisting of various distinct attributes that contribute to the market value of the house (Goodman, 1998). The market value of the property p_i is determined by the sum of these individual attributes k_i: $p_i = p_i\ (k_i)$. Hedonic price functions often apply the following basis specification (Koster & Rouwendal, 2020):

$$p_i = \alpha_0 + \sum_{c=1}^{C} \alpha_i k_i + \epsilon_i \tag{7}$$

Wherein p_i is the transaction price of the property i, α_0 is a constant, k_i are property characteristics $(c = 1, \dots, C)$, with α_i the coefficients of the characteristics and ϵ_i are unobserved housing characteristics. Hedonic price models will result the marginal valuation for each attribute and provide insights into the implicit price of attributes, which are non-tradable (Fesselmeyer et al., 2018). It allows researchers to investigate impacts of untradable goods, for which there is no market present. Examples are the costs and benefits of air quality (Chay & Greenstone, 2005), open space (Irwin, 2002), aircraft noise pollution (Lijesen et al., 2006), historic amenities (Koster & Rouwendal, 2017) and the impacts of place-based policies (Ahlfeldt et al., 2017). The theoretical foundation of hedonic price analysis date back to work by Court in 1939, Griliches in 1961 and Rosen in 1974, who clarified the relation with standard micro-economic theory, including utility maximizing consumers. Hedonic price analysis is characterized as a revealed preference method, implying the estimates are based on actual (observed) behaviour. For such methods, many observations on property (transaction) prices, property characteristics as well as location characteristics are required.

4.2 Identification strategy

To identify the effect of multiple measures of urban density on house prices in VINEX locations, we use a standard hedonic price model, with multiple extensions. We apply a log-linear specification as functional form. This form is often applied, as house price data is often right skewed (Figure B1, Appendix B): most house prices are modest, while only a few houses being extraordinary cheap or expensive (Downes & Zabel, 2002). By applying a log-linear functional form, the issue of skewness is solved, mitigating outliers (Koster & Rouwendal, 2020). In our analysis, the main dependent variable is the logarithmic form of the house transaction price. Let the logarithm of house transaction price p of property i, in neighbourhood c, in district n, in year t be determined as:

$$log(p_{icnt}) = \alpha_0 + \sum_{c=1}^{C} \beta_i k_i + \gamma\ log\ (D_{ct}) + \theta_t + \zeta_{PC4,t} + \epsilon_{icnt} \tag{8}$$

Where α_0 is a constant, $\sum_{c=1}^{C} \beta_i k_i$ are observable property characteristics, D_{ct} is an indicator representing urban density, θ_t includes year or month fixed effects, depending on data availability of the density indicator, $\zeta_{PC4,t}$ is a locational fixed effect (postal code-4 fixed effect) and ϵ_{icnt} is an idiosyncratic error term. The parameter of interest in our study is γ, the effect of an urban density measure on property transaction price. Our main concern in estimating the hedonic specification of Equation (8) is the issue of endogeneity of the variable of interest (i.e., our variable representing urban density), indicating that the variable is correlated with unobserved characteristics, which are captured in the idiosyncratic error term. If we would ignore the fact that our variable of interest is endogenous, it would not be possible to identity the effect of urban density on house prices, without creating biased estimates, i.e., omitted variable bias (Bajari et al., 2012; Koster & Rouwendal, 2020; Goodman, 1998).

To deal with the issue of endogeneity of the variable of interest, we undertake multiple strategies in our analysis. The first strategy is to include an exhaustive set of controls, indicating we control for a set of variables. Including a set of controls that is relevant in determining house transaction prices allows us to reduce the omitted variable bias. Despite it being theoretically possible to have data on all relevant variables, we are unlikely to do so. Using many control variables increase the risk of multicollinearity (correlation among (independent) variables in the model), causing reliability and interpretation problems (omitted variables bias), making it to necessary to rule this out by checking pairwise Pearson-correlations (Koster & Rouwendal, 2020). For example, when there is multicollinearity among two control variables, the control variable considered to have more impact on property prices is left in the model, while the other control variable is left out. We also take the problem of multicollinearity among our density indicators into account, by including the density indicators pairwise or separately in our model. The second strategy that helps us in further reducing omitted variable bias is to include fixed effects (unit dummies) at a low level of spatial aggregation. First, we include time fixed effects (year dummies), which allows us to control for temporal variation in house prices, which are tied to a specific year of month (van Ruijven & Tijm, 2023). House price fluctuation arises from changes in macroeconomic conditions such as inflation rates, (mortgage) interest rates or changes in loan policies from financial institutes. We also include locational fixed effects, consisting of postal code-4 fixed effects (PC4 dummies). This allows us to control for unobserved spatial heterogeneity (crime rate, accessibility to amenities and jobs, ethnic composition, income distribution etc.) and the absolute location of a VINEX property within the Netherlands (Buitelaar et al., 2020; van Ruijven & Tijm, 2022). The latter is also important, as VINEX properties located in or close to important urban areas (i.e., Randstad area) are more expensive than VINEX properties located in more rural areas. A point of attention is the scale level of the location-related fixed effect in relation to the density indicator investigated. For example, if one is interested in variation of a certain density indicator on the neighbourhood level, it is important to choose the locational fixed effects at a coarser scale, for example at postal code-4 level. This makes it possible to correct for average price differences between PC4 areas but allows us to investigate what explains variation between the different neighbourhoods in that postal code area.

4.3 Data selection and descriptive statistics

Our research relies upon two data sets. We use the RUDIFUN dataset from the Netherlands Environmental Assessment Agency (PBL), containing density indicators for the years 2015 and 2021 for the Netherlands, including the floor space index, ground space index, open space index, number of building layers, and mixed-use index (Harbers et al., 2022). Density indicators are aggregated at the district and neighbourhood level. This means that for multiple building density indicators we know the average density value of the neighbourhood and district. Figure 6A and Figure 6B show examples of variation in density among neighbourhoods and districts. Our research includes 363 VINEX neighbourhoods and 165 VINEX districts. In addition, the density measures are available on the gross and net level. The gross level includes other land use types, which are not included in the net level. Examples are public spaces, and local infrastructure, including roads, bike, and walking lanes (PBL, 2022). As resident's valuation for a specific property is strongly impacted by the quality and design of the adjacent environment (Koster & van Ommeren, 2019), we believe that using data on the neighbourhood and district level is appropriate for our analysis. In addition, we also use the data at the gross level, as other land types are relevant in determining the overall density of a neighbourhood or district. Secondly, we use data from the Dutch Association of Real Estate Agents (NVM). This association manages around 75% of all housing transactions in the Netherlands, allowing it to be a reliable sample of all transactions. For 105,869 observations in the period 2010-2021, we know the house transaction price, exact location (e.g., postal code area, neighbourhood, district) and a variety of property characteristics, including property type, construction period, size, maintenance, number of rooms, access to private parking, isolation etc. Based on a selection, the dataset only contains properties at VINEX locations. In addition, Jip Claassens from the Vrije Universiteit Department of Spatial Economics, provided additional data on multiple spatial characteristics, including distance to the nearest train station, airport, and main highway. We have merged all datasets, giving us one dataset, with for every observation, the house transaction price, in combination with property, spatial and density characteristics. Figure 7A and Figure 7B report examples of the fitted values between the house transaction price per square meter and the density indicators floor space index and building layers. Descriptive statistics of our dataset, including the mean, standard deviation (Std. Dev.), minimum (Min) and maximum (Max) value can be found in Table 2. In our dataset, we omit house transaction prices and price per square meters that are respectively lower than €20,000, and higher than €1,100,000, and lower than €550 and higher than €5,500. Finally, house sizes lower than 30 square meters, and higher than 5,500 square meters are omitted as well.

Figure 6A: Variation in neighbourhoods' average floor space index in VINEX locations in Almere

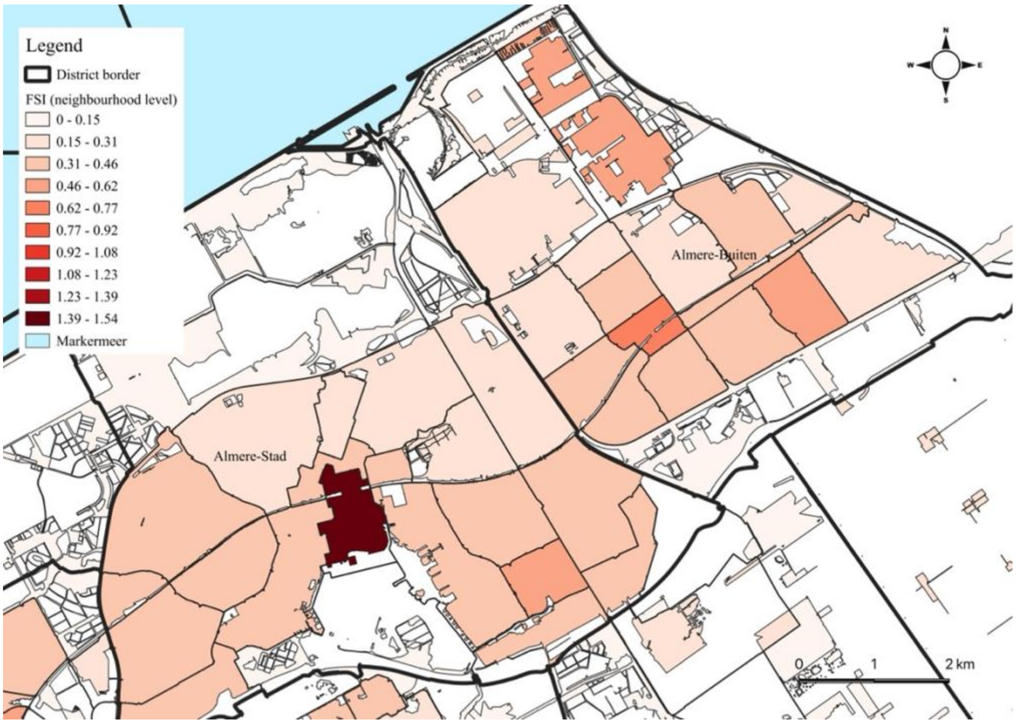


Figure 6B: Variation in neighbourhoods' average building layers in VINEX locations in Almere

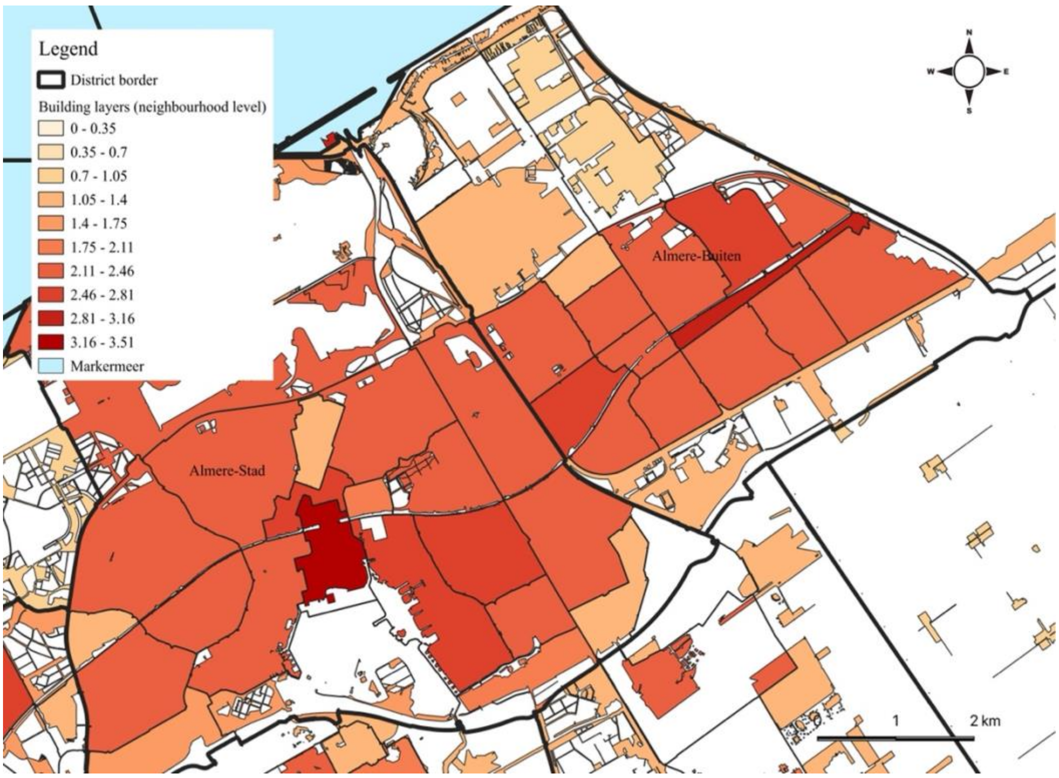


Figure 7A: Relation (fitted values) between transaction price per square meter (€) and floor space index

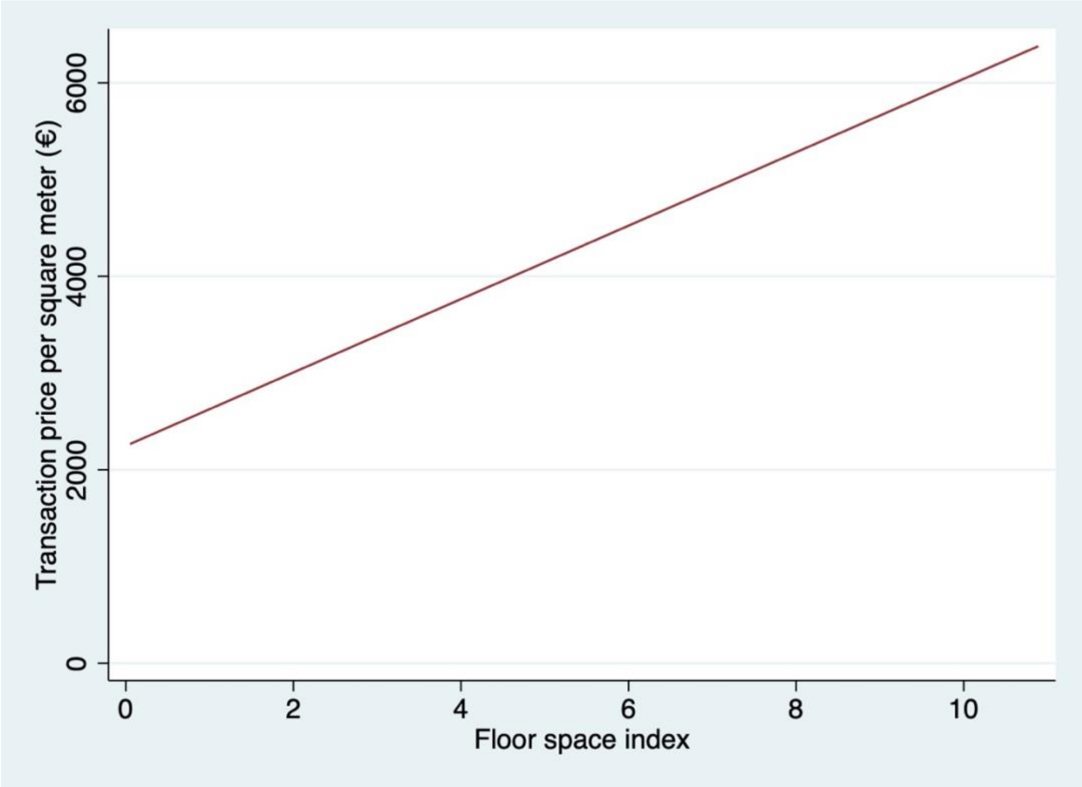


Figure 7B: Relation (fitted values) between transaction price per square meter (€) and building layers.

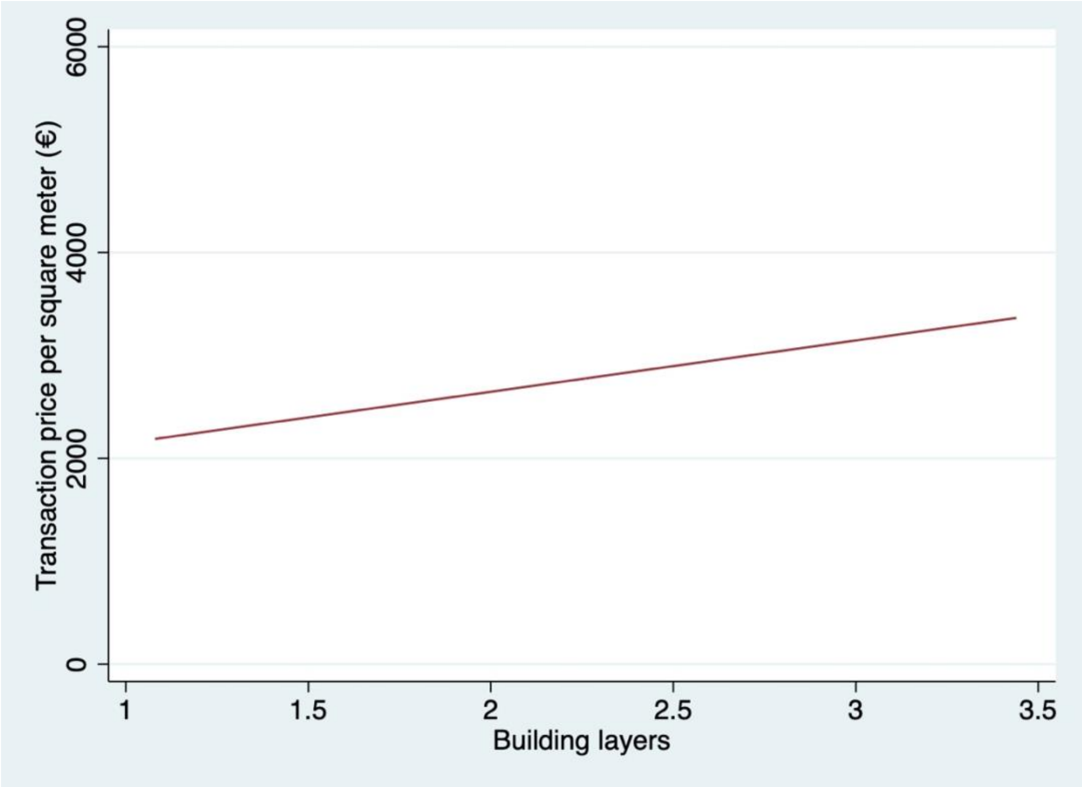


Table 2: Descriptive Statistics: 105,869 observations in the period 2010-2021

Variable		Mean	Std. Dev.	Min	Max
Transaction price (€)		332,718.11	139,089.89	73,500	1,100,000
Transaction price per square meter (€/m²)		2,523.19	749.63	628.14	5,500
Structural characteristics					
Size of property (m²)		132.21	36.77	31	300
Construction year 1995-2004		0.43	0.50	0	1
Construction year 2005-2014		0.30	0.46	0	1
Construction year 2015-2021		0.03	0.18	0	1
Property type: apartment		0.19	0.39	0	1
Property type: semi-detached		0.16	0.36	0	1
Property type: detached		0.07	0.25	0	1
Property type: terraced		0.59	0.49	0	1
Number of rooms		4.64	1.26	1	24
Number of bathrooms		1.05	0.22	1	4
Maintenance state is good		0.98	0.15	0	1
Property has central heating		0.83	0.38	0	1
Complete isolation present		0.72	0.45	0	1
Private parking present		0.27	0.44	0	1
Private garden is present		0.67	0.47	0	1
Spatial characteristics					
Distance to airport (km)		32.37	24.50	1	112.44
Distance to highway entry/exit (km)		1.37	0.93	1	6.05
Distance to train station (km)		2.3	1.75	1	13.15
Residential units in r = 100 meters		126.15	67.29	0	518
Residential units in r = 500 meters		1,458.77	587.26	1	3,978
Floor space index	Neighbourhood	0.64	0.29	0.03	1.15
	District	1.40	1.50	0.05	10.89
Open space index	Neighbourhood	2.33	1.45	0.56	10.89
	District	2.68	1.39	0.88	10.89
Building layers	Neighbourhood	2.42	0.37	1.08	4.18
	District	2.27	0.38	1.08	3.44
Ground space index	Neighbourhood	0.17	0.05	0.01	0.43
	District	0.15	0.04	0.02	0.34
Mixed use index	Neighbourhood	0.90	0.12	0	1

4.4 Hypothesis

To answer the research question, we provide a hypothesis (Table 3) between each density indicator and the house price, based on the described literature in Section 2.5.

Table 3: Hypothesis on relation between various density indicator and house price

Density indicator	*Hypothesis*
Floor space index	Negative relation
Average building height	Negative relation
Ground space index	Negative relation
Open space index	Positive relation
Mixed use index	Positive relation
Residential units per unit area	Negative relation

5. Results

5.1 Effect of building density on property transaction price

The results of the price effects of various building density measures are reported in this section. Table 5 includes the floor space index and building height, measured in the number of layers, as variables of interest. Table 6 includes the ground space index, open space index, and mixed used index as variables of interest. In all specifications, the dependent variable is the logarithm of house transaction price, and density measures are aggregated at the neighbourhood level. In multiple specifications, we apply the logarithm form of the independent variable, which allows us to interpret the results as elasticities. Noteworthy, we could interpret the effect of variable 'X' on variable 'Y' by holding other variables in the analysis constant. To avoid repetition, we will describe this once. Besides structural and spatial control variables, all specifications include postal code-4 fixed effects, as well as year and/or month fixed effects.

Our model explains between 84% and 90% of the observed variation in property prices. The price effect of the floor space index in specification (1) is positive and is statistically significant at the 99%- significance level. An increase in the average neighbourhoods' floor space index of 1%, results in a 0.0142% increase in house price. To put in perspective, the price of an imaginary house in the neighbourhood 'Oostvaardersbuurt', located in the district 'Almere-Buiten', is equal to €450.000. Table 4 reports the density values of multiple indicators. The average floor space index of the 'Oostvaardersbuurt' is equal to 0.31.

Table 4: Density values of the neighbourhood 'Oostvaardersbuurt'

Density indicator	Value
Floor space index	0.31
Building layers	2.56
Ground space index	0.12
Open space index	2.84
Mixed use index	0.79

An increase in the neighbourhoods' floor space index of 1%, causing the average floor space index to increase to 0.3131, increase the house price with €64. Specification (2) includes the price effect of the building height, which is positive but is not statistically significant. Specification (3) and (6) include the price impact of the ground space index and is also insignificant in both specifications. The open space index and mixed-use index are statistically significant at the 99%- significance level. In specification (4), we observe a negative price effect of the open space index. The average neighbourhoods' open space index is equal to 2.84. A 1% increase in the open space index, causing the index to increase to approximately 2.87, results in approximately a 0.0131% decrease in house price. This is equal to a decrease of around €59 if we assume a house price of €450.000. In specification (5), we observe a positive price effect of the mixed used index: an increase in the neighbourhoods' mixed-use index of 1% results in approximately a 0.0317% increase in house price. To put in perspective, the mixed-use index of the neighbourhoods 'Oostvaardersbuurt' is equal to 0.79. A 1% increase in the index, to 0.798, increase the house price with €143. In specification (6) and (7), the price effect of the mixed-use index becomes a little stronger in magnitude: an increase in the mixed-use index of 1% results in an increase in house price of 0.11%. This would raise a house price of €450.000 with around €500.

In addition, the structural and spatial characteristics have plausible values and are generally statistically significant. To avoid repetition and to focus on the most important results, we only describe the results of the structural and spatial variables of specification (1) and (2). The size of the house has a positive impact on house prices: an 1% increase in house size results in an approximately 0.7% higher house price. Besides house size, the maintenance state of the house, presence of a private parking place, and complete isolation is valued positive. A well-maintained property raises the house price with almost 10%. The availability of a private parking increases the house price with 6.9%. A private garden is valued positive but is insignificant in multiple specifications. An additional bathroom raises the house price with almost 3%. Detached houses are valued the highest. Detached houses are on average approximately 30% more expensive than apartments, 27.5% more than terraced houses, and 13% more expensive than semi-detached houses. With respect to the construction year of the property, fewer aging houses are valued positive. The construction period '1995-2004' act as a reference. A house constructed in the period 2005-2014 is around 2.5% more expensive than one constructed in the period 1995-2004. For a house constructed in the period 2015-2021, this amounts to around a 6% higher house price. The spatial characteristics are valued differently. Proximity to train stations and main highways are valued negatively, while proximity to airports is valued positively. An increase of one kilometre in proximity to a train station and main highway amounts to respectively around 1%-2%, and 2.2% higher house prices. The price effect of distance to airports is smaller: an additional kilometre results in around 0.8% lower house prices.

Table 5: Floor space index and building height. Note: FSI and building height are aggregated at the neighbourhood level

Dependent variable: *Property transaction price (log)*	(1)	(2)
Floor space index (log)	0.0142***	
	(0.00269)	
Building height (layers)		0.00523
		(0.00480)
Size (log)	0.684***	0.684***
	(0.00688)	(0.00690)
Number of rooms	0.0128***	0.0129***
	(0.00130)	(0.00130)
Maintenance state is good	0.0979***	0.0978***
	(0.00640)	(0.00640)
Private parking present	0.0690***	0.0692***
	(0.00299)	(0.00299)
Private garden is present	0.00336	0.00370
	(0.00277)	(0.00278)
Complete isolation present	0.0100***	0.0102***
	(0.00236)	(0.00236)
Number of bathrooms	0.0291***	0.0294***
	(0.00532)	(0.00533)
Property type: apartment	-0.307***	-0.307***
	(0.00730)	(0.00735)
Property type: terraced	-0.275***	-0.275***
	(0.00553)	(0.00553)
Property type: semi-detached	-0.135***	-0.135***
	(0.00524)	(0.00523)
Construction year 2005-2014	0.0260***	0.0272***
	(0.00257)	(0.00256)
Construction year 2015-2021	0.0628***	0.0641***
	(0.00512)	(0.00511)
Distance to train station (km)	0.0166***	0.0134***
	(0.00347)	(0.00343)
Distance to highway entry/exit (km)	0.0233***	0.0217***
	(0.00325)	(0.00323)
Distance to airport (km)	-0.00870***	-0.00878***
	(0.00224)	(0.00224)
Constant	9.267***	9.259***
	(0.0374)	(0.0390)
Postal code-3 fixed effects	No	No
Postal code-4 fixed effects	Yes	Yes
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,719	19,719
R^2	0.907	0.907

Notes: Property type 'Detached' and construction year '1995-2004' act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Ground space index, open space index and mixed-use index. Note: GSI, OSI, and MXI are aggregated at the neighbourhood level.

Dependent variable: *Property transaction price (log)*	(3)	(4)	(5)	(6)	(7)
Ground space index (log)	0.00345			0.00226	
	(0.00418)			(0.00416)	
Open space index (log)		-0.0131***			-0.0110***
		(0.00419)			(0.00417)
Mixed use index (log)			0.0317***	0.109***	0.107***
			(0.00686)	(0.0195)	(0.0194)
Structural characteristics	Yes	Yes	Yes	Yes	Yes
Spatial characteristics	Yes	Yes	Yes	Yes	Yes
Postal code-3 fixed effects	No	No	No	No	No
Postal code-4 fixed effects	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	No	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes
Observations	8,987	8,987	19,703	8,987	8,987
R^2	0.846	0.846	0.907	0.847	0.847

Note: standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.2 Effect of residential density on property transaction price

This section reports the estimate of the residential density indicator. Specifically, we include the number of residential units within a radius of 100 meters as main independent variable (Table 7). In specification (1), the dependent variable is the logarithm of property transaction price and in specification (2) the logarithm of property transaction price per square meter. Both specifications include structural and spatial characteristics. In addition, we include postal code-4 fixed effects, as well as year fixed effects. The model explains 85% of more of the variation in house price.

The number of residential units within a radius of 100 meters is statistically significant at the 99%-level and has a negative price effect. To put in perspective, an additional residential unit within a radius of 100 meters decrease the house price with 0.0248%. This is equivalent to a price decrease of 0.248% for 10 additional residential units. With respect to our main dependent variable, there is no difference among the two specifications.

Table 7: Residential units in r = 100 meters. Note: MXI is aggregated at the neighbourhood level.

Dependent variable:	*Property transaction price (log)*	*Property transaction price per square meter (log)*
	(1)	(2)
Residential units in r = 100 meters	-0.000248***	-0.000248***
	(0.0000178)	(0.0000178)
Mixed use index (log)	0.0442***	0.0442***
	(0.00708)	(0.00708)
Structural characteristics	Yes	Yes
Spatial characteristics	Yes	Yes
Postal code-3 fixed effects	No	No
Postal code-4 fixed effects	Yes	Yes
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,703	19,703
R^2	0.908	0.849

Note: standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6. Robustness checks

6.1 Effect of building density at the district level

In Section 5.1, we aggregate all building density indicators at the neighbourhood level. In this section, we include building density indicators at a different level of spatial aggregation. One may argue that appreciation for a certain property also depends on other spatial scales than at the neighbourhood level, whereby the price effect of density may depend on chosen spatial aggregation level. To include this aspect in our research, we aggregate the building density indicators at the district level and investigate whether our main results of Section 5.1 are also robust at a higher level of spatial aggregation. Aggregation at the district level imply that for each building density indicator, we assign the average density value of the district to a property that is in the concern district. We opt for aggregation at the district level for two reasons: firstly, we believe that aggregation at a smaller level of spatial aggregation (i.e., building block level) gives a limited picture of the valuation of the surroundings of a VINEX location, as it focuses more on the appreciation for the vicinity based on only a few houses adjacent to a specific property. Secondly, spatial aggregation at a coarse scale (i.e., municipality level) may lead to a biased result, as it is likely that properties that are not located in a VINEX location are also included. To do so, we estimate again specification (8) as in Section 4.2. Herein, the building density indicators are aggregated at the district level, and we include postal code-3 fixed effects, rather than postal code-4 fixed effects. We still include structural and spatial characteristics. However, we do not report them to prevent repetition.

The price effects of the district' average floor space index, average building height, measured in number of layers, ground space index and open space index are reported in Table 8. Our model explains more than 84% of the variation in house price and the structural and spatial characteristics are again included. Specification (1) includes the estimate of the floor space index and specification (2) of the average building height. Again, the floor space index and building height are valued positive. Both variables are significant at the 99%- significance level. An increase in the average district's floor space index of 1% results in an increase in the house price of 0.0146%. In terms of economic significance, this roughly yields the same price effects as in Section 5.1. An increase of one layer of the average building layer in the district increase the house prices with 3.0%. To put in perspective, the average number of layers in 'Almere-Buiten' is equal to 1.78. An increase in the average number of building layers of the district of one, raise the house price with €13,500, based on a house price of €450,000. Specification (3) includes the average district's ground space index, which is insignificant. Specification (4) includes the district's open space index. The estimate is statistically significant at the 99% significance level. An increase in the average districts' open space index of 1%, decrease the house price with 0.103%.

Table 8: FSI, building height, GSI and OSI Note: indicators are aggregated at the district level.

Dependent variable: Property transaction price (log)	(1)	(2)	(3)	(4)
FSI (log)	0.0146***			
	(0.00287)			
Building height (layers)		0.0302***		
		(0.00730)		
Ground space index (log)			0.00491	
			(0.00543)	
Open space index (log)				-0.103***
				(0.00639)
Structural characteristics	Yes	Yes	Yes	Yes
Spatial characteristics	Yes	Yes	Yes	Yes
Postal code-3 fixed effects	Yes	Yes	Yes	Yes
Postal code-4 fixed effects	No	No	No	No
Month fixed effects	No	No	Yes	Yes
Year fixed effects	Yes	Yes	No	No
Observations	19,719	19,719	8,987	8,987
R^2	0.902	0.901	0.838	0.838

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.2 Effect of residential density at higher spatial scale

In Section 5.2, we use the number of residential units within an area with a radius of 100 meters as an indicator of residential density. We subject the price effect of this indicator to an indicator at a higher scale level, to investigate whether our main results of Section 5.2 are robust. Specifically, we include the number of residential units within an area with a radius of 500 meters as main dependent variable.

Residential units within an area with a radius of 500 meters is statistically significant at the 99%- level and has a negative price effect. As shown in Table 9, the density-coefficient is equal to -0.0000131. On average, an additional residential unit within a circle with a radius of 500 meters results in a price decrease of 0.00131%. This is equivalent to a price decrease of 1.31% for 1000 additional units.

Table 9: Residential units in r = 500 meters. Note: MXI is aggregated at the neighbourhood level.

Dependent variable: *Property transaction price (log)*	Property transaction price (log) (1)	Property transaction price per square meter (log) (2)
Residential units in r = 500 meters	-0.0000131^{***}	-0.0000131^{***}
	(0.00000260)	(0.00000260)
Mixed use index (log)	0.0387^{***}	0.0387^{***}
	(0.00710)	(0.00710)
Structural characteristics	Yes	Yes
Spatial characteristics	Yes	Yes
Postal code-3 fixed effects	No	No
Postal code-4 fixed effects	Yes	Yes
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,703	19,703
R^2	0.907	0.848

Notes: Property type 'Detached' and construction year 1995-2004 act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

7. Discussion

7.1 Limitations methodology

To investigate the impact of urban density on residential property values in VINEX locations, we estimate the effect of multiple density indicators through the application of a hedonic price method. Hedonic price methods are widely used in the context of house price analysis. However, a limitation of a hedonic price method, and consequently a limitation of our research, is that it does not consider the fact that residents differ in their willingness to pay for certain housing characteristics, and thus estimates the average willingness to pay for a certain characteristic. To allow for more preference heterogeneity in our analysis, we apply a log-linear functional form. This function ensures that the marginal willingness to pay for a certain attribute is heterogeneous and depends on the house price, implying that the willingness to pay is higher for individuals living in more expensive houses. As this seems likely, we cannot be sure this relationship is present.

In our analysis, we use multiple building density indicators as variable of interest. To do so, we aggregate the building density indicators at the neighbourhood and district level, allowing us to investigate resident's preferences for the morphology and structure of the vicinity. A possible drawback of this aggregation method is that some properties are located on the edge of a neighbourhood or district, indicating that the average density value assigned to such a property is less representative, compared to a property located in the middle of the neighbourhood or district. A property may be located on the edge of a neighbourhood or district that is characterized by a relatively low density, but adjacent to a neighbourhood or district that is characterized by a higher density, so that the appreciation of density can give a distorted picture than it is. However, VINEX locations are not characterized with discrete jumps in densities at the borders, so that it will have a limited impact on the validity of our analysis.

7.2 Localized urban density and house prices

To investigate the impact of urban density on residential property values in VINEX locations, we employ several indicators at the neighbourhood and district level. Our results show relatively small impacts on house prices, which corresponds Visser & van Dam (2006), who argue that such density indicators are modest determinants of house prices. Both the main results (Chapter 5) and the robustness check (Chapter 6) show that urban density, in terms of floor space index and building height (number of building layers), have a positive price effect, except for the neighbourhoods' number of building layers, as this indicator is insignificant. We believe the results of both indicators logically fit together as both are a measure of a building's space efficiency. With respect to the floor space index and number of building layers, our results are not in line with Lee (2016), who argue that the density, in terms of floor area ratio, has a negative impact on house prices. The estimates of Lee (2016) are based on a case study performed on property data from the city of Seoul, South Korea. A possible explanation for this difference in price effect could be explained by the fact that the average floor space index and building height in Seoul is high, so that the negative externalities of taller building structures (i.e., crowding effects, blocked view, shadow, and wind-tunnel effect etc.) outweigh the positive externalities (shorter commuting and agglomeration economies etc.) for surrounding houses. Unlike in Seoul, the average floor space index and building height in VINEX locations is low, so that a change in the floor space index and building height (e.g., a few additional floors) will not be valued negatively and therefore do not lead to such negative price effects. However, a positive price effect of the floor space index and building height is in line with Buitelaar et. al (2020), who found that the price premium for apartment types in the Netherlands is increasing over time, because of household dilution which is considered an important societal development. The results show that heterogeneity in preferences among residents is important and may explain the found price effects.

We also find a negative price effect for the open space index, both at the neighbourhood level as well as district level. With respect to the magnitude of the estimate, it seems that the open space index of the district is more important for residents. The result of the open space index is not in accordance with what we would initially expect. When looking at the effect of open space (i.e., public parks or other greenery) on house prices, this generally yields a positive price effect. In multiple spatial contexts, access to open space in the neighbourhood or district is valued positive, and consequently capitalized into house prices (Irwin, 2002). The open space index indicator included in our study concerns the ratio between the surface of the undeveloped land and the gross floor area, in which the latter includes all floors of the building: it also includes spatiality. The negative price effect for the open space index that we find indicates that additional unbuilt area is valued negatively and decrease house prices. As the open space index also includes spatiality, the negative price effect also supports preferences for substantial higher buildings and is therefore also in line with the positive appreciation of the floor space index and number of buildings layers. A possible explanation for the negative price effect of the open space index may be that our research relates to VINEX locations that are mainly located on the edges of existing urban areas (suburban residential locations), because of which houses in these locations are already relatively close to open areas, compared to houses located in the inner part of cities. A relatively large abundance of open space in the vicinity of the neighbourhood or district may trigger a 'saturation effect' for open space.

With respect to the mixed-use index, we find a positive price effect at the neighbourhood level. It is important to indicate that the mixed-use index represents the ratio between gross floor area for residential use and total gross floor area, so that a higher index value equates to lower mixed land uses. The results of the mixed-use index suggest that VINEX residents have on average certain preferences for districts and neighbourhoods, characterized with a more homogenous function. This is striking and does not support our hypothesis, as it is generally assumed that mixed functions in a district or neighbourhood have a positive impact on house prices, as described by Koster & Rouwendal (2010). However, Koster & Rouwendal (2010) also emphasizes the importance of land uses that are compatible with residential use and shows that the presence of manufacturing, government and the wholesale sector are negatively related to house prices, while leisure, retail, education, and healthcare are valued positively. In addition, only for apartment occupiers, diversified neighbourhood and districts are significantly different from zero, suggesting only apartment occupiers are willing to pay for an increase in diversity and prefer to live in more mixed-use areas. The findings of Koster & Rouwendal (2010) may be an explanation for our found negative relation between the open space index and house price: a possible explanation may be that the VINEX locations concerned in our study contain a relatively large share of land types that are not or less compatible with residential use and are valued negatively by its residents. In addition, the share of terraced and (semi)-detached properties in the VINEX locations is high – 81 percent, compared to the share of apartments – 19 percent. This indicates that a relatively small proportion of residents are willing to pay a price premium for diversified neighbourhoods and districts, characterized by all land uses. Our estimates, with respect to the mixed-use index, are also supported by the Netherlands Environmental Assessment Agency (2010), who investigated the relation between economic activities and livability in neighbourhoods and district and found that livability is an important source of attraction for starting and existing firms. Small-scale activities have a positive effect on livability in the neighbourhood, as it increases social cohesion among residents. However, The Netherlands Environmental Assessment Agency (2010) also argue that new big firms in a neighbourhood or district led to an increase in livability problems, by increasing nuisance, insecurity, vacancy, and other related problems.

With respect to residential density indicators, we find a negative relation between property price and the number of residential units within a radius of 100 meters: an additional residential unit within a radius of 100 meters decrease the house price with 0.0248%. In addition, we find that an additional residential unit within a circle with a radius of 500 meters decrease the house price with 0.00131%. Our results indicate that residents have a negative valuation for density in terms of number of residential units within a certain area, and that this impact is stronger at a more localized level. These results are in line with our expectation and correspond with Fesselmeyer et al. (2018), Bramley et al. (2010) and Koster & Rouwendal (2010) who all found that housing density negatively affects house prices. High-density neighbourhood and districts are often associated with negative externalities, such as higher crime rates and less privacy etc., as a result, households do not prefer to live in high-unit densities.

Finally, as described in Section 2.2 and Section 2.5, the monocentric city model reports a positive relation between residential property prices and density (Kulish et al., 2011). Multiple density indicators (e.g., floor space index, building height and open space index) in our research report a positive relation between property prices and density, suggesting that elements of the monocentric city model are also applicable to VINEX locations.

7.3 Structural and spatial characteristics

This section focuses on the analysis of the structural and spatial characteristics, in measuring the impact of our density indicators on property prices. Our results confirm and correspond to scientific literature, describing that structural characteristics are important determinants of house prices (So et al., 1997; Visser & van Dam, 2006). Size of the house, maintenance state, private parking and number of rooms and bathrooms are attributes explain a major part of the house price, which logically also applies to VINEX residents. In addition, the results show that the presence of a private garden in many specifications insignificant is, indicating there is not enough evidence to conclude that a property with a private garden is more expensive, than a similar property without garden. We believe this is unlikely, as Turner & Seo (2011) also argue that a private garden has a positive price effect. An explanation for the insignificance of the variable might be that the property type 'Detached' are already characterized with a private garden, causing the insignificance of the variable 'private garden is present'. Our results also show that VINEX residents are willing to pay a price premium for more recently built houses. We use construction year '1995-2004' as a reference year, whereby price premiums increase over the time: properties constructed in the period '2005-2014' are approximately more expensive, and properties from the period '2015-2014' are even more expensive. This is probably because newly built houses have more modern facilities and features, resulting in lower maintenance costs for residents in the future.

With respect to spatial accessibility characteristics, transport accessibility is generally valued negative, resulting in negative house price capitalization (Hoogendoorn et al., 2002; Yu et al., 2023). For VINEX properties, we find that proximity to the nearest train station and main highway have a negative price effect, indicating our results are not in line with Hoogendoorn et al. (2002) & Yu et al. (2023). For VINEX houses, further distances to train stations and highways increase house prices. In other words, it seems that the costs of proximity (i.e., noise nuisance and air pollution) exceed the benefits of proximity to those facilities, in terms of accessibility benefits, because of which VINEX residents prefer to live in more quiet and less polluted residential areas. However, our results also show that proximity to the nearest airport has a positive price effect, which is not in line with the preference for quit and less polluted areas. A possible explanation for this contradiction is that VINEX residents consider the benefits of proximity to transport facilities to be greater than the costs associated with proximity to those facilities when a certain facility is not available in abundance, in this case the presence of an airport. There is only one major airport in the Netherlands, and some smaller ones. This does not apply to train stations and main highways, since VINEX locations are relatively close to cities where these transport facilities are widely available and access point are not far away, so proximity to those facilities is valued negatively, which corresponds to findings from Wittowsky et al. (2020). Important no note, our research shows linear relationships between property prices and proximity to a train station, highway, and airport. However, it is likely the estimates will change when the distances become too large.

7.4 Policy implications

The discussion about densification of existing cities and future development locations is an important topic in the Netherlands, considering the pressure on the housing market and the need to build efficiently, so that limited available space is used as efficiently as possible. The increasing demand for affordable housing and the growing population have led to an intensification of the debate about the desirability of urban densification and its related implications.

The results of our study may also have implications for urban planning policies. We show that the floor space index, the number of building layers, and mixed-use index have positive price effects, while the open space index generates a negative price effect. The residential density indicators included both have negative price effects. Our results suggest that vertical densification might be attractive, but at the same time residents dislike high-unit densities. This indicates that it may be interesting to develop mixed residential environments that exhibit variation in building height (number of building layers) and number of residential units per area unit. An option might be, for example, by developing apartment blocks at some locations that are slightly higher (e.g., one or two additional floors), and by limiting the housing density at other locations. Based on heterogeneity in preferences of residents for a particular living environment, residential sorting can take place at a localized level.

At the same time, as we have mentioned earlier, the found price effects are relatively small. This increases the need to place the results in a somewhat broader perspective, as advocating for a specific urban structure is too simplistic. This is reflected in the fact that urban densification is multi-faceted and complex (e.g., land-use regulations, construction costs, agglomeration benefits etc.), and it also these aspects that should be considered in the policy choice for densification.

7.5 Suggestions for follow-up research

We estimate the impact of urban density, based on multiple density indicators, on residential property values in VINEX locations. As mentioned before, VINEX locations are often located at the edges of cities and is therefore a good example of suburban residential development. It might be interesting to investigate whether the price effects found in this study are also applicable to VINEX houses that are developed in the inner part of the cities, or to urban infill development sites in general. This may also contribute to the discussion and interpretation of future housing development policies, in the context of the housing task in the Netherlands. Another suggestion for follow-up research includes the application of spatial regression models. Specifically, follow-up research could include spatial lag models that considers the fact there might be spatial dependence in house price or include spatial cross-regressive models that considers spatial dependence in housing attributes. In addition, follow-up research could estimate the relationship between urban density and house price through the application of flexible functional forms, allowing the data tell how house prices and characteristics are related, including series approximation and locally weighted regression.

8. Conclusion

The aim of our study is to investigate the impact of localized urban density on residential property values in suburban VINEX locations, contributing to the discussion on costs and benefits of densification. To do so, we have formulated the following research question: *'What is the impact of localized urban density on residential property values in VINEX locations?'.* Through the application of a hedonic pricing model, we employ different indicators of urban density, that relate to building density as well as residential density. With respect to the building density indicators, we find positive price effects for the floor space index, building height and mixed- use index and a negative price effect for the open space index. With respect to the residential density indicators, we find a negative price effect for the number of residential units within a radius of 100 and 500 meters. The impact of density on residential property prices in VINEX locations is therefore strongly dependent on the density indicator that is being investigated.

Our results suggest that it may be interesting to develop environments that have variation in housing density and total floor area of the building block, by developing residential apartment blocks at some locations that have one or two additional floors, and at some locations developing properties with a relatively lower housing density. However, as densification of urban locations is multi-faceted and complex and therefore involves many important aspects (e.g., land-use regulations, construction costs, agglomeration benefits etc.) that should be considered in the decision-making process of urban densification, advocating for earlier mentioned urban structures may be too simplistic. We therefore envision that the results in our study fill a research gap, namely measuring how residents from Dutch new suburban development locations value higher localized density.

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Appendix

Appendix A: Mathematical derivation of the monocentric city model

The utility function u of an individual can be written as:

$$u = u\ (q, h) \tag{A1}$$

The budget constraint of an individual can be written as:

$$q + p\ (x)\ h = y - tx \tag{A2}$$

Maximizing the utility function (A1) subject to the budget constraint (A2), using the method of Lagrange multiplier, results in:

$$\mathcal{L} = u\ (q, h) + \lambda\ (y - tx - q - p(x)\ h) \tag{A3}$$

Where $\mathcal{L}$ is the Lagrange-function.

The first-order condition of the Lagrange-function with respect to the distance to the CBD is equal to:

$$\frac{\partial \mathcal{L}}{\partial x} = 0 \tag{A4}$$

Taking the first order condition results in:

$$\frac{\partial \mathcal{L}}{\partial x} = -t - \frac{\partial p(x)}{\partial x}\ h = 0 \tag{A5}$$

Which can be rewritten as what is known as Muth's condition (A6).

$$\frac{\partial p(x)}{\partial x} = -\frac{t}{h} \tag{A6}$$

Appendix B: Property price distribution

Figure B1: Distribution of transaction price (€)

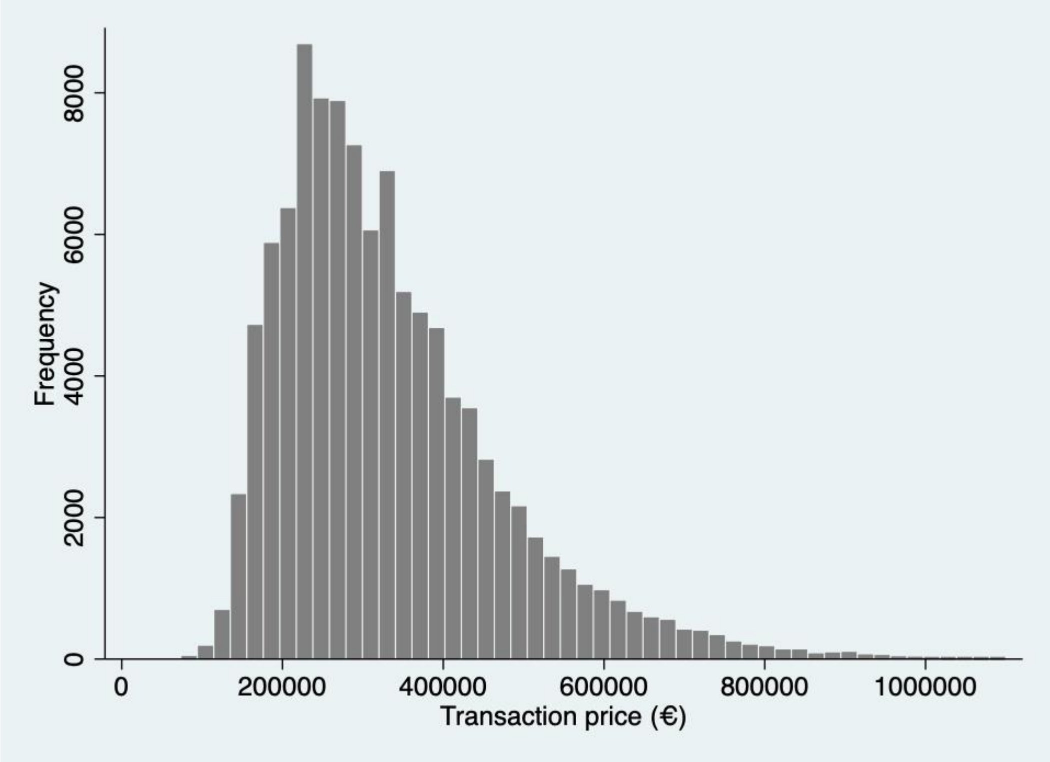
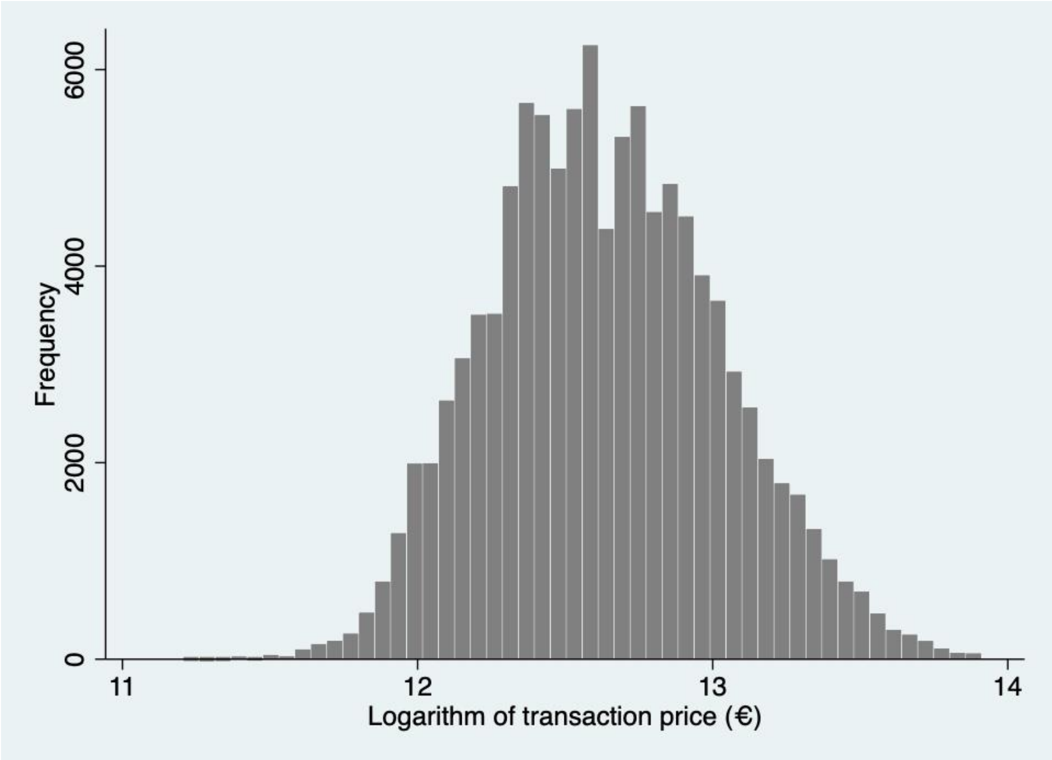


Figure B2: Distribution of logarithm of transaction price (€)



Appendix C: Regression tables

Table C1: GSI, OSI and MXI. Note: GSI, OSI, and MXI are aggregated at the neighbourhood level.

Dependent variable: *Property transaction price (log)*	(3)	(4)	(5)	(6)	(7)
Ground space index (log)	0.00345			0.00226	
	(0.00418)			(0.00416)	
Open space index (log)		-0.0131***			-0.0110***
		(0.00419)			(0.00417)
Mixed use index (log)			0.0317***	0.109***	0.107***
			(0.00686)	(0.0195)	(0.0194)
Size (log)	0.672***	0.672***	0.683***	0.673***	0.672***
	(0.00973)	(0.00971)	(0.00690)	(0.00975)	(0.00972)
Number of rooms	0.0197***	0.0198***	0.0128***	0.0192***	0.0193***
	(0.00167)	(0.00167)	(0.00130)	(0.00167)	(0.00167)
Maintenance state is good	0.0697***	0.0702***	0.0975***	0.0686***	0.0691***
	(0.00787)	(0.00787)	(0.00640)	(0.00792)	(0.00792)
Private parking present	0.0546***	0.0544***	0.0694***	0.0548***	0.0546***
	(0.00390)	(0.00390)	(0.00299)	(0.00389)	(0.00389)
Private garden is present	0.00689*	0.00639	0.00290	0.00516	0.00476
	(0.00396)	(0.00395)	(0.00278)	(0.00398)	(0.00396)
Complete isolation present	0.0110***	0.0111***	0.0103***	0.0118***	0.0118***
	(0.00333)	(0.00333)	(0.00236)	(0.00333)	(0.00333)
Number of bathrooms	0.00270	0.00231	0.0292***	0.00252	0.00217
	(0.00631)	(0.00630)	(0.00533)	(0.00631)	(0.00630)
Property type: apartment	-0.252***	-0.253***	-0.307***	-0.252***	-0.253***
	(0.00979)	(0.00975)	(0.00732)	(0.00982)	(0.00978)
Property type: terraced	-0.242***	-0.242***	-0.275***	-0.241***	-0.241***
	(0.00687)	(0.00687)	(0.00552)	(0.00687)	(0.00687)
Property type: semi-detached	-0.126***	-0.126***	-0.135***	-0.126***	-0.126***
	(0.00624)	(0.00624)	(0.00523)	(0.00624)	(0.00623)
Construction year 2005-2014	0.0119***	0.0105***	0.0267***	0.0105***	0.00925***
	(0.00357)	(0.00359)	(0.00253)	(0.00355)	(0.00357)
Construction year 2015-2021	0.0751***	0.0743***	0.0633***	0.0761***	0.0754***
	(0.00553)	(0.00552)	(0.00510)	(0.00548)	(0.00547)
Distance to train station (km)	0.0103**	0.0122***	0.0111***	0.00448	0.00646
	(0.00462)	(0.00452)	(0.00347)	(0.00458)	(0.00449)
Distance to highway entry/exit (km)	0.0196***	0.0201***	0.0233***	0.0213***	0.0218***
	(0.00421)	(0.00421)	(0.00325)	(0.00420)	(0.00420)
Distance to airport (km)	-0.00418	-0.00371	-0.00825***	-0.00235	-0.00200
	(0.00283)	(0.00285)	(0.00224)	(0.00284)	(0.00285)
Constant	9.847***	9.841***	9.282***	9.866***	9.861***
	(0.0532)	(0.0533)	(0.0375)	(0.0535)	(0.0535)
Postcode-3 fixed effects	No	No	No	No	No
Poscode-4 fixed effects	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	No	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes
Observations	8,987	8,987	19,703	8,987	8,987
R^2	0.846	0.846	0.907	0.847	0.847

Notes: Property type ‘Detached’ and construction year ‘1995-2004’ act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C2: Residential units in r = 100 meters. Note: MXI is aggregated at the neighbourhood level.

Dependent variable:	*Property transaction price (log)*	*Property transaction price per square meter (log)*
	(1)	(2)
Residential units in r = 100 meters	-0.000248***	-0.000248***
	(0.0000178)	(0.0000178)
Mixed use index (log)	0.0442***	0.0442***
	(0.00708)	(0.00708)
Size (log)	0.677***	-0.323***
	(0.00685)	(0.00685)
Number of rooms	0.0129***	0.0129***
	(0.00129)	(0.00129)
Maintenance state is good	0.0948***	0.0948***
	(0.00639)	(0.00639)
Private parking present	0.0709***	0.0709***
	(0.00296)	(0.00296)
Private garden is present	0.00489*	0.00489*
	(0.00279)	(0.00279)
Complete isolation present	0.0122***	0.0122***
	(0.00236)	(0.00236)
Number of bathrooms	0.0292***	0.0292***
	(0.00529)	(0.00529)
Property type: apartment	-0.299***	-0.299***
	(0.00732)	(0.00732)
Property type: terraced	-0.269***	-0.269***
	(0.00550)	(0.00550)
Property type: semi-detached	-0.133***	-0.133***
	(0.00520)	(0.00520)
Construction year 2005-2014	0.0333***	0.0333***
	(0.00256)	(0.00256)
Construction year 2015-2021	0.0623***	0.0623***
	(0.00513)	(0.00513)
Distance to train station (km)	0.00528	0.00528
	(0.00350)	(0.00350)
Distance to highway entry/exit (km)	0.0239***	0.0239***
	(0.00324)	(0.00324)
Distance to airport (km)	-0.00922***	-0.00922***
	(0.00223)	(0.00223)
Constant	9.385***	9.385***
	(0.0377)	(0.0377)
Postcode-3 fixed effects	No	No
Postcode-4 fixed effects	Yes	Yes
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,703	19,703
R^2	0.908	0.849

Notes: Property type 'Detached' and construction year 1995-2004 act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C3: FSI and building height. Note: FSI and building height are aggregated at the district level.

Dependent variable: Property transaction price (log)	(1)	(2)
FSI (log)	0.0146***	
	(0.00287)	
Building height (layers)		0.0302***
		(0.00730)
Size (log)	0.682***	0.682***
	(0.00694)	(0.00695)
Number of rooms	0.0132***	0.0130***
	(0.00132)	(0.00132)
Maintenance state is good	0.102***	0.103***
	(0.00642)	(0.00642)
Private parking present	0.0665***	0.0665***
	(0.00304)	(0.00304)
Private garden is present	0.00506*	0.00521*
	(0.00274)	(0.00274)
Complete isolation present	0.00881***	0.00885***
	(0.00240)	(0.00240)
Number of bathrooms	0.0311***	0.0307***
	(0.00544)	(0.00544)
Property type: apartment	-0.309***	-0.311***
	(0.00738)	(0.00740)
Property type: terraced	-0.280***	-0.281***
	(0.00558)	(0.00559)
Property type: semi-detached	-0.135***	-0.135***
	(0.00531)	(0.00531)
Construction year 2005-2014	0.0345***	0.0338***
	(0.00240)	(0.00242)
Construction year 2015-2021	0.0654***	0.0660***
	(0.00505)	(0.00504)
Distance to highway entry/exit (km)	0.0143***	0.0154***
	(0.00230)	(0.00239)
Distance to airport (km)	-0.00303***	-0.00315***
	(0.00103)	(0.00103)
Constant	9.337***	9.242***
	(0.0351)	(0.0394)
Postcode-3 fixed effects	Yes	Yes
Postcode-4 fixed effects	No	No
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,719	19,719
R^2	0.902	0.901

Notes: Property type ‘Detached’ and construction year 1995-2004 act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C4: GSI and OSI. Note: GSI and OSI are aggregated at the district level.

Dependent variable: *Property transaction price (log)*	(3)	(4)
Ground space index (log)	0.00491	
	(0.00543)	
Open space ratio (log)		-0.103***
		(0.00639)
Size (log)	0.666***	0.666***
	(0.00970)	(0.00970)
Number of rooms	0.0198***	0.0198***
	(0.00167)	(0.00167)
Maintenance state is good	0.0775***	0.0774***
	(0.00793)	(0.00793)
Private parking present	0.0519***	0.0521***
	(0.00394)	(0.00394)
Private garden is present	0.00575	0.00571
	(0.00386)	(0.00386)
Complete isolation present	0.0111***	0.0112***
	(0.00337)	(0.00337)
Number of bathrooms	0.00253	0.00272
	(0.00640)	(0.00640)
Property type: apartment	-0.258***	-0.258***
	(0.00963)	(0.00963)
Property type: terraced	-0.247***	-0.247***
	(0.00681)	(0.00681)
Property type: semi-detached	-0.124***	-0.124***
	(0.00624)	(0.00624)
Construction year 2005-2014	0.0185***	0.0187***
	(0.00328)	(0.00328)
Construction year 2015-2021	0.0814***	0.0815***
	(0.00528)	(0.00528)
Distance to highway entry/exit (km)	0.0193***	0.0190***
	(0.00323)	(0.00323)
Distance to airport (km)	-0.00181	-0.00186
	(0.00137)	(0.00137)
Constant	9.911***	9.904***
	(0.0507)	(0.0501)
Postcode-3 fixed effects	Yes	Yes
Postcode-4 fixed effects	No	No
Month fixed effects	Yes	Yes
Year fixed effects	No	No
Observations	8,987	8,987
R^2	0.838	0.838

Notes: Property type ‘Detached’ and construction year 1995-2004 act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C5: Residential units in r = 500 meters. Note: MXI is aggregated at the neighbourhood level.

Dependent variable: *Property transaction price (log)*	Property transaction price (log) (1)	Property transaction price per square meter (log) (2)
Residential units in r = 500 meters	-0.0000131***	-0.0000131***
	(0.00000260)	(0.00000260)
Mixed use index (log)	0.0387***	0.0387***
	(0.00710)	(0.00710)
Size (log)	0.681***	-0.319***
	(0.00686)	(0.00686)
Number of rooms	0.0129***	0.0129***
	(0.00130)	(0.00130)
Maintenance state is good	0.0968***	0.0968***
	(0.00640)	(0.00640)
Private parking present	0.0698***	0.0698***
	(0.00298)	(0.00298)
Private garden is present	0.00314	0.00314
	(0.00279)	(0.00279)
Complete isolation present	0.0111***	0.0111***
	(0.00236)	(0.00236)
Number of bathrooms	0.0293***	0.0293***
	(0.00532)	(0.00532)
Property type: apartment	-0.305***	-0.305***
	(0.00734)	(0.00734)
Property type: terraced	-0.274***	-0.274***
	(0.00552)	(0.00552)
Property type: semi-detached	-0.134***	-0.134***
	(0.00523)	(0.00523)
Construction year 2005-2014	0.0273***	0.0273***
	(0.00253)	(0.00253)
Construction year 2015-2021	0.0633***	0.0633***
	(0.00511)	(0.00511)
Distance to train station (km)	0.00584	0.00584
	(0.00368)	(0.00368)
Distance to highway entry/exit (km)	0.0242***	0.0242***
	(0.00326)	(0.00326)
Distance to airport (km)	-0.00787***	-0.00787***
	(0.00223)	(0.00223)
Constant	9.343***	9.343***
	(0.0388)	(0.0388)
Postcode-3 fixed effects	No	No
Postcode-4 fixed effects	Yes	Yes
Month fixed effects	No	No
Year fixed effects	Yes	Yes
Observations	19,703	19,703
R^2	0.907	0.848

Notes: Property type 'Detached' and construction year 1995-2004 act as references. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.