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THE RESILIENCE CITY / THE FRAGILE CITY. METHODS, TOOLS AND BEST PRACTICES.

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Cover Image by Maria Rosa Tremiterra of Am Sandtorkai, one of the main streets of HafenCity, a new district located on the waterfront of the City of Hamburg. HafenCity can be considered "a city in the city" and one of the most resilient urban areas in the world to the flooding events thanks to its urban redevelopment strategy.

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The Resilience City/The Fragile City.
Methods, tools and best practices.

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THE VALUE OF URBAN DENSITY

AN EXPLORATORY OF THE RELATIONSHIP BETWEEN URBAN DENSITY AND HOUSING PRICES IN TRONDHEIM, NORWAY

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ABSTRACT

Urban density is considered a cornerstone of sustainable urban form, enhancing the potential for more sustainable lifestyles and fewer greenhouse gas emissions. Urban densification policies have thus become a pillar of the sustainability planning agenda in Norway. Although this strategy has been contested by some who see denser neighbourhoods as problematic, housing prices seem to contradict this view. This paper proposes the hypothesis that urban density is a well-accepted and valued quality reflected in the willingness-to-pay in the housing market. To explore the relationship between urban density and residential property prices in Trondheim, Norway, this analysis first evaluates 23 distinct urban areas with regard to average square metre price and three density measures – built coverage density, dwelling unit density, and population density. Initial correlation results based on 1,255 sales transactions from 2014 and 2015 indicate a positive relationship between the density measures and price per square metre. To investigate this first observation further, a simple hedonic pricing model was constructed, including characteristics such as property type and age of property; proximity measures, such as distance to the next school or bus stop; and the three density measures. It was run for the complete dataset as well as for the two subsets of Trondheim periphery and Trondheim centre. With regard to density, the model shows unexpected results. It indicates that an increase in dwelling unit density can lead to an increase in price, whereas the opposite can happen for increases in population density. This may be linked to local housing market conditions, such as the rise of high-income single-occupant and dual-income no-kid homes in central locations.

KEYWORDS:
Urban density; Urban densification policies; Sustainable city; Housing prices; Hedonic pricing.

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城市密度的价值关于挪

威特隆赫姆城市密度与住房价格关系之探索性研究

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摘要

城市密度被认为是可持续城市形式的基础之一。它能提高一个城市在更多可持续生活方式和减少温室气体排放方面的潜力。因此，城市密集化的政策必须成为挪威可持续发展规划议程的一个核心因素。虽然一些人看到密集居民区的一些问题，因而对此战略提出质疑，但这一观点似乎与住房价格背道而驰。本文提出了城市密度已被普遍接受及重视、且在有支付意愿的住房市场上有所反映这一假设。为研究挪威特隆赫姆的城市密度和住宅房地产价格之间的关系，本文首先评估了 23 个不同的城市地区的每平方米平均价格以及三个密度量度，即建筑覆盖密度、住宅单位密度和人口密度。2014 年和 2015 年的 1,255 宗销售交易数据显示的初步相关性结果表明，密度量度和每平方米价格之间呈正比关系。为了对此初步观察进行深入调研，构建一个简单的特征定价模型，其中纳入了房产类型和房产年限；邻近性量度，例如最近的学校或公交车站距离；以及上述三个密度量度。我们将这一模型运行于整个数据集特隆赫姆周边地区和特隆赫姆中心地区这两个子集。在密度方面，该模型显示了意想不到的结果。即：住宅单位密度的增加可能导致价格上涨，而前者的下降则可能是由于人口密度的上升引起的。这一结果可能与当地住房市场条件有关，例如高收入单一住户和中心地区无孩双收入家庭的增加。

关键词:
城市密度；城市密集化政策；可持续城市；住房价格；特征定价

1 INTRODUCTION

Urban density is widely accepted as a fundamental characteristic of sustainable urban form (Dempsey et al., 2012). This is built on the premise that more compact cities optimise the use of resources. Denser urban environments have the potential to reduce the use of land and optimise the flow of people, energy, and goods (Coppola, 2012, Vitale Brovarone, 2010). They also increase the proximity between dwellings, work places, and public facilities, and consequently demand fewer resources and produce fewer greenhouse gases (Fatone et al., 2012). Since the 1990s, sustainability targets have driven urban densification policies, especially in the cities of developed countries after decades of urban sprawl. However, the feasibility of densification has been questioned by many. In the context of market economies, several studies point toward the lack of social acceptability as a major barrier to the implementation of denser cities (Breheny, 1997; Garcia & Riera, 2003; Bramley et al., 2009; Xue et al., 2016). In such a context, the ideas of freedom of choice and self-interest are dominant forces shaping the way in which urban space is developed and used in everyday life. Thus, people should have the freedom to choose the type of urban environment they want to live in, which means of transport they use, or which housing types meet their aspirations (Høyer & Næss, 2001; Garcia & Riera, 2003; Sager, 2011).

Norwegian cities have applied urban densification strategies with different degrees of success. During the period from 2000 to 2012, Oslo and Stavanger experienced relatively large increases in urban density, in contrast to Trondheim and Bergen where increases were modest (Hernandez-Palacio, 2014). However, in the case of Trondheim, densification policies have been severely criticised by different actors in the public debate. The most common concerns relate to the decline of urban qualities highly valued by Norwegian society, such as the urban landscape, sun and shade, and the views (Hermann, 2015; Sved, 2015). Due to several factors, among them social acceptability, the continuation of a positive trend in the densification of sprawling Norwegian cities seems to be increasingly challenging.

The problem, however, does not seem to be urban density itself, but rather the perception thereof, which in turn also becomes a question of urban quality. Urban density is the result of multiple factors, which are materialised in numerous forms and produce very different environments (Berghauser Pont & Haupt, 2009). Thus, a high concentration of people and activities can result in very different urban typologies, especially when taking into consideration geographical and cultural values (Urhahn & Bobic, 1994). Indeed, the traditional Norwegian city centre, as found in the urban cores built before the 1950s, is notoriously denser than many of the areas developed after. Despite the higher-density environment, average property prices in inner-city locations seem to be higher than in the newer lower-density peripheral locations (Tab. 1). This seems to indicate that there is perceived added value to central yet denser locations. Moderately dense urban environments in proximity to urban services seem a well-valued alternative for house buyers.

To investigate this preliminary observation, property sales data for 1,255 transactions in 2014 and 2015 were collected for 23 distinct, yet representative areas of Trondheim and density measures were calculated. Based on initial correlation analysis of the average sales price per square metre and the density measures, the following working hypothesis was proposed: urban density is a well-accepted and valued quality in Norwegian cities, which is reflected in the willingness-to-pay in the housing market. Homebuyers are willing to pay more per square metre in well-integrated, denser urban areas than in low-density, disconnected locations. Among other things, they pay for the accessibility and proximity of urban services, but also for more intense urban environments such as the ones found in many traditional inner cities.[1]

Trondheim is taken as an exploratory case study to test how hedonic pricing as a research instrument can be used to analyse the impact of urban density on housing prices. Hedonic pricing has been used to assess the impact of different aspects of the built environment on real estate prices, but urban density is a rather

[1] Strictly speaking, the hypothesis to be tested in this study is: urban density has a significant effect on property prices. The null hypothesis accordingly is: urban density does NOT have an effect on property prices.

unexplored aspect. Trondheim was chosen as a critical instance because it provides a good example of a middle-sized city in Norway and other developed countries where urban densification has become a main strategy in planning for more sustainable cities. Despite the limitations that a single case study may have, this exercise shows the potential of hedonic pricing as a proxy instrument to explore the social acceptability of a contested planning strategy.

This paper is organised as follow: Section 2 presents Trondheim as the study area, describes the urban areas under investigation and gives some initial analysis. Sections 3 and 4 present the hedonic pricing model, analysis and results. Section 5 concludes this paper with a discussion of the results and recommendations for future research.

2 TRONDHEIM: STUDY AREA AND INITIAL ANALYSIS

The study area is the city of Trondheim, Norway. Trondheim, with a population of 178,833 in 2015, is the third largest city in the country, after Oslo and Bergen (SSB, 2015). It is located on Trondheim Fjord in central Norway and has an average population density of 3027.5 inhabitants per km², which is considerably less than the average urban density in European cities estimated at 4,345 inhabitants per km² (Dodman, 2009). Trondheim's urban area can be divided into two distinct urban environments: the inner city, comprising the pre-industrial core and its 19th and early 20th century developments, characterised by a denser urban fabric, formed mostly of compact blocks; and the less dense outer city, made up of different developments built during the second half of the 20th century and the beginning of the 21st century. A study of residential qualities in Oslo using hedonic pricing analysis defines these two basic urban environments: a denser inner city environment (*bymessige områder*) and a less compact collage of peripheral developments (*feltutbygginger*) (Sjaastad et al. 2007). This clear differentiation in urban form is also evident in many European cities. According to Benevolo (1993), the urban form of European cities is in general characterised by a dense network core spanning a fairly restricted area, which then grew through multiple additions over the course of the 20th century.

Historically, Trondheim remained a rather compact urban agglomeration, maintaining the dense pattern of the traditional European city, until the early 20th century (Trondheim byarkiv).[2] At this time, a new trend of expansion was set by wealthy families through the introduction of urban villas into the urban landscape. This new form of lower-density townscape was restricted to a small segment of the population. Compact housing schemes, such as terraced houses or courtyard blocks, provided housing solutions for the majority of urban dwellers. This traditional pattern of urban development was dominant until the mid-20th century, when new modernisation trends entered Norwegian cities with force; one of the main consequences was the abandonment of the compact housing scheme as the predominant urban typology. The modern city presents new urban typologies, such as slab blocks and towers. The former typologies, such as terraced houses and courtyard blocks, are still present in the newer parts of the city, but they have become more spacious, allowing for more green spaces and a less dense environment. The ideal of living in the 'green city' rather than in the crowded old city seemed to dominate the housing market during the second half of the 20th century and still is influencing some new developments in the early 21st century.

2.1 THE URBAN AREAS

Initial data on property sales transactions were collected on a case-by-case basis from finn.no, a very popular online marketplace in Norway. Data were compiled for 1,255 sales transactions from 2014 and 2015. The sample was drawn from 23 urban environments with diverse layouts and locations. The first 10 are in the older parts of the city, formed mostly before the mid-20th century, and are referred to in this section as

[2] These observations are based on historical maps from 1893, 1902, 1916, and 1940 available in the Trondheim byarkiv.

Trondheim city centre (Fig. 1). The remaining 13 areas correspond to newer urban developments, and are referred to as Trondheim periphery (Fig. 2)

These areas were selected to cover the most representative types of urban environment in Trondheim. They range from high-density, high-rise buildings in Midtbyen (1) to low density development in Singsaker (7), Ilabekken (11), and Ranheim (22, 23). They cover areas with a high percentage of historic wooden houses in Bakklandet (5) and Møllenberg (6), and areas of urban renewal with an important component of refurbishment of old buildings in Nedre Elvehavn (3) and Persaunet (18). They also include areas in close proximity to large institutions in Gløshaugen (9) and Ila (10), to the fjord in Ila (10), Nedre Charlottenlund (21), and Ranheim (23), to large parks in Ilabekken (11), and to the river in Øya (2), Bakklandet (5), and Sjetnemarka (13). Post-war residential areas, such as Kolstad (14), form another part of the sample, as well as a representative selection of newer residential areas in the periphery, such as Selsbak (12), Tiller (15), Kattem (16), Moholt/Eberg (17), Nardo (19), and Angeltrøa (20).

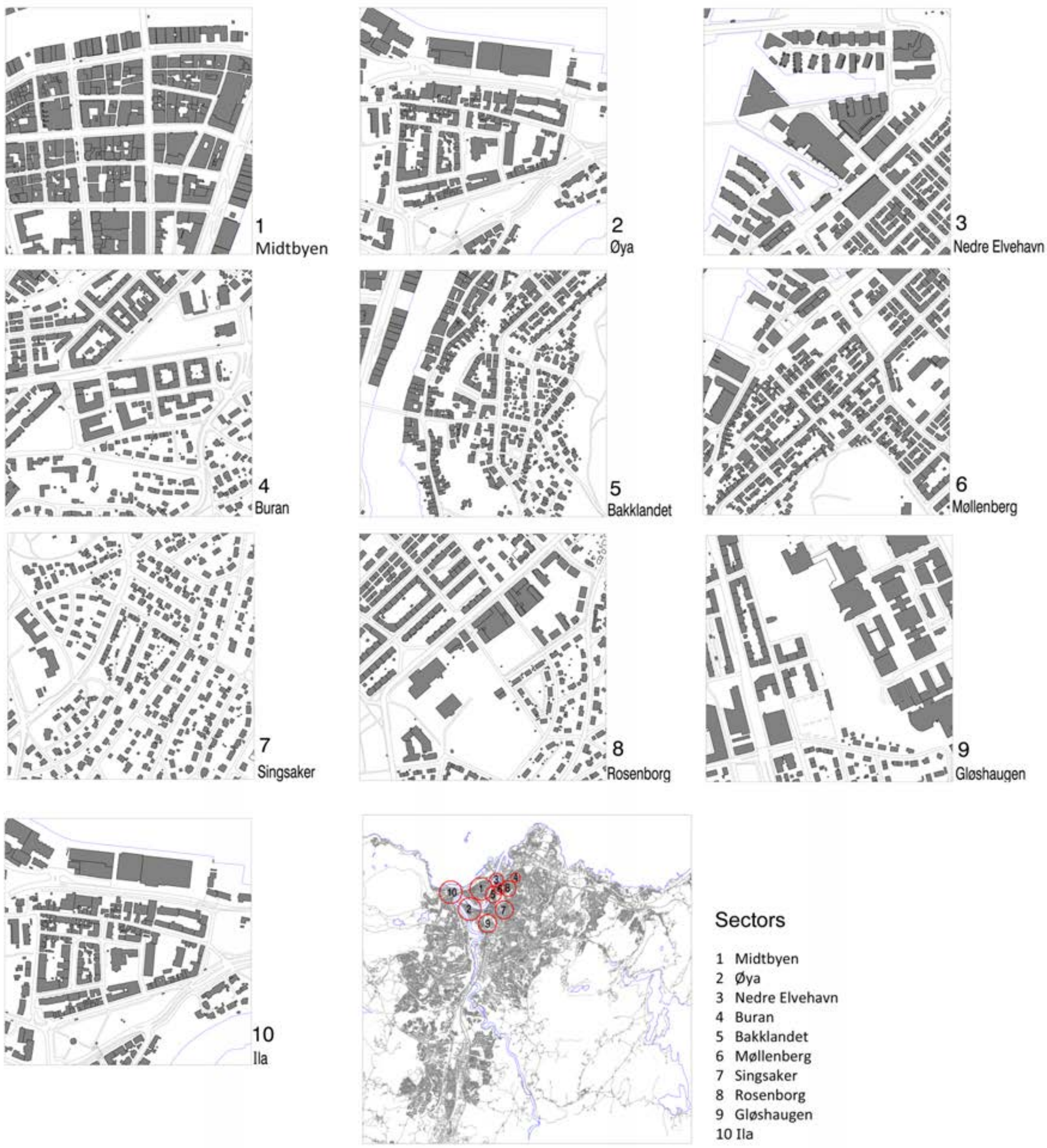

Fig. 1 Analysed areas in Trondheim city centre

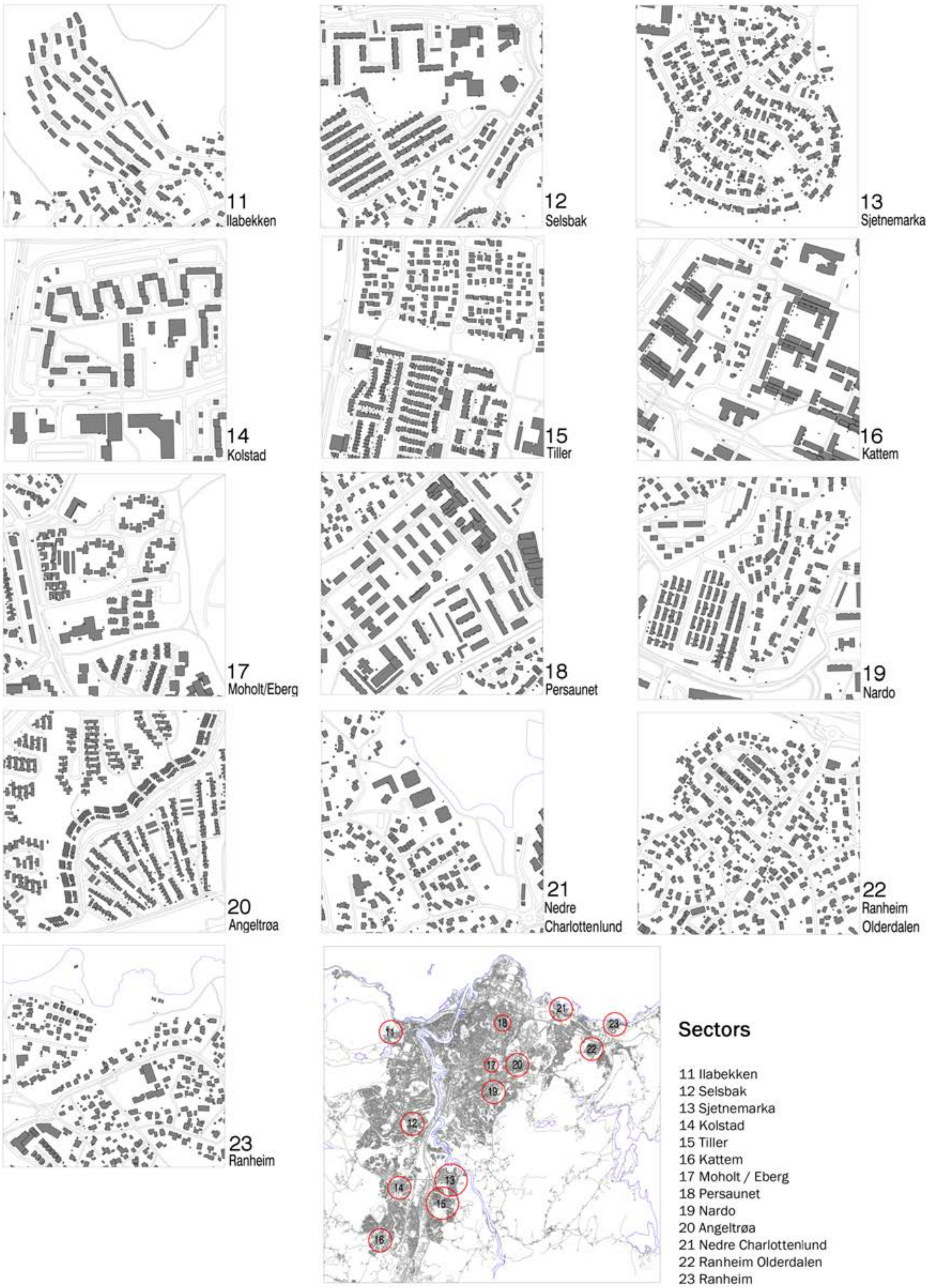

Fig. 2 Analysed areas in Trondheim periphery

urban area	average NOK price per m^2	*GRUNNKRETS*-BASED DENSITIES*			AVERAGE HECTARE CIRCLE-BASED DENSITIES**		
		built coverage density (% plot area)	dwelling unit density (units / ha)	population density (pers. / ha)	built coverage density (% plot area)	dwelling unit density (units / ha)	population density (pers. /ha)
1 Midtbyen	49,522.03	31.243	27.3	37.276	33.556	76.111	105.361
2 Øya	44,144.26	14.993	20.771	25.464	17.813	102.071	119.129
3 N. Elvehavn	56,624.62	28.863	64.061	70.345	22.767	187.493	208.377
4 Buran	43,305.11	33.853	134.598	158.137	22.831	143.588	176.029
5 Bakklandet	52,214.45	33.759	75.383	97.347	33.701	81.264	112.509
6 Møllenberg	43,461.24	33.58	94.721	115.937	26.426	107.365	121.987
7 Singsaker	44,375.01	16.508	18.16	36.471	17.139	53.515	61.091
8 Rosenborg	32,461.6	19.109	43.799	69.961	14.188	32.714	62.286
9 Gløshaugen	42,805.05	24.495	75.253	79.124	17.655	112.023	106.75
10 Ila	45,810.98	22.302	37.159	52.674	21.269	103.96	132.337
11 Ilabekken	33,018.1	8.691	10.429	24.334	11.774	20.2	45
12 Selsbak	36,012.84	13.404	15.112	29.231	9.319	47.61	80
13 Sjetnemarka	26,921.75	11.04	8.36	21.152	15.424	17.143	43.821
14 Kolstad	28,134.39	11.634	22.941	44.358	11.782	57.333	118.867
15 Tiller	30,741.61	18.895	19.993	50.794	16.976	34.402	75.753
16 Kattem	25,880.52	13.064	18.257	43.045	12.201	42.857	103.122
17 Moholt/Eb.	38,341.07	11.916	20.322	33.859	13.529	64.36	96.04
18 Persaunet	43,577.04	21.279	40.691	66.477	12.986	47.333	80.938
19 Nardo	42,775.44	16.843	19.36	32.803	8.954	32.698	53.279
20 Angeltrøa	38,896.6	16.451	15.178	42.968	14.862	40.467	76.4
21 Ned. Charlot.	40,773.57	12.079	13.712	23.966	16.876	28	65.545
22 Ranheim/Old	33,140.5	13.696	13.394	33.632	15.775	19.957	46.087
23 Ranheim	37,320.99	11.172	15.192	33.131	13.617	28.944	36.056

Tab.1 Average square metre prices and densities

* *Grunnkrets* are a type of geographic unit used to provide statistical information in Norway. These basic statistical areas are subdivisions of municipalities intended to cover a homogeneous area. They vary in size and population density.

** Average hectare circles are 1 hectare circles around each sales point. Their purpose is to calculate more detailed density measures in the immediate vicinity of each sales point.

3 HEDONIC PROPERTY PRICING

Hedonic property pricing is based on the assumption that property prices, housing unit prices in this case, are compound measures that reflect not only property characteristics, such as size or number of bedrooms, but also location, neighbourhood, as well as environmental characteristics (Freeman et al., 2014). Its most common functional form is linear or semi-linear regression analysis, whereby expenditures (price or rent) are regressed on housing and location characteristics (Malpezzi, 2002). Hedonic property pricing models have been used to assess the impact of a great number of environmental factors and neighbourhood characteristics on housing prices, such as the impact of air quality (Carriazo et al., 2013; Amrusch, 2005) or noise pollution (Chang & Kim, 2013; Dekkers & Van der Straaten, 2009), proximity to amenities (Cheshire & Sheppard, 1995; Xifilidou et al., 2012), accessibility (Srour et al., 2002; Bartholomew & Ewing, 2011, Tondelli & Scarsi, 2012), proximity to green areas (Bengochea Morancho, 2003; Jim & Chen, 2006), the value of scenic views (Jim & Chen, 2009), the value of urban wetlands (Tapsuwan et al., 2009), the value of urban tree cover (Sander et al., 2010; Vesely, 2007), or the value of cultural heritage in urban areas (Lazrak et al., 2014). However, to the author's knowledge, no such model has previously been used to focus on the value of urban density. In this analysis, a hedonic pricing approach is therefore used to estimate the marginal implicit prices of property, proximity, and density attributes. The marginal implicit price can be understood as the change in amount a person is willing to pay for an additional unit of an attribute (Freeman et al., 2014). The model regresses the log-transformed property prices per square metre on a combination of housing characteristics, distances to amenities, and density measures. It is computed for the complete dataset as well as for subsets of Trondheim centre and Trondheim periphery. The model can be specified as follows:

$$ln\ P_i = \beta_0 + \beta_1 H_i + \beta_2 DIST_i + \beta_3 DENS_i + \varepsilon_i$$

Pi is the price per square metre of property i. Hi is a vector of housing characteristics of property i, such as age of property, housing type, and ground floor access. DISTi is a vector of distance measures from property i, such as distance to nearest supermarket or distance from fjord. DENSi is a vector of density measures for property i. εi is the error term.

3.1 THE DATA

The sales data initially collected included information on sales price, size of property, age of property, years since last refurbishment, type of property (house or apartment), which floor(s) the property occupies, and the type of building the property is or is located in (for a complete list of variables, tab. 2). The 1,255 properties included in the dataset range in price from NOK 800,000 to 14,900,000,[3] and include small (less than 20m²) and large properties (more than 450m²), as well as new ones (built in 2015) and very old ones (more than 100 years old). The oldest property in the dataset was built in 1721 (Tab.3). Two basic types of residential unit are considered: apartments and houses, located in different building types, such as blocks, towers, or detached houses (explained below). The sample includes 23 areas, taken according to distinctive urban morphology patterns visually identified on the map of the city. The sales transactions were chosen to express the diversity of property types and property locations available in Trondheim. As the properties in the sample vary quite dramatically in size, it has been decided for this analysis to focus on the variation in price per square metre. Age of property (*AGE*) and years since last refurbishment (*YEARS_REFURB*) serve as proxies for the condition of the property. Both variables were computed by subtracting the year the property was built or refurbished from 2015. Type of property was dummy coded, taking the value 1 for houses and 0 for apartments (*HOUSE_APART*). The floor information was coded into two dummy variables: *GROUNDFLOOR* and

[3] At current exchange rate about USD 93,000 to 1,700,000.

MULTISTOREY. GROUNDFLOOR takes the value 1 if the property has ground-floor access, and *MULTISTOREY* takes the value 1 if the property spans across more than one floor. As building types are fundamental in the differentiation of urban environments and density distributions, Trondheim's large variety of buildings was reduced to seven basic building types for the analysis (illustrated in Fig. 3). Urban *villas* are single, freestanding dwellings surrounded by private gardens. They can have one, two, or three storeys, and basements. *Big house apartments* are apartment buildings in the settings of large detached houses, surrounded by gardens.

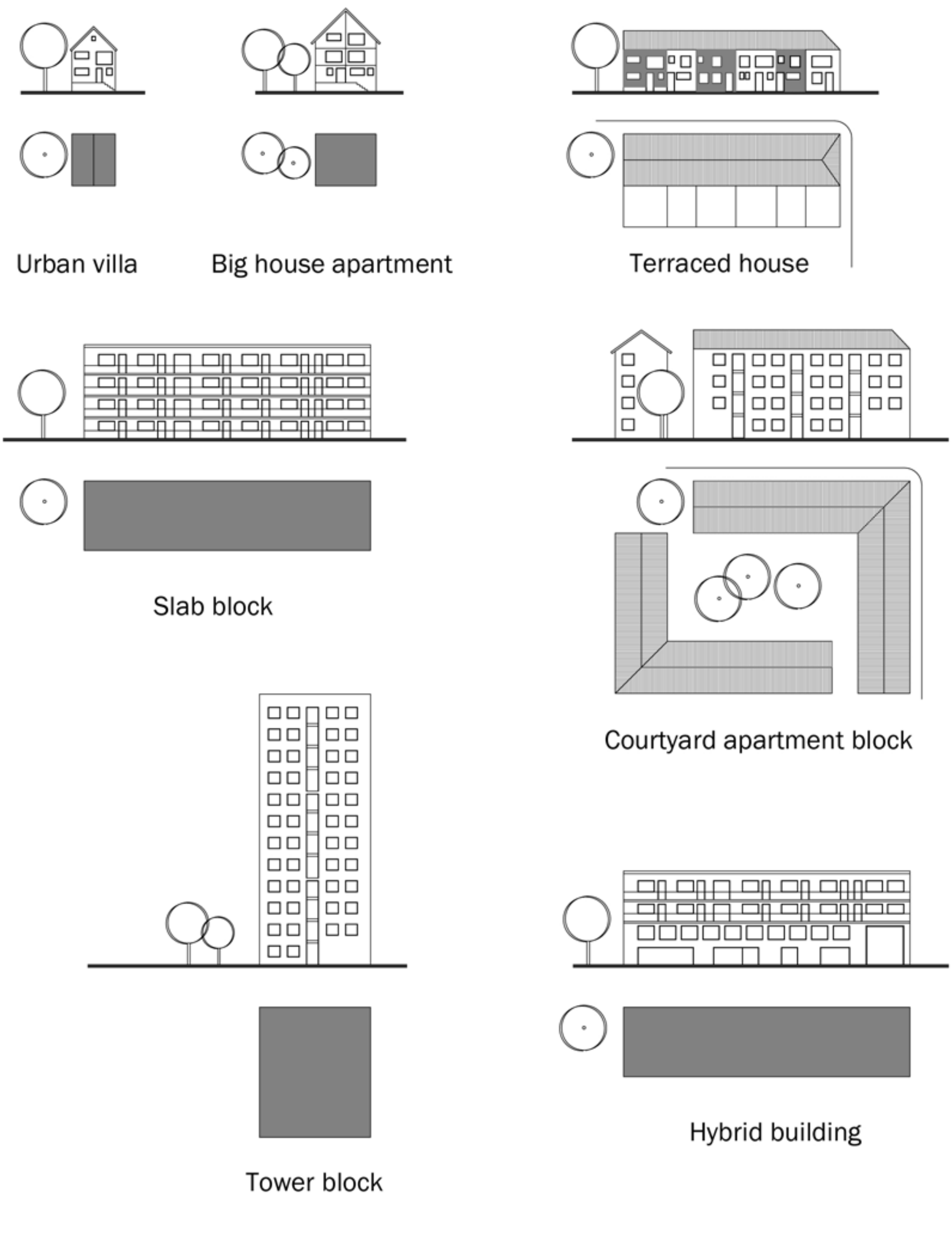

Fig. 3 Building types

In Trondheim, many former urban villas have been internally refurbished into apartment buildings. *Terraced houses* consist of similar residential units sharing side walls, usually forming blocks. They have separate entrances to the street and have gardens of different sizes, allowing natural lighting and cross-ventilation.

In Trondheim, they have normally one, two, or three storeys. *Slab blocks* are multi-storey buildings with lengthened form, in which the apartments are commonly set around a long corridor, or around several staircases and/or lifts with independent entrances. *Courtyard apartment blocks* are constituted by blocks of two or more wings, which fold around an open space.

L and S shape blocks, as well as atrium blocks around a patio are also part of this typology. *Tower blocks* are constituted by a multi-storey building with vertical proportions. They may have one or several dwellings per storey, organised around a central core constituted by staircases, lifts, and other technical components. *Hybrid buildings* correspond to a variety of buildings, mixing different uses and types. In some cases, they also correspond to the existing conditions of the context, such as the adaptation of former warehouses and other industrial buildings into new types and uses. For the purpose of the analysis, the dummy building type variables *BT_COURTYARD*, *BT_HYBRID*, *BT_SLABBLOCK*, *BT_TERRACE*, *BT_BIGHOUSE*, and *BT_TOWER* were coded against *BT_URBANVILLA*.

To compute geographical variables, such as distances to various amenities and density measures, the sales data were mapped in ArcGIS and additional data collected from Statistics Norway (the Norwegian Central Bureau of Statistics) and Norge Digitalt (a geographic information database). *ELEVATION* above sea level was computed for every sales address, depicted as points in ArcGIS, using a digital elevation model (DEM) of Trondheim. Euclidean distances were computed from the sales points to the nearest bus stop (*DIST_BUSSTOP*), supermarket (*DIST_SUPERMARKET*), higher education facility (*DIST_HIGHEREDU*), kindergarten (*DIST_KINDERGARTEN*), school (*DIST_SCHOOL*), shopping centre (*DIST_SHOPPING*) as well as to the fjord (*DIST_FJORD*) and to the recreational areas surrounding the city (*DIST_NATURE*).

Buses are an important mode of transportation in Trondheim. Approximately 10% of the population use them on a daily basis to commute (Hjorthol et al. 2014). Increasing the share of collective transport is a crucial aspect of the urban sustainability policies in Trondheim (Trondheim Kommune, 2008). Supermarkets are the main source of food for the majority of people in Norway. Easy access to them is therefore considered a plus for homebuyers. Close proximity to kindergartens and schools, referring here to elementary schools, middle schools, and high schools, can be an important factor when a young family is hunting for a new home. Trondheim is a university city and higher education institutions, such as the Norwegian University of Science and Technology (NTNU) and the University College of Sør-Trøndelag (HIST), are some of the biggest employers.

Being close to these institutions is therefore considered a desirable attribute for many homebuyers. As Norwegians have a high disposable income, shopping has become a favourite pastime for many. The shopping centres referred to are the biggest and most popular malls in the city. Norwegians also have a particular affinity for nature; not only do they enjoy the views that their country is famous for, they also spend a lot of time outdoors—hiking, skiing, fishing, and foraging. That is why the distances to Trondheim fjord as well as to the recreational green areas were also included in the list of variables.

As briefly mentioned above, for the density measure calculations, 1-hectare circles were drawn around each sales point. To calculate the percentage of built area or built coverage (*PERC_BUILT*), the sum of areas covered by buildings was divided by the total land area within the circle. Total land area excluded areas covered by water bodies, such as the main river Nidelva or the fjord. Number of people and dwellings were available on a building by building basis. Population per hectare (*POP_HA*) and dwellings per hectare (*DWELLINGS_HA*) were thus computed by adding all population and dwelling counts within a 1-hectare circle, respectively.

VARIABLE NAME	DESCRIPTION	EXPECTED RELATIONSHIP TO DEPENDENT VARIABLE
Dependent variable		
PRICE_M²	Price per square metre in NOK	
Property variables		
PRICE	Sales price of property in NOK	(incl. in dependent variable)
SIZE	Size of property in m^2	(incl. in dependent variable)
AGE	Year property was built subtracted from 2015	Negative
YEARS_REFURB	Year property was last refurbished subtracted from 2015	Negative
HOUSE_APART	Dummy variable indicating general type of property (1 for house / 0 for apartment)	Negative
GROUNDFLOOR	Dummy variable indicating whether property has ground floor access (1 for YES / 0 for NO)	Positive
MULTISTOREY	Dummy variable indicating whether property has multiple storeys (1 for multi / 0 for single)	Negative
ELEVATION	Elevation of the lot on which the property sits in m	Positive
BT_COURTYARD	Dummy variable indicating whether property is a courtyard block (1 for YES / 0 for NO)	?
BT_HYBRID	Dummy variable indicating whether property is a hybrid building (1 for YES / 0 for NO)	?
BT_SLABBLOCK	Dummy variable indicating whether property is a slab block (1 for YES / 0 for NO)	?
BT_TERRACE	Dummy variable indicating whether property is a terrace house (1 for YES / 0 for NO)	?
BT_BIGHOUSE	Dummy variable indicating whether property is a big house (1 for YES / 0 for NO)	?
BT_TOWER	Dummy variable indicating whether property is a tower block (1 for YES / 0 for NO)	Negative
BT_URBANVILLA	Dummy variable indicating whether property is a urban villa (1 for YES / 0 for NO)	?
Proximity variables		
DIST_BUSSTOP	Distance to nearest bus stop in m	Negative
DIST_SUPERMARKET	Distance to nearest supermarket in m	Negative
DIST_HIGHEREDU	Distance to nearest higher education facility in m	Negative
DIST_KINDERGARTEN	Distance to nearest kindergarten in m	Negative
DIST_SCHOOL	Distance to nearest school in m	Negative
DIST_SHOPPING	Distance to nearest shopping centre / mall in m	Negative
DIST_FJORD	Distance to Trondheim fjord in m	Negative
DIST_NATURE	Distance to recreational green areas / nature in m	Positive
Density variables		
PERC_BUILT	Percentage land area that is built area within 1-hectare	?
POP_HA	Number of people within 1-hectare circle	?
DWELLINGS_HA	Number of dwellings within 1-hectare circle	?

Tab. 2 Variable descriptions and expected relationship to dependent variable PRICE_M²

The variables PRICE and SIZE are used to compute the dependent variable PRICE_M². They are therefore not included in the regression model and no statements about the expected relationship of the variables to the dependent variable are made. For all other variables, the expected relationship is shown. A positive relationship indicates that an increase in the independent variable would likely be associated with an increase in the dependent variable, whereas a negative relationship indicates that an increase in the independent variable would likely be associated with a decrease in the dependent variable. A question mark indicates uncertainty with regard to the expected relationship.

VARIABLE NAME	MEAN	STANDARD. DEVIATION	MINIMUM	MAXIMUM
LN_PRICE_M²	10.59	0.3	9.73	11.28
PRICE_M²	41,366.13	11,771.49	16,889.76	79,513.6
PRICE	2,980,022.00	1,352,609.00	813,983.00	14,900,000.00
SIZE	80.14	46.73	15	481
AGE	49.85	39.31	0	294
YEARS_REFURB	31.02	31.45	0	173
ELEVATION	59.08	57.56	0.9	168.6
DIST_BUSSTOP	162.87	98.05	8.39	578.57
DIST_SUPERMARKET	298.81	199.86	0.16	1,102.05
DIST_HIGHEREDU	1,951.83	2,374.48	44.26	8605.3
DIST_KINDERGARTEN	230.68	142.56	0.03	742.54
DIST_SCHOOL	425.17	240.21	30.32	1,353.48
DIST_SHOPPING	1,208.8	898.38	53.2	3,602.85
DIST_FJORD	2,470.23	2,711.56	27.71	8,737.99
DIST_NATURE	300.92	220.48	0.00	958.38
PERC_BUILT	19.76	10.59	0.00	58.34
POP_HA	103.55	57.11	0.00	353.00
DWELLINGS_HA	74.07	55.73	4.00	333.00
HOUSE_APART	0.17	0.37	0.00	1.00
GROUNDFLOOR	0.43	0.49	0.00	1.00
MULTISTOREY	0.21	0.41	0.00	1.00
BT_COURTYARD	0.21	0.41	0.00	1.00
BT_HYBRID	0.09	0.28	0.00	1.00
BT_SLABBLOCK	0.33	0.47	0.00	1.00
BT_TERRACE	0.21	0.41	0.00	1.00
BT_BIGHOUSE	0.07	0.25	0.00	1.00
BT_TOWER	0.01	0.07	0.00	1.00
BT_URBANVILLA	0.09	0.29	0.00	1.00

Tab. 3 Summary statistics

4 ANALYSIS AND RESULTS

Tab. 4 presents the results of the model outlined above for the complete dataset as well as for the two subsets, Trondheim centre and Trondheim periphery. Fourteen observations that had a population and/or built coverage density of zero were excluded. A population and/or built coverage density of zero should not be possible in a populated built-up area, but due to data inconsistencies arising from different ages of the underlying datasets, i.e. the population data being slightly older than the building data, and the building data being slightly older than the sales data, it nonetheless occurred.

After heteroscedasticity was detected following some of the initial model runs, achieving significant results with White's general test (e.g., for the complete dataset, Global version 1 below, Chi2 = 183.97, p = 0.00) and occasionally with the Breusch–Pagan test that tests for linear forms of heteroscedasticity (e.g., for City centre version 1 below, Chi2 = 5.02, p = 0.03), (heteroscedasticity) robust standard errors were used in the subsequent analysis.4 A common problem in hedonic pricing models is multicollinearity, which arises when independent variables are highly correlated. To address this issue, a correlation matrix for all independent variables was computed. Five variable pairs were identified as highly correlated (r>0.8***): HOUSE_APART and MULTISTOREY, DIST_HIGHEREDU and ELEVATION, DIST_FJORD and ELEVATION, DIST_FJORD and DIST_HIGHEREDU, POP_HA and DWELLINGS_HA. As there are very few multi-storey apartments in the dataset, but houses generally are multi-storey properties, the variables HOUSE_APART and MULTISTOREY practically describe the same thing and consequently the variable MULTISTOREY was dropped. Most higher education facilities are located in proximity of the fjord, which means that for most of the dataset as distance to the fjord increases so does distance to higher education; and as elevation increases with distance to fjord, these three variables point in the same direction. That is why, for the analysis, only DIST_FJORD was included. Since the focus of this analysis is density, neither dwelling unit density nor population density was excluded, rather separate models were run, including one or the other. After further conceptual considerations and initial regression rounds, it became evident that the variable HOUSE_APART and the building type variables when coded against BT_URBANVILLA, which is the single-dwelling free-standing house in the dataset, effectively describe the same matter, the building type variables being the more detailed version. However, since adding the building type variables to the model, rather than HOUSE_APART, did not increase the variance explained by the model and the general conclusion remained the same, that is that apartments are overall more expensive than houses, the HOUSE_APART variable was chosen. Due to the clustered nature of the initial data collection, potential issues of spatially auto-correlated residuals were not explicitly addressed in this study.

The regression results of the model clearly show that there are substantial differences between the two subsets, Trondheim centre and Trondheim periphery. The R^2 –values, which measure the quality of fit of the models, are much bigger for the periphery (and the whole dataset) than for the city centre, indicating that the model as it is specified now explains more of the variation in property prices of the periphery dataset and the whole dataset than it does for the city centre dataset; which is a reasonable finding given the fact that there are likely many more factors contributing to property prices in the city centre than are included in this study. Taking a closer look at the coefficient estimates, one also finds considerable differences between what is and what is not significant in the different versions of the model. The only three parameters that are significant for the global, centre, and periphery versions of the model are age of property (*AGE*), house or apartment (*HOUSE_APART*), and distance to fjord (*DIST_FJORD*).

The parameter estimates of AGE in the global versions of the model (columns 1 and 2 in Tab. 4) seem to indicate that an additional year would result in a decrease in price per square metre of between 0.109 and 0.117%, ceteris paribus.[5] At a mean property sales price per square metre of NOK 41,366, this results in a marginal implicit price of between NOK -45.09 and -48.40. In the city centre (columns 5 and 6), the decrease in price per square metre is smaller for every additional year added (between 0.095 and 0.096% or between NOK -39.30 and -39.84 evaluated at the mean property sales price per square metre), whereas in the periphery (columns 3 and 4) it is greater (between 0.263 and 0.312% or between NOK -108.79 and -129.06). This might be due to different valuations of building age in the periphery and the centre. In the city centre, many buildings are historic and/or under heritage protection, whereas in the periphery many developments are newer and age is not seen as a positive attribute, but rather as a potential cost factor. With respect to years since last refurbishment (*YEARS_REFURB*), the estimates were only significant for the global and the city centre versions of the model. The marginal implicit price of increasing the time since last refurbished by one year, evaluated at the mean property sales price, ranges from NOK -37.68 to -38.09 for the global model and from NOK -

[4] In the presence of heteroscedasticity, which is a common occurrence when using cross-sectional data, the least squares estimator is still a consistent and unbiased estimator, yet it is no longer best (i.e., efficient). There is another estimator with a smaller variance. Moreover, the standard errors computed for the least squares estimator are incorrect. Confidence intervals and hypothesis tests based on standard errors may therefore be misleading. A common solution to this problem is the use of heteroscedasticity robust standard errors.

[5] For the remainder of this discussion ceteris paribus, i.e. all other variables held constant, is assumed.

30.36 to -30.44 for the centre model. As with age of property, the price per square metre decreases with an increase in time passed.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Global	Global	Periphery	Periphery	Centre	Centre
AGE	-0.00117***	-0.00109***	-0.00312***	-0.00263***	-0.000963***	-0.000950***
	(0.000180)	(0.000181)	(0.000554)	(0.000559)	(0.000195)	(0.000194)
YEARS_REFURB	-0.000911***	-0.000921***	-0.000909	-0.000969	-0.000736***	-0.000734***
	(0.000221)	(0.000221)	(0.000601)	(0.000592)	(0.000228)	(0.000227)
HOUSE_APART	-0.209***	-0.193***	-0.221***	-0.168***	-0.145***	-0.140***
	(0.0205)	(0.0206)	(0.0225)	(0.0230)	(0.0535)	(0.0540)
GROUNDFLOOR	-0.0180	-0.0126	0.0591***	0.0693***	-0.0199	-0.0201
	(0.0146)	(0.0146)	(0.0172)	(0.0170)	(0.0187)	(0.0187)
DIST_BUSSTOP	5.57e-05	5.24e-05	-0.000304***	-0.000314***	0.000227**	0.000216**
	(7.05e-05)	(7.04e-05)	(8.73e-05)	(8.58e-05)	(0.000105)	(0.000105)
DIST_SUPERMARKET	9.36e-06	3.60e-05	1.31e-05	6.90e-05	-1.22e-05	1.01e-05
	(4.04e-05)	(4.11e-05)	(5.03e-05)	(5.08e-05)	(6.89e-05)	(6.95e-05)
DIST_KINDERGARTEN	-9.03e-05*	-9.66e-06	-0.000167**	-0.000139*	-7.94e-06	2.99e-05
	(4.79e-05)	(4.83e-05)	(7.98e-05)	(7.95e-05)	(6.94e-05)	(6.76e-05)
DIST_SCHOOLS	1.59e-05	6.21e-07	0.000131***	0.000161***	-8.88e-05*	-0.000108**
	(3.14e-05)	(3.20e-05)	(4.95e-05)	(4.78e-05)	(4.92e-05)	(4.89e-05)
DIST_SHOPPING	-4.38e-05***	-3.74e-05***	-2.85e-06	3.81e-06	-0.000189***	-0.000188***
	(8.79e-06)	(8.97e-06)	(1.23e-05)	(1.20e-05)	(2.53e-05)	(2.51e-05)
DIST_FJORD	-5.08e-05***	-5.13e-05***	-4.54e-05***	-4.15e-05***	7.21e-05***	7.03e-05***
	(3.15e-06)	(3.18e-06)	(4.21e-06)	(4.24e-06)	(2.13e-05)	(2.10e-05)
DIST_NATURE	0.000205***	0.000175***	0.000282***	0.000322***	0.000132**	0.000105
	(3.81e-05)	(3.98e-05)	(5.49e-05)	(5.37e-05)	(6.25e-05)	(6.42e-05)
PERC_BUILT	0.00115	0.000491	0.00147	8.05e-05	-0.00166*	-0.00178*
	(0.000780)	(0.000776)	(0.00184)	(0.00183)	(0.000963)	(0.000923)
POP_HA	-0.000455***		-0.000267		3.97e-05	
	(0.000116)		(0.000238)		(0.000155)	
DWELLINGS_HA		0.000143		0.00143***		0.000243*
		(0.000118)		(0.000364)		(0.000141)
CONSTANT	10.86***	10.79***	10.78***	10.60***	10.89***	10.88***
	(0.0402)	(0.0397)	(0.0679)	(0.0722)	(0.0549)	(0.0543)
Observations	1,241	1,241	609	609	632	632
R-squared	0.537	0.533	0.540	0.550	0.253	0.256
Root MSE	0.203	0.204	0.199	0.197	0.186	0.185
Mean VIF	1.60	1.64	1.64	1.66	1.85	1.85

Dependent variable = LN_PRICE_SQM
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Tab. 4 Regression results

Looking at the property type parameter estimates, house or apartment (*HOUSE_APART*), the estimates indicate that buying a house rather than an apartment reduces the price per square metre, in the case of the global versions by between 19.3 and 20.9%, in case of the periphery versions by between 16.8 and 22.1%, and in the case of the city centre versions by between 14.0 and 14.5%. Calculating the marginal implicit prices (for the mean sales price per square metre), this translates to NOK 5,791.24 and 5,998.07 for the city centre, NOK 6,949.49 and 9,141.89 for the periphery, and NOK 7,983.64 and 8,645.49 for the global versions. The dummy variable *GROUNDFLOOR* is significant only in the periphery, where ground-floor access seems to be a valued commodity, increasing the price per square metre by between 5.91 and 6,93%.

With regard to the distance measures, proximity to a bus stop is a desirable attribute in the periphery, but not so in the city centre. In the periphery, the price per square metre decreases when the distance to the nearest bus stop increases. An additional 100 metres will reduce the price per square metre of a property sold at the mean sales price per square metre by between NOK 1,257.53 and 1,298.89. In contrast, an additional 100 metres distance in the city centre will increase the price per square metre of a similar property by between NOK 893.51 and 939.01. This could be due to the perception of a bus stop. In the centre, where many bus stops are frequented by multiple bus lines, a bus stop can be perceived as a noise pollutant and a nuisance;

whereas in the periphery a bus stop is an important access point to the public transport network and represents an improvement in the general accessibility of the property.

Easy access to supermarkets has not been significant for any of the versions of the model. That is perhaps because supermarkets are scattered all over the city, and food seems to be readily available everywhere. Distances to shopping centres, on the other hand, have proven highly significant at a 0.01 level for the global and city centre version of the model. Evaluated at the mean sales price per square metre, an additional 100 metres in distance to the nearest shopping mall will reduce the price per square metre of the property by between NOK 154.71 and 181.18 globally and between NOK 777.68 and 781.82 in the city centre. Living close to a school seems to be an attractive quality in the city centre, but not so in the periphery. In the city centre, an additional 100 metres in distance to the nearest school can decrease the square metre price between NOK 367.33 and 446.75, whereas in the periphery the square metre price can increase between NOK 541.89 and 665.99. A kindergarten, on the other hand, is valued only in the periphery, where an additional 100 metres in distance reduces the square metre price between NOK 574.99 and 690.81.

In considering proximity to the fjord (*DIST_FJORD*), estimates for all three versions of the model are significant. For the periphery and globally, an increase in distance away from the fjord results in lower property prices per square metre. An additional 100 metres decreases the price per square metre in the periphery by between NOK 171.67 and 187.80 and globally by between NOK 210.14 and 212.21, evaluated at the mean sales price per square metre. For the city centre, however, property prices per square metre seem to increase with an increase in distance to the fjord. An additional 100 metres away from the fjord adds between NOK 290.80 and 298.25 to the property price per square metre. This distinction might be due to Trondheim's inner-city coastline characteristics. Much of Trondheim's waterfront is industrial rather than residential, which could explain why homebuyers in the centre prefer to avoid proximity to the coast and the industrial areas. In the periphery, however, the fjord provides attractive views for many privileged dwellings.

With regards to proximity to green and recreational space (*DIST_NATURE*), parameter estimates for the global, periphery, and one of the city centre versions of the model are significant, indicating that an increase in distance away from the city boundaries and nature increases the price per square metre of a property. An additional 100 metres in distance to nature (and thus closer to the centre), again evaluated at the mean sales price per square metre, can add between NOK 723.91 and 848.00 globally, between NOK 1,166.52 and 1,331.99 in the periphery, and NOK 546.03 in the city centre. This is a plausible finding because properties close to green space (especially large ones) tend to be perceived as more isolated and far away from everything.

The parameter estimates of the density measures are not what one would have expected given the findings of the initial correlation analysis. Ideally, the estimates should have been significant throughout and all pointing in the same direction. However, they are not. Population density is only significant in the global model, where it indicates that adding 10 additional people within the 1-hectare circles would decrease the square metre price by NOK 188.22. Built coverage on the other hand is only marginally significant (at a 10% level) in the city centre, where according to the estimates a 10% increase in building mass would result in a square metre price reduction of between NOK 68.67 and 73.63. This could be due to the fact that above certain thresholds of building density spatial qualities such as natural lighting, ventilation, green spaces, and views are negatively affected. Where this threshold lies is dependent on the particular context, which is influenced by cultural and aesthetic values of the population. It seems that in Trondheim city centre where the larger values in build coverage exist, density is already perceived as high enough. The only variable that has a positive impact on square metre price in this model is dwelling unit density. The variable *DWELLINGS_HA* is significant in the periphery and the centre, where an additional 10 dwellings per hectare would add NOK 59.15 and 100.52 to the square metre price, respectively. These findings are somewhat hard to interpret. On the one hand, the model results seem to indicate that Trondheimers value spaciousness, i.e. space away from other people and from the next building. On the other hand, they also seem to value a certain degree of dwelling unit density.

This, however, correlates with the fact that apartments, which are usually located close to other apartments, are generally more expensive per square metre than free-standing houses.

5 DISCUSSION AND CONCLUSION

A preliminary analysis comparing the average sales prices per square metre with population density and dwelling unit density measures indicates a pronounced positive correlation between higher densities and higher prices per square metre. From this initial observation, the working hypothesis was proposed that urban density is a well-accepted characteristic in highly valued urban centres of Norway and that therefore the housing market would reflect the Norwegians willingness-to-pay for higher density well-located urban environments. The hedonic pricing model, however, even though it did not contradict this hypothesis, displays a more nuanced picture in which higher dwelling density per hectare positively influenced housing prices, but population density per hectare had a contrary effect. Multiple factors could have contributed to this finding.

The materialisation of density in the built environment involves a large variety of forms that influence urban and architectural qualities in different ways. How people value these qualities is a context-specific issue that influences the diversity of urban environments that exist, not only in different places but also through time. The variables of density and proximity used in this analysis are common measures, but they do not encompass all the spatial qualities affecting housing prices. The variables included in the hedonic model, as well as the size of the sample, do not allow for the explanation of the apparent inconsistencies between the positive influence of an increased dwelling density on housing prices and the negative influence of people per hectare. One would assume that if in a given area an increase in dwelling density positively affects prices, the same would hold true for population density, but this is not the case here. However, dwelling and population density do not necessarily increase at the same rates. The concentration of single-occupant and dual-income no-kid homes in a given location increases the dwelling density but not the population density. This is especially true when compared to areas in the periphery that are characterised by larger dwelling units, which are more popular among families with children. This fact could explain this paradox. If this is the case, even though the hedonic analysis does not confirm the initial working hypothesis, neither has it offered solid evidence to prove it wrong.

The sampling method, based on the visual identification of 23 representative urban patterns, may account for the diversity of urban environments of Trondheim, but it does not allow for the estimation of the extent to which the sales transactions are likely to differ from the total housing transactions in the city; that is, the housing transactions clustered in the 23 characteristic urban areas are not necessarily representative of the total housing transactions of the city. This represents a clear limitation for any generalisations drawn from this study and points towards the need of expanding the sample. Any future study of density and property prices in Trondheim should therefore either be based on a complete dataset of sales transactions over a certain period or on a random sample. What can be concluded from this study is that property prices and the measures of urban density correlate, indicating that properties are more expensive in denser locations. Yet it also shows that there is ample room to further study the relationship of urban density and housing prices. Is density indeed a quality reflected in property prices and thus socially accepted? Or is it a mere secondary object of consideration when buying a new property? Whilst the initial correlation analysis seemed to show that urban density is a valued quality in Trondheim's housing market, this study following the regression analysis cannot confirm this preliminary observation.

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IMAGE SOURCES

Fig. 1: Analysed areas in Trondheim centre: Own elaboration based on data from the Norwegian Mapping and Cadastre Authority https://www.kartverket.no/

Fig. 2: Analysed areas in Trondheim periphery: Own elaboration based on data from the Norwegian Mapping and Cadastre Authority https://www.kartverket.no/

Fig. 3: Building types: Own elaboration

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