THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

The monetary value of urban form

Examining the relationship between accessibilities and attractiveness in Oslo

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Abstract

Today and for the foreseeable future we experience a global urbanisation, which requires development of buildings, roads, and plots, also called urban form. Most often it is urban planning and design that determine changes in urban form, and it should be valuable with knowledge of its monetary value. Considering both the rapid urban development and that buildings and roads are slow variables in cities, it should be an important factor for urban planning and design to be aware of the value created or lost with proposed development. This research aims to examine the nature of the monetary value of urban form by reviewing prior research and through hedonic modelling empirically estimate the marginal willingness to pay for location in Oslo, Norway. The review is conducted through an overview of previous projects from practice on the topic and a systematic review of peer reviewed papers. The empirical examination is principally built on the connection of a geographic model to quantify urban form, and an economic model to estimate monetary values. Two empirical studies are carried out to first estimate the intrinsic monetary value in urban form, and second to investigate how the monetary value changes with distance to amenities, such as parks. The findings suggest that there are indeed monetary values connected to urban form and that urban form variables in comparison with more commonly used variables to describe location have a higher explanatory degree in the economic model. The empirical findings also suggest that there are clear non-linear relationships between distance to amenities and price, indicating that not only urban form influence housing prices but also the composition of urban form. The results provide knowledge to the planning and design practice to appreciate attractiveness of aspects of plans and designs. The results also bring new knowledge to the research field of urban morphology of the monetary value of urban form and shed light on methodological deficiencies in the research field of urban economics.

Keywords: urban form, monetary value, accessibility, hedonic price model, urban planning, urban design, urban economics, attractiveness

List of publications

This thesis is based on the work contained in the following papers:

Paper I: Heyman, A., & Manum, B. (2016). Distances, accessibilities and attractiveness; urban form correlates of willingness to pay for dwellings examined by space syntax based measurements in GIS. The Journal of Space Syntax, 6(2), 213–224.

Contributions: AH initiated, contributed much, and decided on the conceptualisation and design of the study. AH collected the data. AH wrote most of the paper, both preceding conference paper and journal paper. AH performed the analysis.

Paper II: Heyman, A. V., Law, S., & Berghauser Pont, M. (2019). How is location measured in housing valuation? A systematic review of accessibility specifications in hedonic price models. Urban Science, 3(1), 3.

Contributions: AH and SL initiated, contributed, and decided most on the conceptualisation and design of the study. AH collected the data and SL helped specify the search terms. AH wrote most of the paper. AH performed the analysis. AH read most of the papers.

Paper III: Heyman, A. V., & Sommervoll, D. E. (2019). House prices and relative location. Cities, 95, 102373.

Contributions: AH initiated and contributed much to the conceptualisation and design of the study. AH and DES decided on the conceptualisation and design of the study. AH collected the data. AH and DES contributed equal to the writing. AH performed all the spatial analysis. AH made a smaller contribution to the econometric analysis in the beginning.

Paper IV: Łaszkiewicz, E., Heyman, A., Chen, X., Cimburova, Z., Nowell, M., & Barton, D. N. (2022). Valuing access to urban greenspace using non-linear distance decay in hedonic property pricing. Ecosystem Services, 53, 101394.

Contributions: AH initiated, contributed much, and decided on the conceptualisation and design of the study. AH collected the data. AH, EL and DNB wrote most of the paper. AH performed all spatial analysis. AH performed the early-stage analyses, including all econometric analysis in a preceding conference paper.

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My family has given me great support. Malin and James, thank you for good discussions and moral support. Thank you, dad for both practical help and moral boosting. I would like to express a special thanks to my mom, who has been truly supportive, both in practical matters and with moral support. My children – Tora and Ante – have also been truly supportive and given me much-needed energy. Last but not least, I would like to express my deepest gratitude to my dear wife, Jessica for putting up with me all this time, and for your ability to change my focus from work to much-needed mental rest.

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1. Introduction

Cities constantly evolve and add new or regenerate existing physical structures to adapt to new circumstances, most often managed by urban planning and design. In recent decades, the evolution of cities has been driven by global migration to urban areas, and the planning and design of cities is critical. But we know that the urban growth is not equally distributed everywhere. It differs between different parts of the globe, between different cities within countries and regions, and between different parts of a city. On the one hand, people follow jobs (Muth, 1971), on the other, it has also been found that jobs follow people (Carlino & Mills, 1987; Hoogstra et al., 2017; Mulligan et al., 1999). Reasons for the urban migration is manifold and differ in different places but is frequently related to a search for a sustained or higher quality of life. This also holds true for migration within cities, seeking higher quality of life within the same city. Hence, to entice people and activities, cities need to consider their attractiveness for residents as well as workplaces.

One aspect to consider is urban planning and design, which potentially have a decisive effect on the attractiveness of a city, although other parameters in this complex formula are relevant, such as climate, history and a neighbourhood's social composition or political orientation. The effect of urban planning and design on attractiveness can be exemplified by the existence of two similar dwellings in different parts of a city that differ in price, implying that the location is a decisive factor when choosing home. A place can thus be appreciated to a different degree due to various aspects in how it and its surroundings are planned or designed. The urbanization leads to a need for more housing and more activities in a city, which must be planned and designed. At least in a western context, this is administered and permit-

ted by the local government, which makes it important to consider how the development could be composed to create higher quality of life for the city's residents and workers.

The effect of urban planning and design on attractiveness, based on the assumption that attractiveness is public opinion, can essentially be analysed with two optional approaches: stated or revealed preferences. Stated preferences are people's opinions based on interviews or surveys. In this case, one would ask what aspects of the urban environment people prefer and combine their answers to build knowledge of the population's aggregated preferences. The critique of this method is that people might answer differently to how they would act if a real choice was given to them between different aspects to trade off of. Possibly, people behave differently than what their stated preferences say. To remedy this, one can use a revealed preference method, which seeks to analyse people's preferences through their actual choices.

This research follows the revealed preference approach to analyse the effect urban planning and design has on attractiveness. This requires relevant input in form of quantitative measures of urban planning and design, as well as of attractiveness.

Urban planning and design primarily concern urban form, which in its most basic form consists of streets, buildings, and plots. The distribution and composition of these elements are defined by urban planning and design. The land use of these elements, parks, housing, offices etcetera, are also an important aspect of urban planning and design. The quantification of urban form concerns in simple terms the measurement of how streets, buildings, and plots are composed individually and in relation to each other. For instance, we can measure the density of buildings or plots within an area or how the street network creates particular distances between different buildings and plots in a city. In extension, it also includes the distribution and composition of land uses in this landscape of urban form.

To fit the purpose of this research it is important that the measures of urban form correspond with people's perception and what planning and design can influence. For that reason, it is helpful to look at urban form from a locational perspective, meaning that the chosen measures of urban

form are done to describe how a place is located. The description of location can purposefully be divided into absolute or relative descriptions of location. Absolute descriptions of location describe for example a building's location as located in a certain neighbourhood or at specific cartesian coordinates. Relative descriptions of location describe a building's location in relation to other places, for example next to a certain train station or five minutes' walk from a park. Importantly, relative location is normally measured by straight-lines to other location, but it can also be measured following the street system, that is, as determined by urban form. This division of descriptions of location does not imply that a place has different locations, but that its location can be described in different ways. Methodologically, absolute and relative location are measured differently and thus have an impact on the results when revealing preferences.

Typically, a market would reveal a population's preference based on supply and demand, implying that higher demand and or lower supply in a market results in higher prices that could serve as a proxy for attractiveness. However, in the case of urban form, it is only traded on a market to a limited degree. Buildings and plots, but not streets, are traded, and the configurations of urban form are arguably never traded in a market. Thus, the preference for it cannot be interpreted from a market price or number of sales. Instead, one can turn to methods that reveal the preferences indirectly through the trade of other goods. A fitting example of such a good is housing, which theoretically can be seen as consisting of many characteristics that are valued individually (Lancaster, 1966). With a sufficient sample of dwellings, it is possible to differentiate the price for each of the characteristics, which is typically called hedonic price modelling (Rosen, 1974). In housing, the different kind of characteristics can be divided into structural (for example number of rooms), neighbourhood (for example public transit access), and environmental (for example noise pollution) (Freeman, 1979). The estimated marginal prices for the different characteristics will then represent the corresponding revealed preference and stand as an estimation of the monetary value of urban form.

This approach would benefit a more balanced discourse for how to plan our cities. From a market perspective, urban planning and design can easily be perceived as a bureaucratic cost and its ability to generate economic value is likely underestimated. The underestimation might be be-

cause the most visible economic upside for a local government in city development is the revenue from selling land or through development agreements, and to some extent reliefs in municipal expenditures. This is problematic since urban planning and design greatly influences land prices in the long term, including prices of land that is privately owned and consequently will benefit those private interests. However, the monetary value of urban form has only been researched to a limited degree, and the fact that the revenue usually comes long after the planning and design, makes the connection between the urban form and land prices less obvious. The monetary value of urban form, expressed as preferences approximated from housing prices, could be seen as a possible means to reach sustainable urban development.

1.1 RESEARCH AIM AND QUESTIONS

The aim of this thesis is to investigate the nature of the monetary value of urban form, especially the role of the street network, exploring measures of relative location in hedonic price modelling. Using sale prices on free hold apartments and corresponding measures of urban form in Oslo, Norway, the aim is to proxy attractiveness and estimate the monetary value of urban form. The aim of the thesis is not to provide a complete planning guiding tool but to inform urban planning and design about the monetary value planning and design creates. Furthermore, the research aims to contribute to the development of the methodology of economic valuation.

On this background, three research questions have been defined.

- How has the international literature measured relative location through urban form in housing evaluation studies?
- How do location variables based on relative descriptions perform in a hedonic model compared to those based on absolute descriptions?
- How does the relation between distance and price look like in the example of accessibility to urban greenspace in hedonic property pricing?

1.2 SCOPE, LIMITATIONS, AND DELIMITATIONS

This thesis uses Oslo, Norway, as a case study to investigate the aims and objectives accounted for above. It is situated in a quantitative analytical paradigm that to some degree connects urban form, economics, and geography. The interdisciplinary nature of the work is relevant for many epistemological framings, and are touched upon in chapter 2 and 3 with focus on urban morphology, which is most relevant for this work.

Further limits of this research are partly related to the investigation of a single case and partly to the delimitation of using free hold apartment prices to measure attractiveness through housing prices. The measure does not include the whole Oslo housing market but is a first step and a proof of concept for investigating preferences for non-market goods. Although there is no reason to believe that Oslo differs much from other western cities in terms of preferences of location, the results must be viewed in the context of a medium-sized capital city in northern Europe. Furthermore, the research concerns preferences for free hold apartments, which might differ from other tenure segments in the market, such as rentals or condominiums and most probably from single family houses. Another limitation is the focus on quantitative measures of urban form, which excludes more qualitative measures that would enhance the description of urban form. It is consumer preferences that are estimated, which most probably include qualitative aspects. The lack of qualitative measures, such as the atmosphere of the neighbourhood or the aesthetic appeal of buildings, have probably led to omitted variable bias to some extent. Limitations in data, not least for structural variables (such as if the dwelling has a balcony or a fireplace), is another issue that should be mentioned. Information on parking, balconies, ceiling heights, fireplaces, room layouts, and view quality would make the models more reliable. Limitations related to the individual papers are stated therein, where the format or scope of research put restrictions on what to include.

1.3 RELEVANCE

Attractiveness in terms of the location of cities, that is, where they are located geographically, is determined by

many factors, such as whether the city is close to the coast and what the climate is like (Chen & Rosenthal, 2008). Differences in attractiveness within cities are to a degree determined by relative location defined by urban form, which in turn has implications on social (Åslund et al., 2010; Putnam, 2001; Wang et al., 2016), ecological (Ewing & Cervero, 2010; Holden, 2004; Jabareen, 2006), and economic (Duque et al., 2022; Ghaffar & El Aziz, 2021; Glaeser, 2012; Jacobs, 1970) value. In the ongoing rapid urbanization, where the growth of cities leads to profound changes in their urban form, it is relevant to understand the nature of its monetary value.

In extension, by defining location, urban form affects fundamental socioeconomic value, notably also outside the boundary of the area of intervention. Even though the relation between socioeconomic values and urban form has been investigated previously, the description of urban form has usually been vague and the results therefore difficult to translate into urban planning and design practice. As a consequence, planning interventions and their implications on socioeconomic values are today commonly assessed within the boundary of the area of intervention, while contextual effects outside this boundary are ignored.

1.3.1 Societal relevance

Urban development is highly complex, including a range of actors from public authority, private enterprise, and civil society (Innes, 1995). This heterogeneous group of stakeholders often have diverging interests and come from different positions in society. Furthermore, the game board on which urban development is carried out includes many fields, such as legal, economic, ecologic, spatial, and social, just to mention a few. It becomes obvious that the diversity of actors and the variety of fields can create both inefficiency and lack of transparency. Research on the monetary value of urban form could potentially serve as a ‘shared language’ between different actors in the urban development process. By subscribing economic value to urban form, the value of urban planning and design could more readily be communicated to developers, just as city budgets could note changes in value created by urban planning and design. A relevant comparison could be cost-benefit analyses of transport development, where the changes in travel time are given a monetary estimation to be able to appreciate the impact and weigh against other interventions.

From a planning authority perspective, increase of property value is rarely a goal in itself, but rather a side effect. However, since planning and design always concern investments in land, changes in property value are almost inevitable. Being able to predict the changes, could prove beneficial in the processes. Hopefully, the present study can offer planning authorities some means to improve the calculation of the increased value of land due to urban planning and design. This in turn could change the feasibility in many urban development projects. Although social and ecological values are usually sought in a city's vision, the economic side is often given more weight in the city budget.

This line of argument also holds for Oslo, the capital of Norway. It is one of Europe's fastest growing capitals, having grown with 27 percent between 2005 and 2018 (Statistics Norway, 2022). The predicted growth means that much new housing, commercial space, and infrastructure will be added or regenerated, which could be seen as a challenge but also as a great opportunity. Since the growth consists of changes of urban form in the city, which in turn creates or reduces attractiveness, it would be possible to steer the socioeconomic processes in a desired direction through urban planning and design. This research's introduction of monetary value in urban form should be of relevance for building the strategy of how to transform the city over the coming decades.

Introducing a more informative description of urban form, and its influence on relative location, and relating it to attractiveness and monetary value should make it possible to allocate public investments more efficiently. Introducing informative descriptions to investigate the nature of monetary value of urban form may help clarify that variations of an aspect of urban form is highly important in the analysis and interpretation. For example, the relationship between density and monetary value is not as simple as higher density means higher monetary value, but it is a matter of how density is made. The same is true for green or mixed use. This is essential information to planning and design practice.

The knowledge about attractive urban form is important because of its longevity and because it is a slow variable in the complex system of a city. Urban form, especially in terms of street layout and connectivity, lasts for a very long time, not uncommonly hundreds if not thousands of years.

This means that making informed decisions in urban planning and design is of critical importance.

1.3.2 Scientific relevance

This work connects two fields of research, urban morphology and urban economics, and can thereby contribute to both. The relevance to these two fields can briefly be described in that urban economics benefits from using more precise descriptions of location and urban morphology benefits by translating the vague concept of attractiveness into microeconomics.

The benefit of using more precise descriptions of location comes from the basic assumption in hedonic theory that in order to estimate the willingness to pay for characteristics in a good, the variables used in the model must reflect consumer perception (Palmquist, 2005). Furthermore, the characteristics must be valued by the consumers in order to infer willingness to pay. For example, because living close to the urban centre of a city or its central business district has been estimated to create a premium on housing prices (e.g. Huang & Yin 2015, Sohn et al. 2012, and Zhang et al. 2022), one could (as a planner) draw the conclusion that we should build very dense in the city centre or close to it to build attractive housing. However, with more detailed descriptions and measures of location, one could determine what makes the central location attractive in much greater detail and also understand what this centrality should be combined with. This is also connected to the relevance of this research for the scientific field of urban morphology, where it contributes to the central issue of being accurate about what measures or descriptions of urban form are relevant for a particular method or research question.

1.4 THESIS ORGANISATION

This thesis is based on the four papers listed below. The first two papers identify and clarify the research aim by reviewing contemporary research on the topic and identifying knowledge gaps. The third and fourth papers report from empirical studies that try to fill the identified gaps.

Paper I. Axel Heyman and Bendik Manum (2016). Distances, accessibilities and attractiveness: Urban form correlates of willingness to pay for dwellings examined

by space syntax-based measurements in GIS. The Journal of Space Syntax, 6, 213–224.

Paper II. Axel Heyman, Stephen Law, and Meta Berghauser Pont (2019). How is location measured in housing valuation? A systematic review of accessibility specifications in hedonic price models. Urban Science, 3, 3.

Paper III. Axel Heyman and Dag Einar Sommervoll (2019). House prices and relative location. Cities, 95, 102373.

Paper IV. Edyta Łaszkiewicz, Axel Heyman, Xianwen Chen, Zofie Cimburova, Megan Nowell, and David N Barton (2022). Valuing access to urban greenspace using non-linear distance decay in hedonic property pricing. Ecosystem Services, 53, 101394.

Paper I looks at previous studies that have used different techniques for measuring urban form and correlating it with housing prices. The studies reviewed are not published in peer-reviewed journals but are found in consultancy work and hence are not completely transparent regarding methodology or data. Nevertheless, Paper I compiles the results and methodological approaches and relates them to the literature in the field. It is found that accessibility is a key factor in people's preferences for location. One key observation is that the specification of variables describing the characteristics of a dwelling plays a large role in terms of the perception of the buyer. This, in turn, is key in the hedonic theory on which the studies are based. Essentially, if one only seeks goodness of fit in the models for estimating marginal willingness to pay (MWTP), one might end up with significant variables that in fact are not considered in the market since they are not perceivable from the perspective of the consumer or buyer. It is also observed that preferences for proximity to amenities in the urban environment should vary with distance, which means that the MWTP fluctuates with distance in a non-linear manner. This relationship is poorly considered in the studies reviewed, resulting in coarse and potentially incorrect information to planning.

Paper II is a systematic review of contemporary peer-reviewed research on hedonic price models (HPMs) using accessibility as explanatory variables to describe location. It frames the review according to different specifications of

accessibility and concludes where the field lacks adequate description of location and where it is sufficiently defined. First, the paper notes that accessibility is a way to quantitatively measure relative location. Furthermore, the paper finds that accessibility is often specified unsatisfactorily. It argues that the unsatisfactory specifications correspond poorly to consumer perception, and subsequently an argument of causality in the studies could be questioned. In addition, the paper identifies that the distance decay, in this case the way in which housing prices tend to decrease with distance from certain attractions, is not satisfyingly specified or theoretically underpinned.

From the identification of the problem in the previous papers, **Paper III** empirically tests how the specification of explanatory variables, using relative location as the description of location, performs in HPMs from a statistical, in particular explanatory, point of view. In urban economics and housing studies, location is often 'controlled for' by including postal codes or census tracts in the model – a description of absolute location. The models then estimate in which areas housing prices are higher and lower ceteris paribus. Paper III specifies different models and compares this common practice of postal code dummies with the relative location specification to see how well price variations are explained in the respective model. The paper concludes that relative location by itself is comparable to absolute location in terms of degree of explanation even though the models with relative location variables use fewer explanatory variables. More interestingly, if descriptions of absolute and relative location are combined in one model, the absolute descriptions become insignificant. This suggests that descriptions of relative location better describes variables that consumers value and that using descriptions of absolute location will overlook them.

Paper IV uses descriptions of relative location similar to Paper III but another econometrical modelling technique that also allows for including a distance decay function for each variable. To handle the supposed non-linear relationship between house prices and an explanatory variable, two alternatives are common practice – 'dummy-cuts' and pre-defined functional transformation, also referred to as the parametric approach. The former means that the distance to a park is cut into different dummy-variables simply stating whether the dwelling is within, for exam-

ple, 200 metres from a park or between one and two kilometres. The latter means that a predefined distance decay is approximated by using the logarithm of the variable. In contrast to these common approaches, Paper IV uses the penalised spline spatial error model (PS-SEM) to estimate the non-linear relationship. The results are functions of each significant locational explanatory variable, revealing how the prices vary with respect to distance. From this, it is revealed that the distance decay curves for many variables coincide with how far people are willing to walk. This suggests that the location of a dwelling to a large degree is considered from a pedestrian point of view. It is also revealed that the configuration of urban form itself has a monetary value.

In the next chapter, following this introduction, an overview of the background and the theoretical framework is presented. In Chapter 3, the overarching methodological approach is presented to supplement the methodological descriptions in each paper. Chapter 4 presents the results from all the papers, and Chapter 5 ties them together in a discussion. The last chapter draws some general conclusions from the work.

2 Background and theoretical framework

The challenge presented in the previous chapter is related to urban planning rooted in the scientific fields of urban morphology and urban economics. These fields constitute the theoretical framework in which the research is conducted and relevant parts of these are further developed in this chapter. The methods used in this research are empirically founded and located within geographical spatial analysis and econometrics, which are connected to the abovementioned scientific fields and further developed in the Approach chapter.

One key aspect of the thesis is to introduce upgraded measures of urban form to economic valuation methodology. The measures should both give relevant information for urban planning and design decisions, and it should connect to consumer perceptions, and by extension consumer behaviour. Urban morphology is the study of the physical and spatial form of cities and human settlements, although there is no common strict definition of the field (Oliveira, 2016). The field is usually described to be consisting of three schools – the English (Conzen, 1960; Slater, 1990; Whitehand, 2001), the French (Choay, 2014; Lefebvre et al., 1996; Panerai et al., 2004), and the Italian (Caniggia & Maffei, 2001; Cataldi et al., 2002) – which have applied related but different approaches. The English school typically is interested in descriptions and categorisations, while the other two schools are interested in using the elements of urban form and their configuration from the point view of the urban designer in urban planning and design (Xiao, 2017, pp. 42).

It has been recognised that the three schools all do research on multiple scales and most often by categorisations into types (Moudon, 1997). Furthermore, it is commonly added that the field includes the study of the evolution of urban

form over time. For a collection of definitions, though still incomplete, see Marshall and Çalişkan (2011). The field is concerned with the physical form of cities although it stresses the point that this form has co-evolved with humans over time and is therefore not an isolated phenomenon (Kropf 2018, pp. 14–15). The three directions of urban morphology described above agree that urban form can be broken down into the three main components of buildings, streets, and plots (Moudon, 1997). The combinations and configuration of those is called the urban tissue and can be said to be the primary unit of the urban expansion or regeneration that urban planning and design drives (Kropf, 2018, p. 15).

Although the definition of urban morphology is not set in stone, a general agreement on the focus of study exists among scholars (Gauthier & Gilliland, 2006). However, the approaches in the study of it and towards what ends differs widely. There has been an overweight towards qualitative approaches within the schools (Levy, 1999; Pont & Marcus, 2015; Serra & Pinho, 2013), although approaches outside these, such as Martin and March (1972), Hillier and Hanson (1989), and Steadman (1983), have used quantitative analyses. Together, the quantitative approaches have been defined as a direction within urban morphology called 'space morphology' (Moudon, 1992). Furthermore, the measurement of urban form has increasingly been supported by computer technology, for example GIS, where advancements are rapidly made (Gil et al., 2012). Advancements have also been made on data availability, especially during the last decade (Wei et al., 2022). Quantification of urban form has been undertaken by Alexander et al. (1977), Hillier and Hanson (1989), Marshall (2004), and Sevtsuk (2010) as prominent examples. Although these examples mainly analyse cities as networks, Gil et al. (2012) argue that integration of different morphological approaches is needed to attain a well-founded set of urban environmental attributes.

In Figure 2.1 a mapping of the field is presented where distinctions are made between normative and cognitive approaches and between externalist and internalist approaches on two orthogonal axes. Internalist studies treat urban form as an independent system, whereas externalist studies treat urban form as a result of other processes. Being used in many other fields of research and professional practice – for example, geography, architecture, urban planning and

design, and archaeology – the different approaches show a dispersal over the two axes (Kropf 2018, pp. 9–10). The urban morphological methods used in this thesis are foremost located in the cognitive and internalist quadrant since the aim is to describe location and to treat urban form as a system that is mostly determined by urban planning and design.

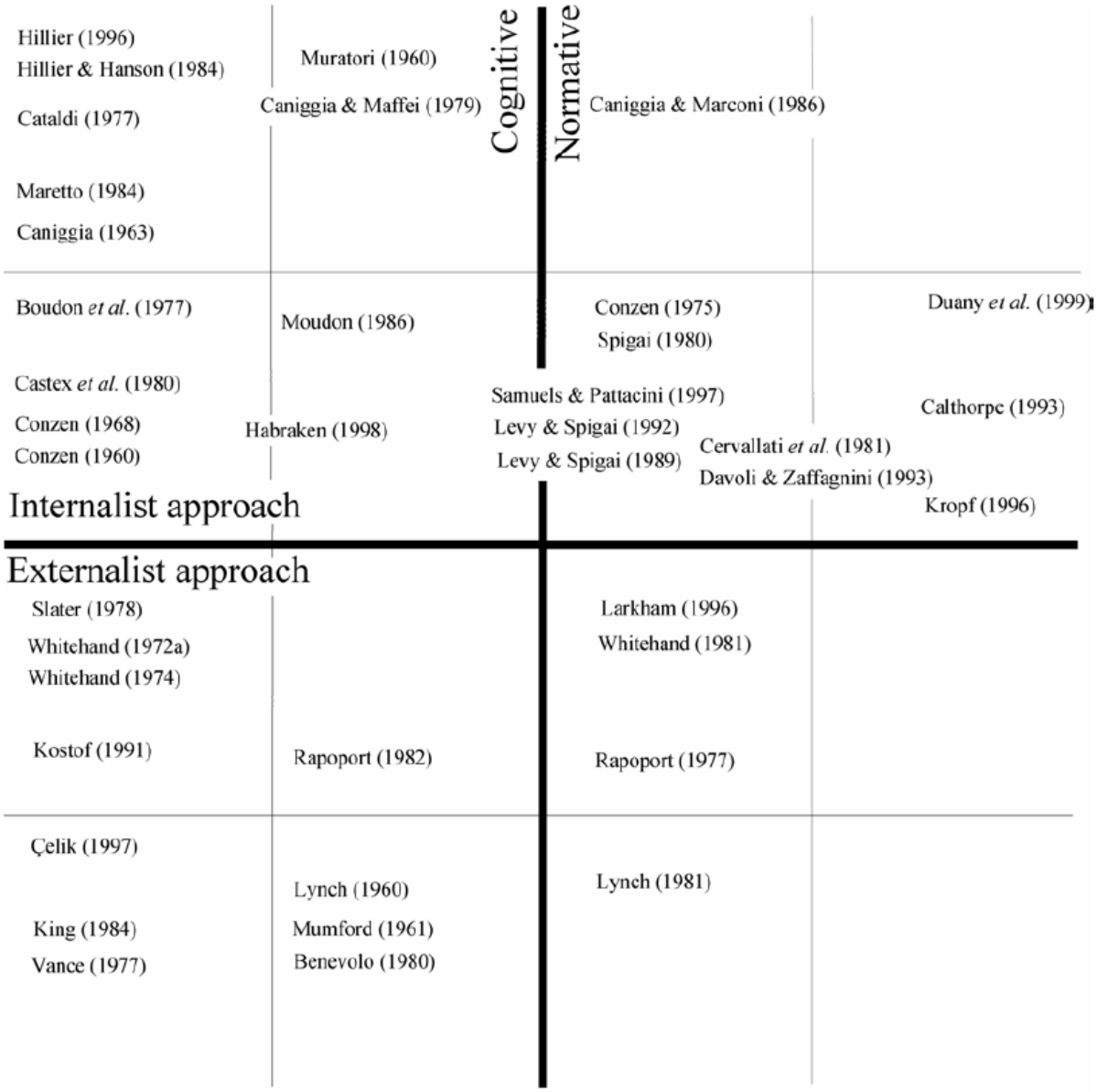


Figure 2.1. A classification of the main theoretical contributions in the field of urban morphology (Gauthier & Gilliland, 2006).

The economic side in this thesis boils down to a subfield within economics called urban economics or urban and regional economics. In principle, it is the field where processes connected to geography on an urban scale are examined via economic methods. There are no restrictions as to methods, but research tends to be of microeconomic

character rather than macro- or institutional economics. It is also connected to the field of research called housing studies, which, in contrast, takes much interest in macro- and institutional economics. However, this thesis is in its methodology using econometrical methods in the sphere of microeconomics. One of the axioms of urban economics is locational equilibrium, which also is at focus in this thesis (O'Sullivan 2011, pp. 7). In the case of housing, the locational equilibrium of the market is achieved when people move, and less coveted housing locations are compensated for by lower price (O'Sullivan 2011, pp. 7–9). An introduction to the field of urban economics on a general level, concerning locational equilibrium but not housing alone, is given here to contextualise the thesis.

Location and economic activity have been on the research agenda for a long time, with early examples of what can be defined as economic geography. Often the work of Johann Heinrich von Thünen is considered to be the first to take a spatial factor into the economic reasoning (von Thünen, 1826). It is based on the theories of the 'economic man' by Adam Smith[1] and the theories of land rent by David Ricardo[2], suggesting that man acts rationally and with a self-interest in profit maximisation. These assumptions have been criticised over the years, not least by Karl Marx and John Maynard Keynes, but many contemporary economic ideas and methods are based in the school of neoclassical economics. It is also considered as one of the axioms of urban economics that individuals maximise their utility, and firms maximise their profits. What von Thünen added to the theories was a spatial factor, suggesting that within this theoretical framework people will grow different crops in different locations based on distance to the market place. The distance was measured in a Euclidean space representing a concentric city or region.

Further, Hotelling took trading into consideration and argued for centralisation based on spatial market shares. Businesses will find a locational equilibrium where they are located next to each other in a market's spatial centre (Hotelling, 1929). This phenomenon is often referred to as Hotelling's paradox and holds true for two firms in a one-dimensional space and three firms in a two-dimensional space (McCann 2001, p. 32). However, the results do not hold true if the businesses also has the possibility to compete with price (d'Aspremont et al., 1979). For industrial

[1] The concept was originally published in Smith (1776) but has been thoroughly examined since.

[2] Although built on earlier work, the theories of land rent were largely developed by Ricardo (1891).

location, production and transport costs are considered, and their locational equilibrium can be derived from the Weber location-production triangle. The triangle sets the optimal location of the firm in a Euclidean representation of space, where the access to natural resources, workers, and the market are best (Weber, 1929). Losch (1954) and Christaller (1966) had similar ideas in regard to the location of firms, very much based on access to consumers, which in combination form a system of cities – a region. They based much of their work on hexagonal shapes as representations of space. In relation to the above, Alonso (1964) investigated residential location in the urban setting by applying von Thünen's model. The work of Alonso has also been developed by Herbert and Stevens (1960) by using discrete zones as the representation of space.

In the same scientific sphere, the new economic geography should be mentioned. It considers the location of production in space and argues for the agglomeration of production, in various forms, in urban areas (see Krugman 1991; Fujita et al. 1999; Porter 1998). Historically, the economic geography field has been practiced mainly by geographers and the new economic geography can be considered an attempt by economists to include a geographical dimension in their reasoning (Sjöberg & Sjöholm, 2002).

The aim and objectives of this research have theoretical challenges, which are presented below in the form of two main problems that are investigated.

2.1 FIRST PROBLEM: ATTRACTIVENESS RELATIVE TO HOUSING PRICES

The choice of trying to reveal attractive urban form through the proxy of its price on a market is presented with an obvious problem: urban form is not traded on a market. The contributions of urban planners, such as a park, which can be seen as an example of urban form, are rarely bought or sold and thus have no direct market value. Instead, in the context of urban planning, the market is to a large degree limited to the property market, where demands for new housing or commercial space drives a city's changes in its urban form. This presents the possibility to use housing prices as an alternative for how to approximate attractiveness in cities, assuming that prices correspond to consumer preferences. The solution to the problem is the immobility

of housing. Since housing cannot be moved to another location, its price depends on both the quality of the house and the quality of its location (Kiel & Zabel, 2008). Given that dwellings are sold at higher prices when they have preferable locations, one can distinguish which locations are considered attractive based on housing prices and describe urban form attributes in that location as a means to put a price on it.

This narrows down to what is referred to as the economic exchange value in neoclassical economics, or the market price. This is different from what Marx conceptualises as exchange value, which is what a commodity would trade for in other commodities and is not the same as the price (Marx 1890, p. 18). Broadening this perspective of value, things tend to also possess an economic use value in addition to an exchange value, which was recognised already by Aristotle. In this thesis, the differentiation between use and exchange value is of importance to illuminate that the economic value that can be assigned urban form need not be the only value but a value. The economic use value could be just as important for the societal good but is often harder to estimate. In the practice of urban planning and design, a use value of a place could be that it is healthier, which is of obvious benefit for the society but not necessarily economically more valuable. Broadening the perspective even more, the use value does not have to be monetary at all to be of relevance. For example, a place could generate a great sense of belonging and be valued highly socially, which most probably would benefit the society but not in an economical, at least direct, way.

That said, the use of housing prices as a litmus for preferences has been practiced extensively, for example, to support policy making (Whitehand, 2012). One of the most common methods for doing so is called a hedonic price model (HPM), which takes its name from hedonism due to the theoretical underpinning that actors on a market seek to maximise their pleasure or utility. The HPM is a method by which to distinguish the willingness to pay for differentiated goods – goods assumed to have a set of characteristics that influences the price (Kain & Quigley, 1970; Rosen, 1974). Although Rosen is often referred to as the core reference for the method, it was first used by Andrew Court in 1939, who defended General Motors against allegations of overpricing (Goodman, 1998). He showed, by calculating

the price for each characteristic of the automobile, that the increase in price was in balance with the increase in the quality of the good. This is also the fundament of the method – to see the good as a schedule of prices for different characteristics and through multivariate regression analysis estimate the price for each individual characteristic in housing. The rationale is based on the assumption that the utility given to a consumer is not based on the good per se but for their characteristics or properties individually (Lancaster, 1966). This means that consumers value a dwelling based on its characteristics and not as a whole (Rosen, 1974).

The theory of HPM is based on implicit markets and requires the supply of a large number of goods and a market characterised by many small actors who, one by one, have negligible influence on market conditions and prices (Palmquist, 2005). In hedonic analyses, the heterogeneous goods or dependent variable (in this case dwellings) are characterised by numerous variables (or attributes) that, one by one, provide benefit or disadvantage – that is, they affect the price, such as size or noise level. By multivariate regression analysis, the method estimates the price-effect of a change in each attribute, other attributes being constant. The hedonic approach can be seen as an umbrella for many different modelling approaches within econometrics (Sheppard, 1998). The approach has two stages, where the first stage does not take the characteristics of the consumers of dwellings into consideration, such as income or type of household, which gives the result of implicit marginal prices (Taylor, 2008). The second stage estimates preferences but is dependent on data on income for every consumer (Palmquist, 2005).

One advantage of the HPM is that it is based on the households' real preferences revealed on a market rather than stated in an inquiry with hypothetical alternatives (Cropper & Oates, 1992). Another advantage is that the model serves as a framework for both the characteristics of a location and on a dwelling's structural qualities (Baranzini et al. 2008, p. 4). Furthermore, the advances in geographical analysis and data supply open for the analysis of large samples, which by extension means the potential for better results (Angrist & Pischke, 2008).

2.1.1 Housing as a good and limitations in HPM

A model is a simplification of the reality and thus consists

of assumptions for choosing simplifications. Hedonic price models (HPMs) assume perfectly competitive markets, a fixed supply of goods with a continuous supply of product continuum, and perfectly informed sellers and buyers (Taylor, 2008). These are typical microeconomic assumptions introduced previously in this chapter. One obvious critique of the hedonic pricing methodology often mentioned is that such assumptions clearly cannot hold for any given good and perhaps less so for housing due to its heterogeneous nature. However, Whitehand (2012) argues that such models should be judged based on whether or not the information that they supply helps us understand housing systems.

What is most commonly estimated is the first-stage HPM, which estimates implicit marginal prices on the characteristics of dwellings. This means that the model predicts price premiums for characteristics in the market, which can be related to preferences (Sheppard, 1998). However, it is not the same as the demand on the market, for which the second stage is necessary (Taylor, 2008). This connects to the matter of budget constraints – simply the issue that consumers have different abilities to pay. For example, the implicit marginal prices from a first-stage HPM could suggest that constructing a park in a neighbourhood would increase the housing prices, but it might be that the prices hold still since the budget constraints in the market might not allow for higher prices.

One important issue with HPMs is omitted variables, when characteristics of the dwellings are not included in the model, which have an impact on price (Baranzini et al. 2008, p. 5). Moreover, variables included in the model, and which are preferred by consumers, can still be estimated as insignificant because they are evenly distributed over the market. An example would be grocery stores, which might be preferred to have near home by consumers but if all consumers have easy access to one, it will not have an effect on the marginal prices.

On top of the basic neoclassic economic assumptions, housing as a good has some special characteristics that need consideration in the interpretation of the results of a HPM. One is that it is commonly an expensive investment, and a household usually buys only one, for which they are dependent on financial institutions to afford and which comes with many restrictions and regulatory differences between

both markets and individuals (Taylor, 2008). Furthermore, housing is heterogeneous with respect to its characteristics, can last for a long time with proper maintenance, and is associated with high transaction costs that make consumers hesitant to move when income or housing preferences change (O'Sullivan 2011, p. 367).

2.1.2 Predicting prices or estimating consumer preferences

One use of hedonic models is to estimate monetary value or willingness to pay (WTP) for characteristics of goods, but perhaps more common is to try to predict prices in a market. By building a model that explains a large share of the price variation in a market, such as a housing market in a city, the prices of housing can be predicted. For example, this could, be used for areas in a city that are planned for development to appreciate their value by measuring the characteristics of the planned housing in the area. Therefore, to predict prices, a good correlation between housing characteristics and prices is needed. In principle, the model does not have to catch causal relationships in order to have high explanatory power. For this reason, much work in econometrics is done with little consideration to causality but more so to model specifications that give explanatory power (Angrist & Pischke, 2008). In the subfield of spatial econometrics, this is particularly true because the field has been occupied with solving the spatial issues of the problems (Gibbons & Overman, 2012a).

One important issue regarding causal relationships in hedonic price models of housing markets is the perceptions of the buyer and seller of the house (Palmquist, 2005). The model is based on the assumption that buyers and sellers make informed decisions about whether or not to buy or sell, which gives a market value. Looking at it from another angle, to estimate the preferences of a specific attribute of housing in a market derived from a market price, the attribute needs to have been considered by the consumer. If so, consumer preference can be inferred, and causality cannot be ruled out. If the consumer has not perceived the attribute, it is unlikely that the attribute affects the price and that a causal relationship between the attribute and the price exists. Rather, it is likely that it is a proxy for something else and that the variables that affect the price have been omitted from the model. One example is that air pollution, which is very hard to perceive by a buyer, has been estimated to have a negative effect on housing prices (Higgins

et al., 2019; Hui et al., 2007; Yoo et al., 2014; Zhou et al., 2006). It is more likely that higher levels of air pollution are associated with other negative effects, such as noise or barrier effects, which are easier to perceive by the consumer (Palmquist, 2005). For the prediction of prices, this makes little difference as long as the explanatory power is strong, but for estimating consumer preferences the link to perception is needed.

A related topic is that of functional form – the form of the relationship between prices and attributes. A linear relationship is possible but far from certain when complex variables such as distance to primary schools is analysed. Following the logic of Tobler (1970), where closer things are more related than distant ones, it may be preferable to be at a certain, intermediate, distance and not too far away. In such cases, the functional form needs to be modified to fit the relationship. There is also a potential risk of not measuring how the consumer perceives the attribute. What is more disturbing is that the ad hoc choice of functional form might be biased towards getting better explanatory power and model fit at the cost of the potential omission of variables.

2.2 SECOND PROBLEM: CONNECTING URBAN FORM, RELATIVE LOCATION, AND ACCESSIBILITY

For the purpose of this research, relevant measures of urban form are needed to be able to include it in the econometrical model. This means quantification of urban form with a set of requirements to fit the econometrical model as well as informing urban planning and design practice. The quantification of urban form in simple terms concern the measurement of how streets, buildings and plots are composed individually and in relation to each other. As mentioned before, it is important that measures of urban form coincide with economic theory and planning and design practice. For that reason, it is helpful to look at urban form from a locational perspective. That means that the chosen measures of urban form are done to describe a place's location.

Location, location, and location is often the answer from realtors on the question of what matters most for the price of a dwelling. This suggests meaning that where the dwelling is situated is more important than its style or its technical standard. We know that there is a great variance in housing

prices even for dwellings of similar standards. This favours the realtors' hypothesis that something not structural (connected to the building or apartment itself) is also affecting the price. It is not hard to imagine that there is a spatial effect in prices, meaning that if all structural characteristics of two dwellings are equal, it is the spatial factor that determines the price – the spatial factor being the location. Figure 2.2 illustrates the price per square metre for apartments in the urban area of Oslo municipality. It reveals that the mean prices are higher in some city districts and lower in others. Assuming that the style and technical standard in dwellings are relatively evenly distributed in the municipality, the figure should show which locations are preferred by the market.

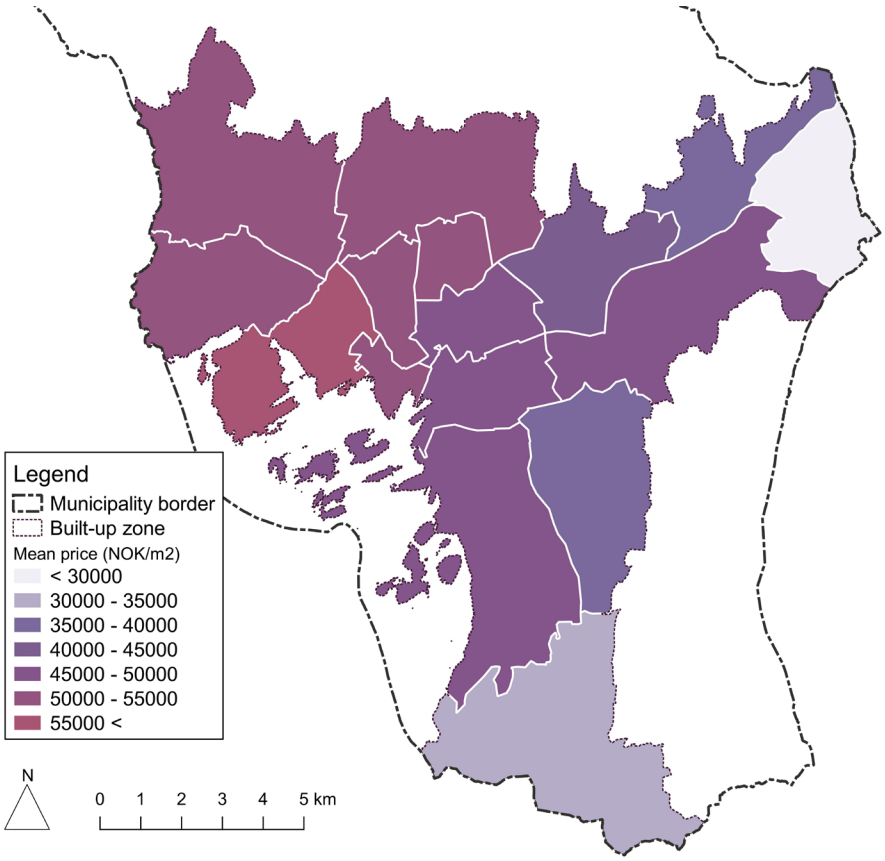


Figure 2.2. A map over the urban part of Oslo municipality.

This brings us to the core of this research – to identify what in these locations make them preferable. To do so, we need the kind of analysis discussed in section 2.1, which measures different attributes of location so that they can be compared. Subsequently, how the location is described affects what questions we can ask and what answers we get. The distinction between the relative and absolute location, mentioned in the introduction, are useful concepts. Abso-

lute location is the given position in terms of the geography of an object, for example, that Norway is located in Europe. This description of location can give information on where in the city the locations of dwellings are preferable. However, it does not inform planners and decision makers on which aspect in the location that is preferable. Knowing that a certain neighbourhood is attractive and trying to copy its urban form to an existing less attractive neighbourhood, or on a new development area, without knowing what attributes of urban form to copy has less of a chance to be successful. Relative location, in contrast, describes a location as relative to the surroundings, for example, that Norway is located west of Sweden. A dwelling's location in a city can be described in the same way, for example if it is located in a certain city district (an absolute description) or how close it is to a park (a relative description). A place's location can thus be described in both absolute and relative terms. It is reasonable to assume that the price paid for the location of a dwelling corresponds to both the relative and the absolute aspects, an assumption which is empirically tested in Paper III. The relative location of a dwelling essentially corresponds to the opportunities in its surrounding and the dwelling's spatial relation to those opportunities, which plausibly influences buyers' willingness to pay for it. Important to note again is that location has to be described to fit buyers' and sellers' perceptions if it is to be used as an explanatory component in house price valuation (Palmquist, 2005; Rosen, 1974; Sheppard, 1998). A neighbourhood's or city district's brand, which is described as absolute location, is also a factor to consider in housing valuation (Kiel & Zabel, 2008). That is, a neighbourhood might have a good reputation and therefore have more expensive housing, with a premium paid for being within a certain neighbourhood, in addition to its relative location. From the simple mapping shown in Figure 2.2, one can see where people prefer to live, the absolute location description, but not which attributes of location, the relative location description, they prefer. To be relevant for urban planning, the attributes of location are of interest and can be revealed by describing the location as relative.

Relative descriptions of location can be conducted in many ways. There is a fundamental difference between descriptions where the distance to other locations is measured along the relevant infrastructure for movement (streets, paths, rail), which can be called "morphological measure-

ments", and descriptions that measures the distance to other locations along what is called "desire lines", that is, as straight lines between locations. In this thesis, based in urban planning and design, distances are measured in accordance with the first mode, both since it proves more accurate and since it is more relevant for the practices of urban planning and design. By doing so, the location can be described in relation to opportunities, such as parks or public transit, and thus relate to factors that urban planning can influence. Assuming that this description corresponds to how people perceive and use the location gives the opportunity to identify which attributes of the location people prefer over others. The morphological relative location description proposed in this thesis is suggested to better align with a potential causal relationship between location and price, since it can describe urban form in a way that corresponds to consumer perception. It is also relevant to urban planning and design practice, since it describes urban form in a way that corresponds to the interventions associated with the practice.

It was established in the previous section that prices vary over the geography because of the immobility of buildings (Kiel & Zabel, 2008). However, in a sense the location of the building can change. The relative location description can be changed by changing the configuration of the urban form without moving the building.

2.2.1 Relative location description and the modifiable areal unit problem

To be able to distinguish the locational variables from each other in the econometric analysis, the measures must be kept as disaggregated as possible so that the variance in the selection is kept (Lee et al., 2016; Reynolds, 1999; Unwin, 1996). When describing location in relative terms, the abovementioned benefits of fitting to consumers' perceptions and to planning practice will be achieved, but, importantly, the modifiable areal unit problem (MAUP) is also avoided to a large degree. Fetching aggregated values, which is essentially the use of absolute location description, will not give the actual number of, for example, reachable workplaces since it is limited to administrative borders. The aggregation and loss of variance is called the scale effect, and the fact that one gets different values depending on how the borders of the tract are drawn is called the zoning effect (Reynolds, 1999). Together these phenomena stand

as the MAUP. The MAUP is traditionally seen as a human geographical problem, but it is also a problem in physical geography when simplifying reality in a map (Dark & Bram, 2007).

When describing a dwelling's location relative to other places, the scale effect is cancelled out. However, depending on how the relative location is measured, the zoning effect might still be present. One example is to describe how many restaurants can be reached within walking distance from the dwelling. Depending on what the definition of walking distance is set to, the value will change; this is the zoning effect. In this example, and other similar cases, an important notion is that the walking distance differs among individuals, groups of individuals, and the purpose of the travel (Moudon and Lee 2009; Yang and Diez-Roux 2012; Millward, Spinney, and Scott 2013).

The scale effect is described in Figure 2.3 with an example of accessibility to the right and its likeness aggregated into postal codes to the left regarding walking distance to a metro station. The loss of variance in the absolute description of location is easily visible. When using the absolute location description at this postal code level, the average walking distance is typically what is accounted for in the econometric analysis, compiled with and impossible to separate from all other attributes of location. Additionally, a home-

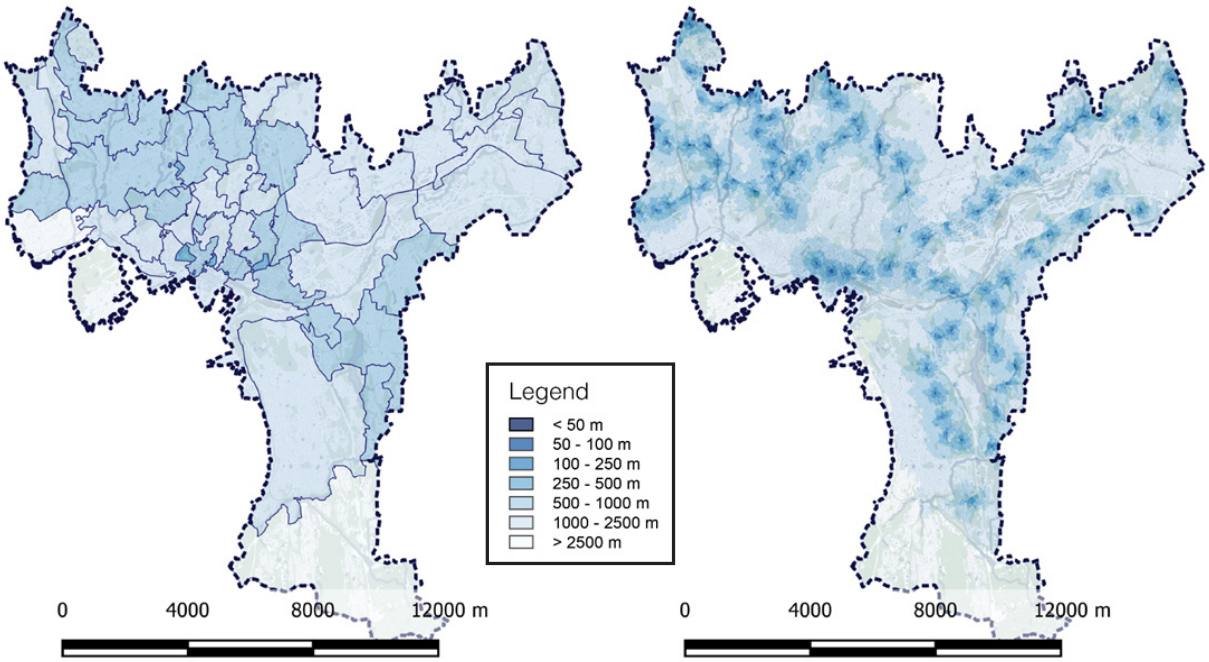


Figure 2.3. The walking distance to the closest metro station on the right and the average walking distance to metro station on the left (A. V. Heyman & Sommervoll, 2019)

buyer most probably does not consider the average distance to, or number of a given amenity in a neighbourhood but rather the locational features of the specific dwelling. The relative location description in this example is of a morphological nature, taking the street network into consideration, but could also be measured as the metrical distance to a metro station via 'desire lines' and not take the morphological aspect into consideration.

Connected to this issue, a common approach when analysing urban form and architecture is to divide the urban environment into typologies. Although it might correspond to some homebuyer's perception of the location of a dwelling, it likely describes multiple aspects of location and thus is less informative to planners and decision makers. An example is the typology of 'postmodern blocks' in Sjaastad et al. (2008), which probably corresponds to more than one quality in the environment that buyers consider. It is also poor guidance for planners and decision makers since the contemporary way of building might not allow the reproduction of older types.

2.2.2 Accessibility and urban form

Relative location is typically measured as accessibility. When it comes to accessibility measures, the pallet is broad and opportunities many (discussed in Paper II) and it is methodologically sound in the context of hedonic price modelling. In principle, to measure the accessibility to different amenities and destinations from a place is to describe its relative location in a way that captures the distribution and composition of streets, buildings, plots, and uses, which is the main concern of urban planning and design.

In essence, cities' main attributes are proximity, closeness, and density (Glaeser, 2012). All three of these attributes are technically measures of accessibility, which can be defined as 'the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality, and character of the activities found there' (Handy and Niemeier 1997). Accessibility analysis to a large degree quantifies the description of relative location, since accessibility is a measure of the spatial relation between spatial elements and the elements' characteristics. The literature on accessibility is elaborated more upon in Paper II, but other feasible and well-used definitions can be found in Hansen (1959) and Ingram (1971). Accessibility is a term that is

used in different fields an may have different meanings. The above examples of definitions are from fields that use geographical aspects in their analyses, but accessibility can be categorised as geographic and geometric, where geographic consider access between real-life places and geometric consider access between abstracted locations within the network itself (Jiang et al., 1999; Jiang & Claramunt, 2002). Another relevant distinction is between general and specific accessibility, where general accessibility is the accessibility to all locations and specific accessibility can be viewed as a general accessibility weighted for a selection of locations (Webster, 2010). All of the above can help to describe a place's location in relative terms.

Since this thesis deals with a spatial problem, the destinations referred to in the definition above are spatial elements. This makes the step to urban form clearer since urban form deals with spatial elements in human settlements (Oliveira 2016; Kropf 2009, 2018). The distribution and composition of the spatial elements within urban form can therefore be conceptualised and measured as accessibility. The specification of accessibility is examined in Paper II, where it is found that accessibility is specified very differently even among studies using hedonic price modelling on housing prices. However, three common components of accessibility measures are origins (or agents), opportunities (also referred to as destinations), and impedance. These components can be supplemented by the demographics of the agent and a temporal component to take differences in time into consideration (Geurs & van Wee, 2004).

Accessibility can be divided into the following five principal types of measures: spatial separation, cumulative opportunity, gravity, utility, and space-time measures (Bhat et al., 2000). Some of the types are highly complex and some are simple; some are precise, and some are general. Based on the interpretability of planners and decision makers, and on how perceivable it is for consumers, more complex measures are not always the best fit to answer a question. In addition to exactness, efficiency in analysing is also an important factor when choosing type (Bach, 1981).

From the above description of accessibility and its different components, it is logical to view most accessibility as varying with changes in urban form, as opposed to a description of absolute location. This is essential for the outcome of

this thesis and its societal relevance, since changes in urban form due to urban planning and design cannot be described in absolute terms. It becomes evident that the accessibility can be changed in three principally different ways – first, by moving or adding opportunities; second, by moving the origin; or third, by changing the impedance. As an example, the access by walking to green space from a school can be increased either by adding more green space in the surroundings of the school (opportunity), by moving the school closer to green space (origin), or by changing the configuration of the street network that connect the school better to existing green space (impedance).

2.2.3 Impedance and representation of space

In addition to the spatial elements in urban form, the component of impedance must be defined to specify accessibility. The impedance can be many things, including Euclidean or network distance, travel time, cost (Heyman, Law, and Berghauser Pont 2019). To connect it to the perception of homebuyers, Euclidean distance has the disadvantage of not taking into account obstacles in space, such as buildings or fences. Therefore, it corresponds poorly to how people use the space and arguably also to how they perceive and value it. In essence, people experience their environment from street level (Dalton, 2006; T. Yang & Hillier, 2007). The network distance, travel time, and cost are network-based, even though the networks might look different. In cities, it might be of most interest to look at transport networks, since that is how humans use cities in a physical sense. It is possible to use travel time by public transport (Hu et al., 2014; L. Yang et al., 2020) with a network of public transit or travel time by car (Nguyen & Nguyen, 2020; Yu et al., 2012) with a network of roads for cars. The network distance could also be topological distance, for example the number of changes of directions for a particular route in a network.

A relevant choice of network is the continuous open space through which the relations between the spatial elements are made. Using this network would benefit the investigation of the local realm of the dwelling and it would take the relation between the spatial elements of urban form into consideration. This choice connects well to urban planning and design, which can be said to be about folding space. That is, by placing spatial elements defined in urban morphology in space, space is folded from something Euclidean

into something more complex (Koch, 2016). The configuration of space is changed.

However, the network of open public space must also be represented. Lefebvre (1991, vol. 142, p. 83) argues that 'space is not a thing, but rather a set of relations between things', while space syntax theory treats space as 'an objective entity in itself' (Hillier, 1993). Space must have valid representation as an entity in order for it to be used as an impedance in quantitative spatial analysis. One obvious alternative is the street network, which represents spaces for movement that connects the spatial elements. However, it is often only considering streets and paths, not squares or other open spaces, and therefore potentially does not connect all spatial elements or represent the whole extent of continuous open space (Dhanani et al., 2012). Another way to tackle the representation is with an axial line, which is linearly extended space that connects all convex spaces in the continuous system (Hillier and Hanson 1989, pp. 90–93) – the convex space being the space from which a person can see freely from a given point (Hillier 1996, pp. 114–115). Furthermore, the axial line has the properties of both visibility and of permeability, that is, how far it is possible to walk in a straight line (Krüger, 1989). This means that barriers, such as high traffic roads or rivers are taken into consideration in the network. It has been established that much of the network for walking is lost when not taking pedestrian facilities into the network, implying large errors when using vehicular networks (Tal & Handy, 2012). Furthermore, taking footpaths and underground network into consideration can further improve pedestrian connectivity and includes many more links and a longer network (Sun et al., 2021).

The axial line as a representation of space corresponds well with walking behaviour since there is a linearity to both human perception (seeing) and movement (walking) (Hillier 1996, p. 116). Furthermore, based on the work of Gibson (1986), the axial representations of space have been argued to represent 'affordances and especially affordances of a generic kind such as those constituted by the human abilities of visibility and movement' (Marcus, 2015). However, it is important to acknowledge that axial lines do not take jurisdictional regulations into consideration. For example, crossing a street may only be possible at designated crossings, which increases the travel distance, whereas no such

considerations are made in an axial map. The axial network is the main contributing component of this work's use and investigation of urban form, since it is used as the impedance in most accessibility analyses.

Revisiting the early models used in urban economics described in the introduction to this chapter, it is fair to say that they are based on a representation of space that is less than optimally connected to human movement and visibility. In principle, most probably for simplicity, the models use Euclidean space in two-dimensional or in Hotelling (1929) even one-dimensional space. William Alonso describes the city that he models as though 'it lies on a featureless plain, and transportation is possible in all directions. All employment and all goods and services are available only at the centre of the city' (Alonso 1964, p. 18). As a comparison of two different representations of space as impedance in accessibility measures, Figure 2.4 shows the minimum distance to the Oslo Fjord in Euclidean space and through the axial network.

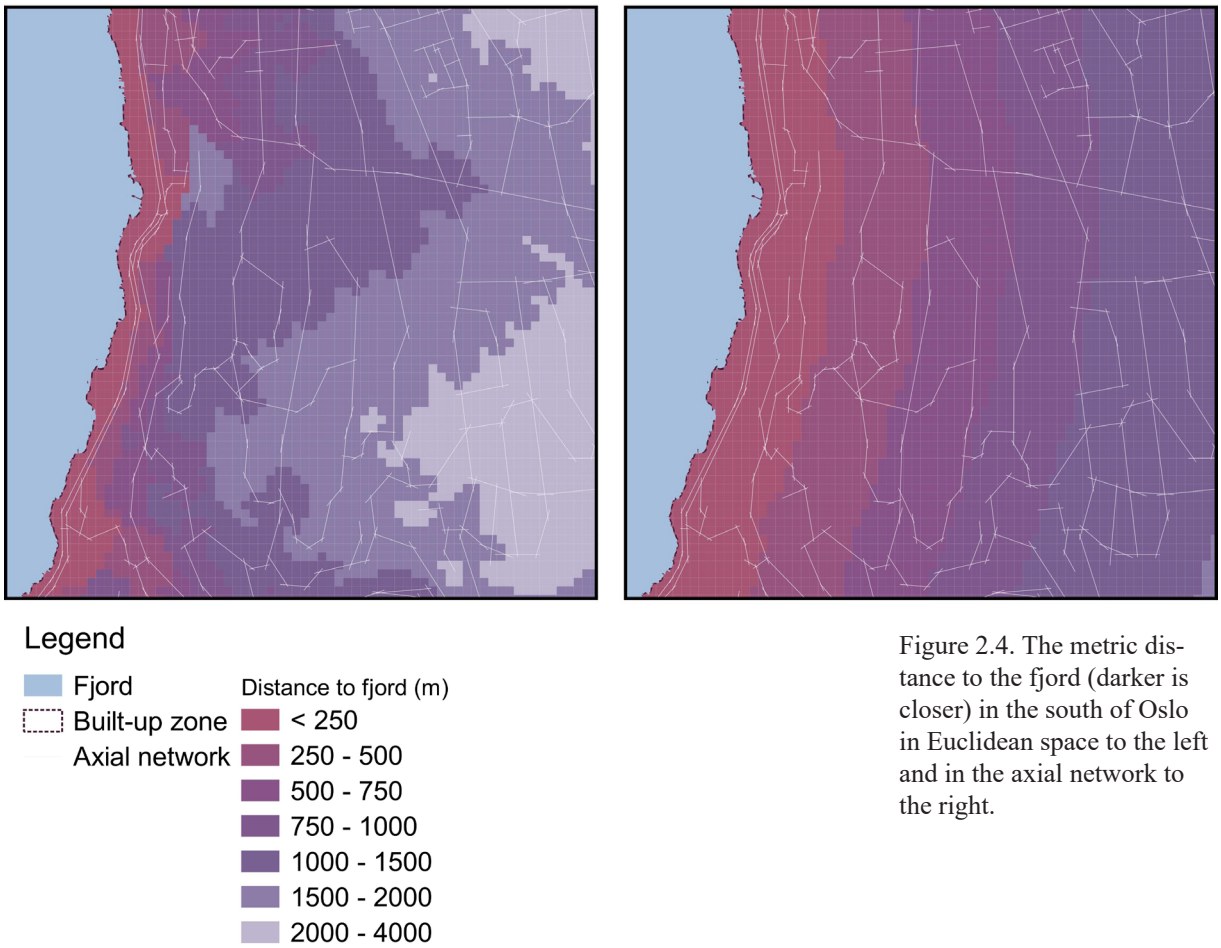


Figure 2.4. The metric distance to the fjord (darker is closer) in the south of Oslo in Euclidean space to the left and in the axial network to the right.

2.2.4 Capturing urbanity and centrality

There should be no confusion as to whether or not centrality impacts people's preferences for a place's location. However, it could be questioned if it is centrality in itself that is preferable or the effects thereof. In Paper II, it is found that access to the central business district (CBD) or city centre is the most frequent statistically significant opportunity in explaining housing prices. However, it is not the only way to describe centrality, and it is not obvious what is in the measure regarding omitted variables. Furthermore, it is ambiguous as to whether better access is more preferable or not as American cities tend to have richer neighbourhoods in the suburb, and European cities have richer neighbourhoods in the central city (Brueckner et al., 1999; and Hohenberg 1985, p. 299).

Much of the work on this topic is based on the assumption of a monocentric model of a city, where there is a single core and a surrounding periphery (e.g. Muth 1969; Alonso 1964; and von Thünen 1826). However, the centrality can also be measured as something more multifaceted. One simple example is to add more centres in the city (Wen et al., 2014). Another more profound notion of centrality is found within space syntax theory, where the configuration of the previously mentioned axial lines can be analysed through graph analysis to quantify the centrality in space itself, one form of which is called integration (Hillier 1996, p. 25). The method has its foundation in urban morphology and concerns a very particular description of continuous open space, which is used to analyse specific forms of network centrality. This measure is an example of general accessibility described above (Law 2018). The centrality in network analysis has many forms but is a description of relative location, provided relevant networks are used. Although the centrality measure of integration used in space syntax analysis has some peculiarities apart from the creation of the axial network itself (described in section 2.2.3 above) those are based on the aspiration to ascribe human behaviour in the model. Firstly, the graph built for analysis is dual, meaning that the axial lines are treated as nodes in the graph and that the intersections between the lines are treated as vertices, and not the other way around, which is more common. Secondly, the integration measure is normalised with respect to the size of the network (Hillier & Hanson, 1989; Teklenburg et al., 1993). Thirdly, integration can be calculated on different scales or radii, which pick

up different aspects of centrality. For a closer description and a calculation example of integration, see Appendix A.1 in Paper III. An advantage with the use of integration as a measure of centrality, with respect to consumer perception, is its connection to human cognition (Hillier, 2003). A comparison between centrality as distance to CBD and as integration in the axial network is presented in Figure 2.5.

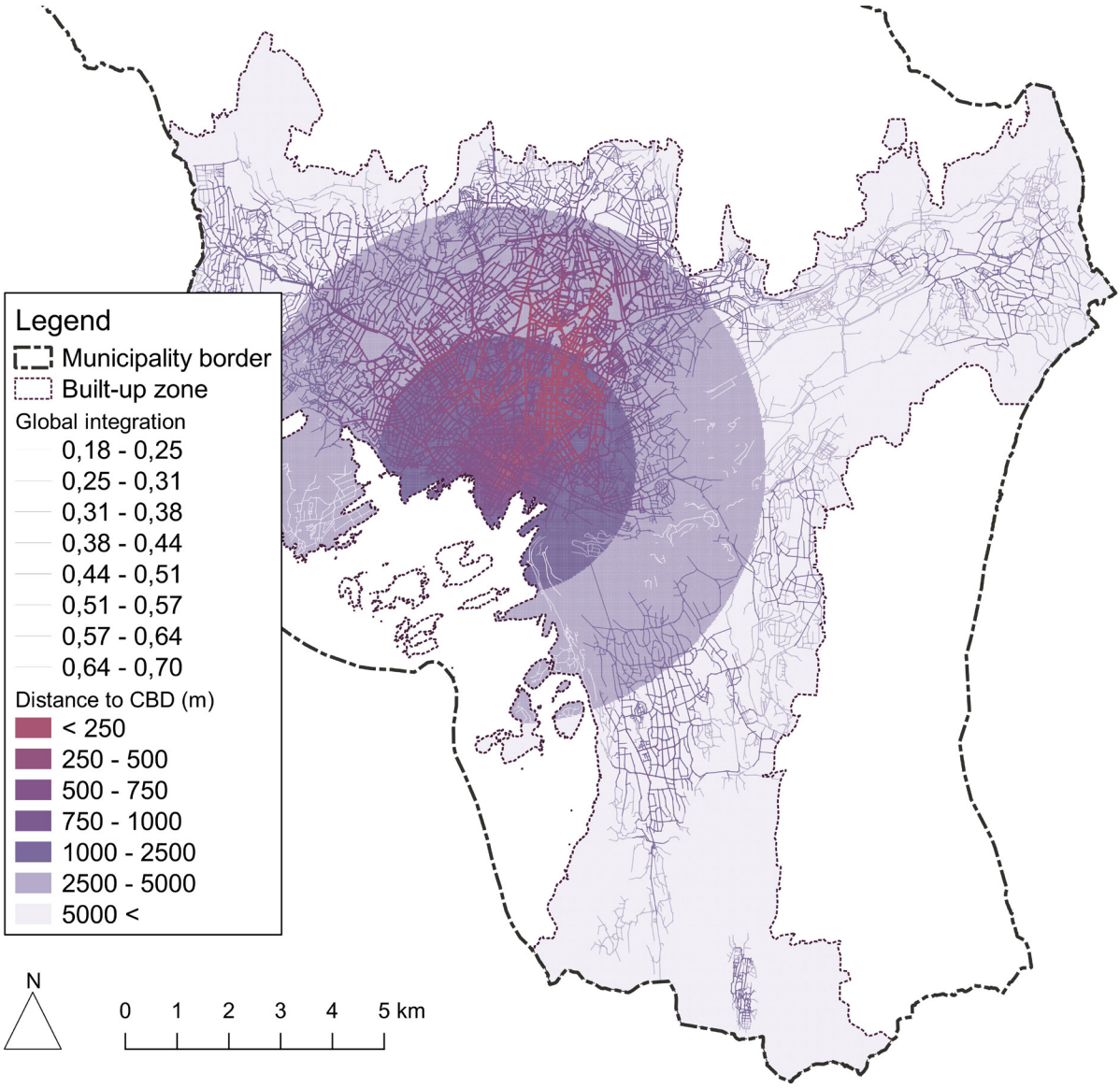


Figure 2.5. A map where Global integration and Euclidean distance to the CBD are overlayed.

Hillier (1996, p. 127) describes urbanity as movement in space, or, more specifically, 'Good space is used space'. Integration is a measure of the centrality of space itself, as defined by urban form, but has also been associated with other phenomena. It has repeatedly been associated with pedestrian movements (Hillier et al., 1993; Hillier & Iida, 2005), and has lately been included in 'urban types' which also have a strong correlation with pedestrian movements

(Berghauser Pont et al., 2019). Integration has been shown to correlate with pedestrian movement at different radii, from low radii to higher or global (Sharmin and Kamruzzaman 2018). Moreover, it has been associated with retail concentration (Enström & Netzell, 2008; Scoppa, 2012); however, it is probably the movements that work as an intermediary in this process (Marcus & Colding, 2014). Yet another association has been made between integration and housing prices (Chiaradia et al. 2013; Law et al. 2013; Navaraez et al. 2014; Navaraez 2015; Xiao et al. 2017; Yao and Karimi 2015; Yang, Orford, and Webster 2016).

Regarding the concentration of retail or amenities in the city, it can be argued that this is a big part of the omitted variables in centrality measures. If we assume that people do not seek a central location for its own sake but rather the effects of centrality, access to amenities should be included as one of the effects. Following the argument of Hotelling, business will locate centrally in the market to be accessible to as many consumers as possible (Hotelling, 1929). In a spatial representation of axial lines where centrality is determined by their configuration, follows that the integration in the network should correlate with the number of amenities. The location of amenities in cities has an impact on where people settle because locations with a strong amenity advantage attract rich residents (Brueckner et al., 1999).

3 Approach

It was stated in the Background chapter that this thesis is theoretically situated somewhere between urban morphology and urban economics. This also holds true for the methodology, where this thesis used combined methods from urban morphology and urban economics. Epistemologically, this thesis draws to urban morphology more than urban economics. The approach is very much corresponding to the epistemological framework for urban morphology proposed by Scheer (2016). Apart from a third step where temporal changes are analysed, this research followed the steps proposed to be shared across all schools of urban morphology presented in the previous chapter. The steps followed were collection of formal data, recognition of common patterns, and linking results of the physical analysis to conditions not directly related to urban form.

The overall approach in the thesis can be divided into a reviewing part and an empirical testing part. The review was conducted in part as a positioning paper and in part as a systematic review to frame and sharpen the focus on the research problem and is described methodologically below in section 3.1. Once the problem was sufficiently framed, the identified gaps were to be filled by empirical testing (Paper III and IV). The empirical testing methods can be divided in two main categories of spatial analysis and econometric analysis. These are described in subsections 3.2 and 3.3. The empirical papers use similar methods for the measurement of urban form but differ more in the econometrical testing to cover different angles.

To answer the research questions, the urban form was measured and quantified in a way that enabled inclusion of the results in econometrical models to analyse the relationship between housing prices and urban form. The empirical part of this thesis was thus to build two different types of models for Oslo – a geographical model, through which the ur-

ban form was analysed, and an economic model, where the relationship between urban form and housing prices could be estimated.

3.1 MAPPING THE FIELD

In Paper I, two consultancy reports from Stockholm and Copenhagen, which both examine the monetary value of urban form by applying hedonic price modelling (HPM). The paper concludes that HPM approach is well-suited for the purpose of the thesis well, but raises some issues that need to be resolved. Furthermore, it explains the methodology, discusses the differences in approaches, and to some extent summarises the results from the two reports (Figure 3.1).

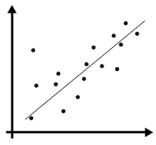
As the next step, Paper II reviews how previous peer-reviewed papers, which investigates the relationship between accessibility and land or housing prices, specify and analyse accessibility. The systematic review is a way to review results from many studies on a topic based on a predefined set of criteria and a clear research question (Petticrew & Roberts, 2006). As opposed to meta-analysis, a systematic review does not gather the data used in the examined studies for further analysis but rather uses the studies and their results themselves as data, based on a strict categorisation. The data collection is done by pre-defined search terms on databases for scientific articles. In this case, Scopus and Web of Science were searched. Specifics around search terms and date for search are presented in the article. Worth noting is that some known papers did not get included, which either depends on the search terms or that they are not indexed in the two databases. In particular some Nordic literature was missing (e.g. Wilhelmsson, 2000; Wilhelmsson & Ceccato, 2015). The systematic review was chosen as a method in this thesis to achieve an overview of how accessibility was measured in contemporary HPM studies. The categorisation of the different specifications is presented in Figure 3.2 and drawn from Bhat et al. (2000). In this case, the individual variables in the studies were categorised according to their specifications and compiled in tables to be examined for patterns and to draw conclusions. The results and implications are also discussed in the paper.

VARIABLES

Built environment	People and building density	Green structure	Green spaces
	Workers and workplace dencity		Sporting facilities
	Dwellers and dwelling dencity		Spaciousness
	Compactness		Water/coast
	Entrance density		
	Properties	Traffic	Axial network
	Blockshape		Public transit
	Mix of uses		Accessibility to city center
	Industrial areas		Road network
	Hotells		Noise
	Cultural institutions		
	Schools		
	Social aspects		
	Urban amenities		

TESTING & INDEXING

$$\sum P(i,j)$$



SIGNIFICANT VARIABLES

<u>Stockholm apartments</u>
Closeness to city center
Within 500 m walking distance of train-, metro- or light rail station
Accessibility to pedestrian network (network integration R12)
Accessibility to urban amenities within 1000 m walking distance
Accessible park within 1000 m walking distance
Closeness to open water
Block shape (closedness and entrances facing street)
Socioeconomic index

<u>Stockholm single family houses</u>
Accessible working inhabitants within 30 min public transit commute
Dwellers within 30 min car commute
Train-, metro-, or light rail station within 700 m walking distance
Urban amenities within 500 m walking distance
Accessible open water within 3000 m
Closeness to ferry station
Accessible green space within 500 m walking distance
Detached house
Beachfront propery
Living space
Socioeconomic index

<u>Rule of thumb in Copenhagen/Aarhus</u>
Park or nature within 500 m
Closeness to coast within 300 m
Variation in businesses within 1000 m
Number of bars, cafés, restaurants etc. within 100 m (negative)
Closeness to commuter train stations within 1500 m
Closeness to metro station within 200 m
Noise level 60 dB (negative)
Closeness to railway within 100 m (negative)
Closeness to large road within 400 m (negative)

Figure 3.1. A schematic image of hedonic price model methodology combined with aggregated results (A. Heyman & Manum, 2016).

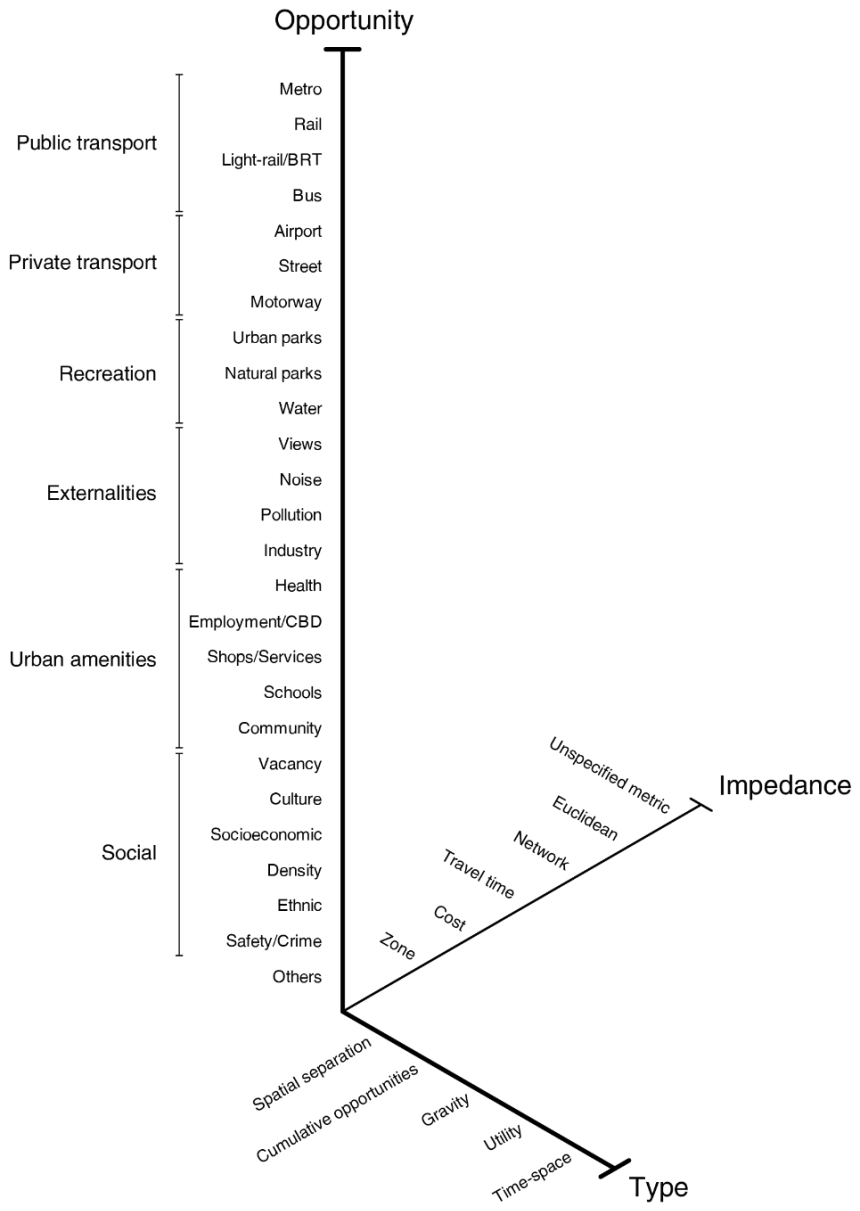


Figure 3.2. The categorisation used in the systematic review of hedonic models in Paper II (Heyman, Law, and Berghauser Pont 2019).

3.2 MEASURING LOCATION – THE GEOGRAPHIC MODEL

This thesis investigates a spatial problem. It asks how urban form is related to attractiveness, and since urban form is geographical, its spatial characteristics needs to be described to put it in relation to attractiveness. The spatial characteristics being urban form, it has consistently been analysed as accessibility throughout this thesis.

For the measurement of urban form, the geographic model was built in a geographical information system (GIS) to

facilitate the information attached to physical objects, such as streets or buildings. In particular, the QGIS environment (QGIS Development Team, 2009) was used with the plugins PST[3] and Space Syntax Toolkit[4]. These software packages together enable a wide spectrum of spatial analyses based on geographical data that contain geographical and other information. In principle, GIS is a system that holds layers of spatial objects in the shape of either points, lines, or polygons that represent the geographical context. For every layer there is a table attached, where each spatial object has a line where columns with information can be added. With this system, it is possible to produce maps in a regular sense by letting an object added to the map display with different colours, shapes, symbols, etc. One can also produce maps based on the information for the spatial objects, such as building height, showing darker colours for taller buildings on a map, an example presented in Figure 3.3.

[1] PST was developed by the KTH School of Architecture, the Chalmers School of Architecture (SMoG), Spacescape AB, Alexander Ståhle, Lars Marcus, Daniel Koch, Martin Fitger, Ann Legeby, Gianna Stavroulaki, Meta Berghauser Pont, Anders Karlström, Pablo Miranda Carranza, and Tobias Nordström.

[2] https://github.com/SpaceGroupUCL/qgisSpaceSyntaxToolkit

Figure 3.3. An example of visualisation of information connected to geographic objects in GIS.

The next step is to ask the GIS spatial questions. Depending on what kind of information the layers hold, more or less advanced questions can be answered. For example, if there were information on the number of people living in every

building, one could ask how many people live in a certain neighbourhood or how many people live within a one-kilometre radius from a metro station (Figure 3.4). How this was approached in this research is further described in section 3.2.2 below.

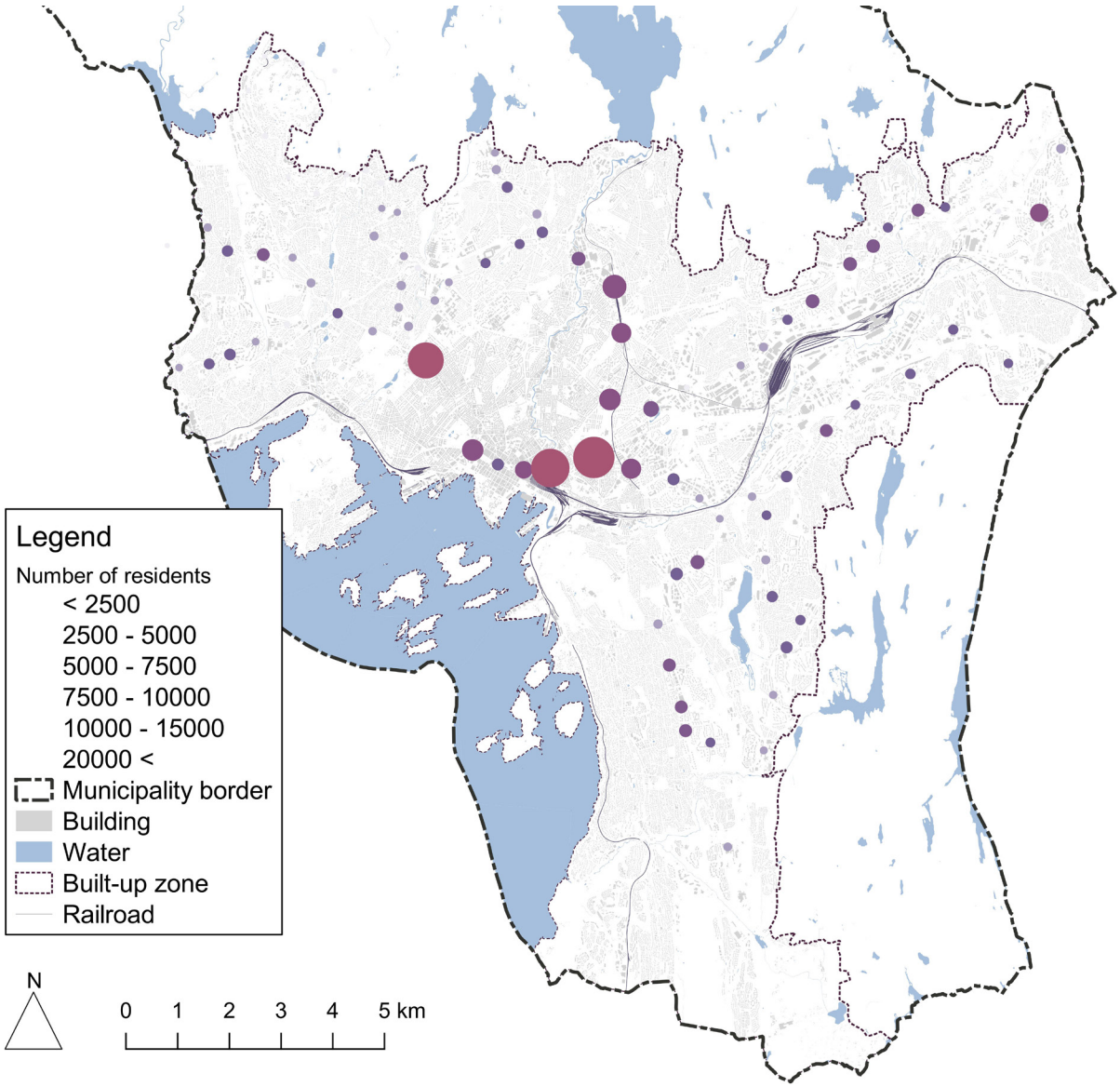


Figure 3.4. A map of metro stations in Oslo where size and colour represent how many residents that are reached within one kilometre.

3.2.1 What to measure in location?

There were two essential criteria to consider when choosing which characteristics, both locational and other, to include in the model. First, it was important to choose characteristics that home-buyers value. Second, characteristics that could fit into the econometric model had to be chosen. In alignment with the scope of the research the measurements of location had to capture the aspects relevant for estimating attractiveness as reflected in housing prices. This means

that, as discussed in the Background chapter, the variables included in the econometric model had to correspond to the characteristics of the location that the consumers perceive when they bid on it. If the descriptions of location do not correspond to consumer perception, a correlation to housing prices is most probably confounding with either price or the characteristics of the dwelling. Consequently, the perceivable effects should be measured and correlated to housing prices in order to draw conclusions on price differentiation based on these preferences.

Starting from the scope of this research, analysing how urban form correlates to housing prices, opens up for testing many variables since there is great variation in urban form in cities. But using a great number of variables in econometric analyses runs a higher risk of selecting significant correlations based on statistical results rather than on what is likely to be causing an effect on the marginal price. Hence, instead of the approach found and examined in Paper I, where more than 1000 variables for location were tested in the examined studies, the empirical work included in this dissertation aimed to narrow that number to a size that comprehends more likely variables and would require less exclusion or inclusion decisions based solely on statistical measurements.

This means that the variables describing urban form was selected with more care to better fit the research aim. To do so, this research has based its selection of locational variables on previous significant results from the studies reviewed in Papers I and II and on the theoretical foundation described in the same papers as well as in the Background chapter. The variables found to be significant and fit for the purpose in Paper I seemed reasonable to test in the Oslo environment as well since there was no reason to believe that the markets of Copenhagen and Stockholm differs too much from the housing market in Oslo. In Paper II, the significant locational variables came from a wider geographical area, but the systematisation of the significant variables made it possible to find patterns of more common variables that were important to include in this empirical analysis. Something that became evident was that many of the reviewed studies used locational variables that did not correspond to consumer perception nor were in the scope of planners and decision makers. Such a variable was the distance to the central business district (CBD), which turned out to be the

most frequent locational variable in the sample. It might be that in some cases this is what is actually sought for by the homebuyer, but this research proposes that it is more probable that the distance to CBD is a proxy for the supply of services that tend to cluster in central places of an urban area. Furthermore, a planner should seek to know what it is in a location that is attractive, not that it is attractive to be close to an attractive location. Otherwise, the planning will be occupied with building as much as possible close to the CBD when in fact it should be making more CBDs, or rather, more of the characteristics of the CBD.

3.2.2 How to measure the location?

In principle, location in this research is described in relative terms. As was explained in the Background chapter, this means that the location, in this case the location of dwellings, is described through its relation to its surroundings. This way of describing location is close to how people perceive their environment and therefore how homebuyers plausibly evaluate the location of a potential home. The other way of describing location is in absolute terms, with coordinates or administrative borders, such as city districts or postal codes. When a homebuyer values a location, this is probably a part of it, perhaps for a neighbourhood's reputation or status, but it is not the whole picture. The conclusion was that the relative location needed to be measured and tested against housing prices.

However, measuring relative location is complex. Just as there are many aspects of which location to measure, there are many ways to measure it as well. The literature on accessibility described in the background chapter is a good framework for mapping how relative location description can be specified in various ways. The description of relative location of a dwelling can be quantified as its access to its surrounding environment. In the specification of accessibility, there is always an origin, an impedance, and one or many opportunities, which can all have various shapes. Depending on what question is posed to the geographical model, the specification of the accessibility measure that answers it varies. The approach to this often-bothersome task is presented below.

To begin with, this research in all cases uses dwellings as origins since it is their location that is of interest for the research question. For this, a sample of sold apartments in

Oslo has been used; the size and characteristics of that sample is described in section 3.4. For the purpose of describing the spatial analysis in this section, it is only necessary to mention that all dwellings used are points at the entrances of every building – address points; see Figure 3.5.

Figure 3.5. A map of the location of address points.

Measuring relative location

Impedance can be defined in many ways, but in narrowing it down to the geographical variants of accessibility, some kind of spatial network through which the access takes place must be defined. This can take the form of anything from simple Euclidean space or very advanced networks representing multiple modes of transport. With these networks, different impedances can be used. For the Euclidean space, perhaps distance is most appropriate, but for a multimodal network, very advanced impedances of travel time can be calculated. For the purpose of this research, a network for non-motorised modes of travel was most relevant. The network used was the axial map, which represents the accessible space through which pedestrians and bicyclists can move freely, presented in Figure 3.6. In contrast to a network of pedestrian and bike paths, the axial map can be argued to have a built-in cognitive aspect that

corresponds better to walking behaviour, further developed in section 2.2.3. Furthermore, a pedestrian and bike path network can be too rigid for modelling actual movements, for example, by following a winding path where going straight is an option. It is also an issue of reliability of data in alternative sources for transport networks. There are open crowdsourced alternatives, which differ in quality in different places in Oslo, and there are official transport networks, which in many cases lack smaller paths, especially on semi-private properties. As the unit to use for the accessibility metric, distance was chosen. Walking distance, defined as the distance through a network available to pedestrians, was preferred because the functional form of the

Figure 3.6. The axial map used in this research.

variables is more easily conceptualised compared to, for example, angular distance, where the angular change threshold is not as easily interpreted. There is also an argument that walking distance is easily interpretable by planners and decision makers.

Measuring absolute location
The absolute location is, in the scope of this thesis, a proxy for a neighbourhood's brand or reputation. That is, a neighbourhood can be considered attractive in itself due to its reputation, regardless of its location. This means that the name supposedly also affects the housing prices in addition to the relative location. It is not something that planners and decision makers can make use of in development strategies but something that is indeed valued by homebuyers. In this research, both postal codes and city districts have been used to describe the dwellings' absolute location.

Knowing that absolute location does matter to some degree, it needs to be measured properly to fit the economic model and answer the right question. The concern is what the relevant delimitation of a neighbourhood is, for example, city districts, postal codes, census tracts, or election constituency. Postal codes and census tracts usually have different aggregation levels, which means different geographical spread and that a choice as to which aggregation level is most relevant for the question has to be made. In order to get a more precise description of location, the smallest aggregation level was used. It should also be mentioned that adding more variables in a hedonic model, the economic model in this research, will increase the explanatory power of the model simply due to the number of variables. Hence, consideration was required.

Centrality with space syntax
Centrality is a factor that is often described as important when choosing where to live. It differs between different parts of the world as to whether it is considered positive or negative to live in a central location (Brueckner et al., 1999), but it most probably has an impact on the attractiveness of a dwelling. However, there is no exact definition of centrality even though it is very common in economic analysis to use distance to central business district (CBD), most often as spatial separation in Euclidean distance or travel time (Heyman, Law, and Berghauser Pont 2019). Centrality would typically describe location in relative terms.

In this research, two principally different descriptions of centrality have been included. First, the effects of centrality have been approximated, such as number of public or commercial services, which can both be perceived by consumers and changed by planners. Second, the centrality in space itself has been included through space syntax measure integration, introduced in the Background section. This measure is perceivable by consumers in terms of how easy it is to find a place or how connected it is to its surroundings. Furthermore, it is something that planners can modify. Connecting streets, or spaces, differently will affect the network integration, and thus centrality is manipulated, in contrast to the distance to CBD, which can only be changed marginally by moving the dwelling or the CBD or making straighter connections to it.

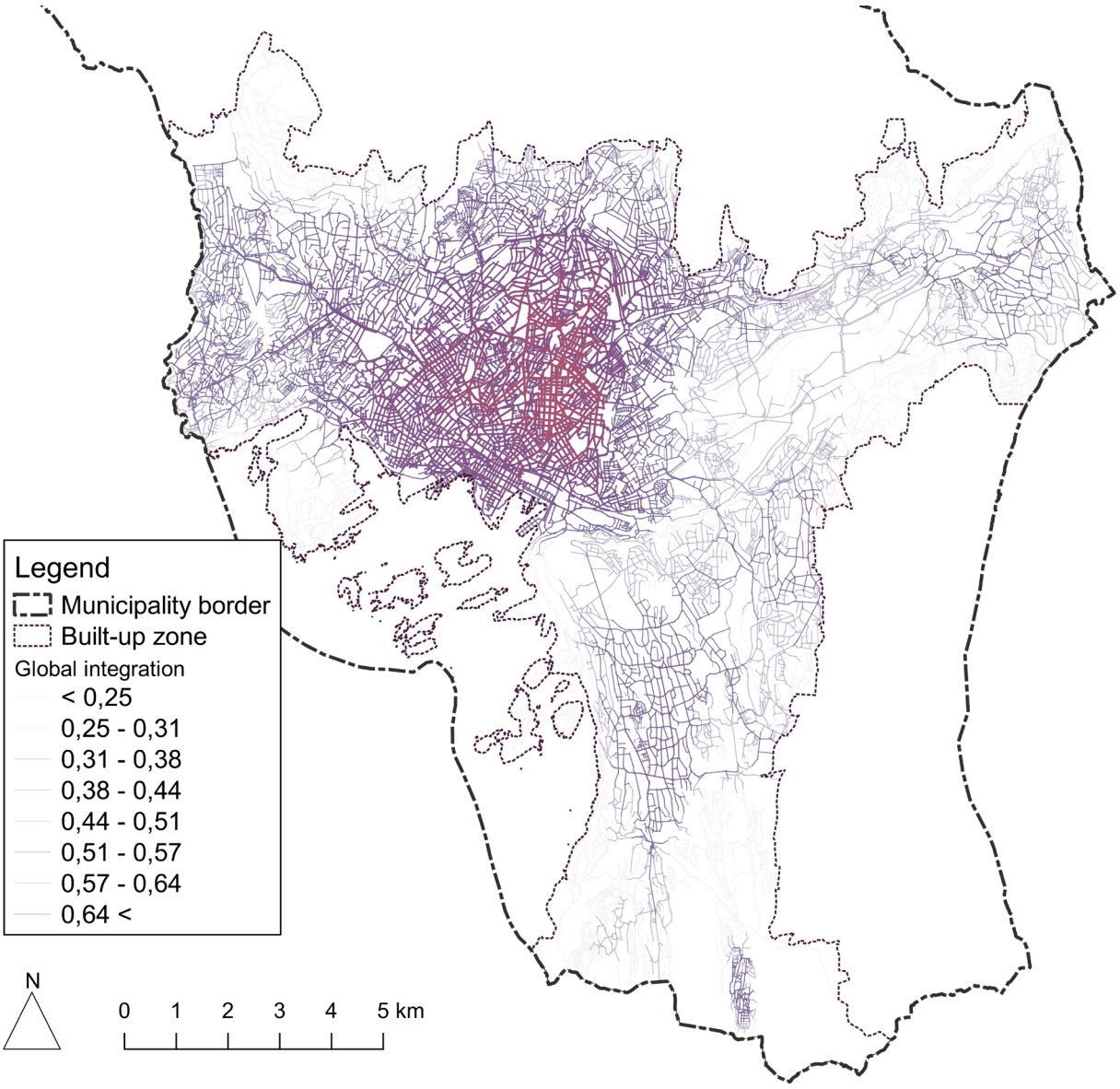


Figure 3.7. A map of the global integration in Oslo.

As was mentioned in the Background chapter, integration can be measured with different radii. In this research, many radii have been tested, and two in particular have been repeatedly estimated as significant – global and local – more precisely 30 (Figure 3.7) and 3 axial steps (Figure 3.8). Global integration was added to estimate the sense of centrality in the city as a whole, not restricted to the CBD but also central urban places outside of that. The local integration was added to estimate the sense of more central streets in the surrounding neighbourhood. This corresponds more to, for example, the local high street or the quiet street along the green space in the neighbourhood.

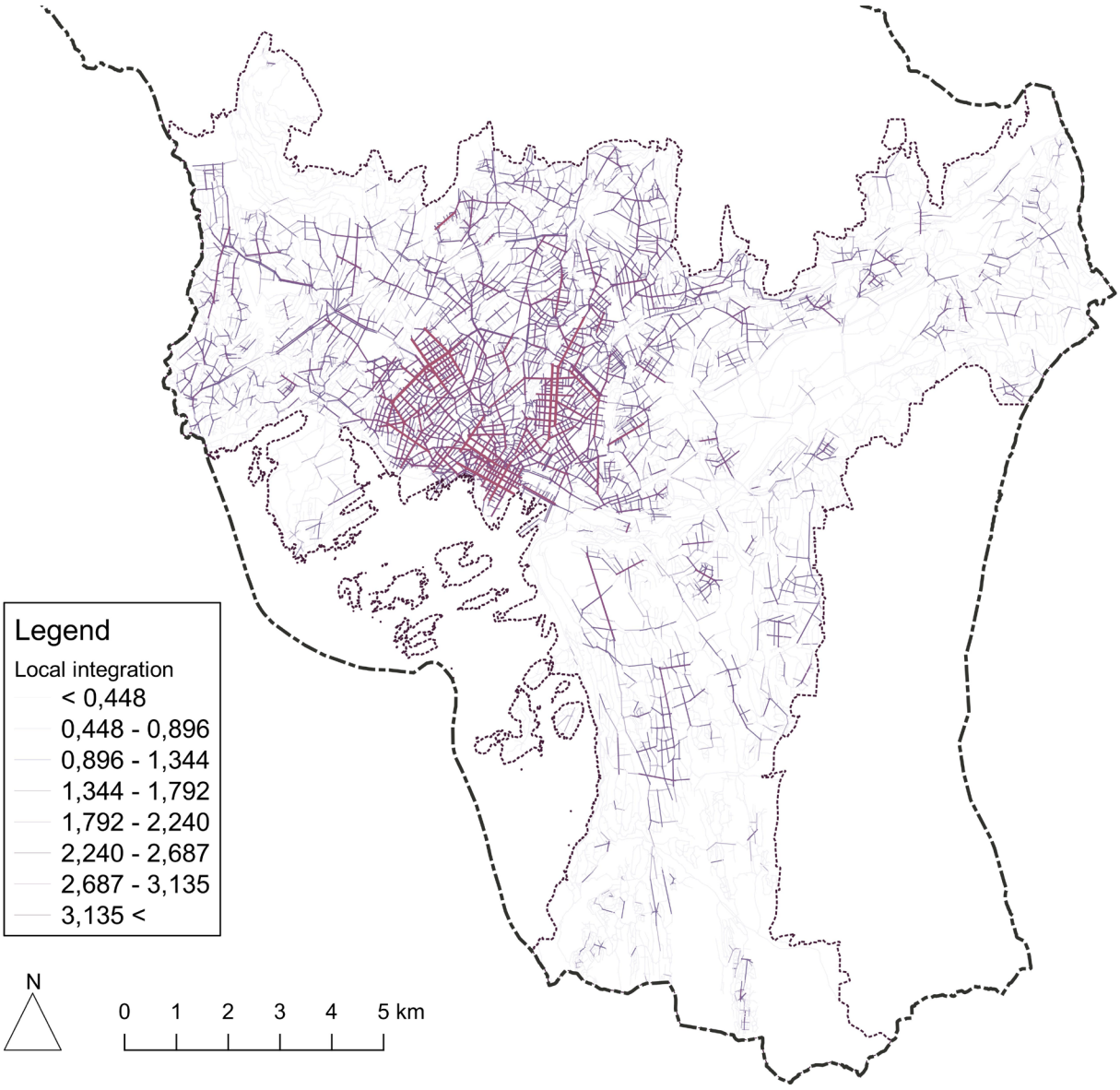


Figure 3.8. A map of the local integration in Oslo.

The network integration value that was used in the analysis was that of the closest axial line in Euclidean distance from the address point; see Figure 3.9. This could potentially mean that the axial line that is perhaps most used by the dwellers is not the same as that used in the analysis since private space in general is not included in the axial map. However, due to the nature of the network integration values, the difference between lines that are close is not very big.

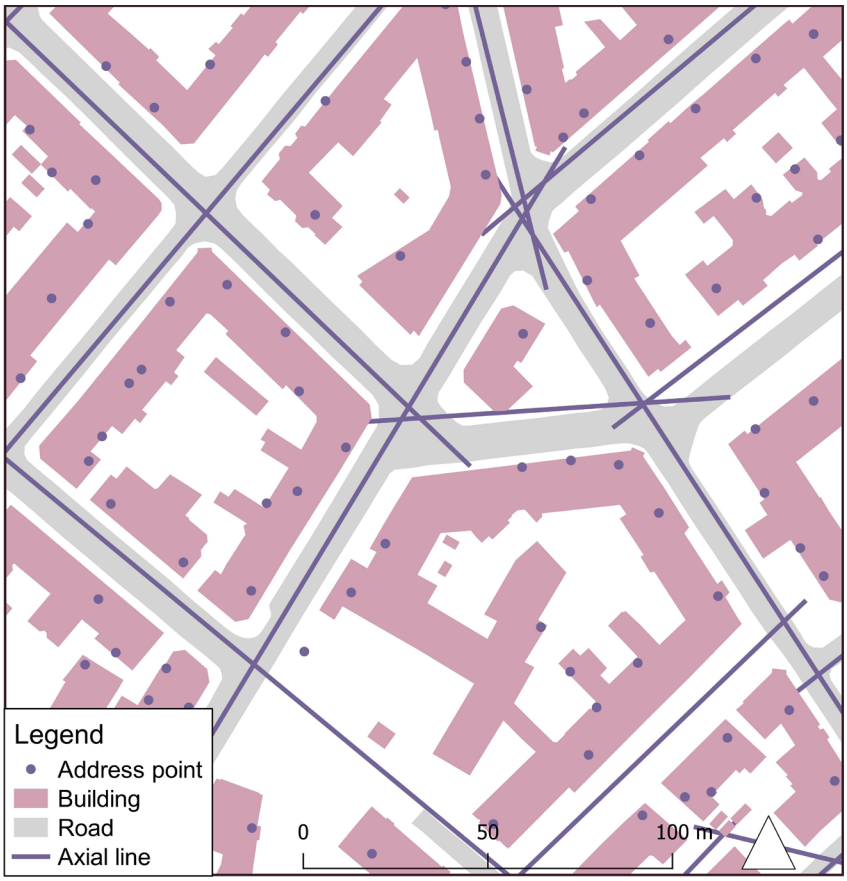


Figure 3.9. A map of address points and axial lines.

The example of access to the Oslo Fjord

Describing the relative location of a dwelling through accessibility can be done in many ways. The accessibility measure can be changed with regard to the key elements' origin, impedance, or opportunity. One example of a locational variable often used in hedonic price models is the access to water. In Paper II, it is found that from the sample of articles reviewed, most use a spatial separation measure for this, but a few uses cumulative opportunities, and one even measures access to water by gravitational accessibility, where closer and more water gives higher value. Furthermore, the impedance used is mainly an unspecified metric distance or Euclidean metric distance. Network

distance and travel time are not as common and measuring within zones is as common as network distance. Below is a description of how the measures in this work have been specified through examples of how the access to the Oslo Fjord; with the opportunity set as the Oslo Fjord, the variations between the measures are in origin, impedance, and type of measure.

Starting with access to the fjord for each city district, Figure 3.10 shows whether or not they are directly connected to the fjord. In this example, the origins are the boundary of the city district, and the impedance is topological. Acces-

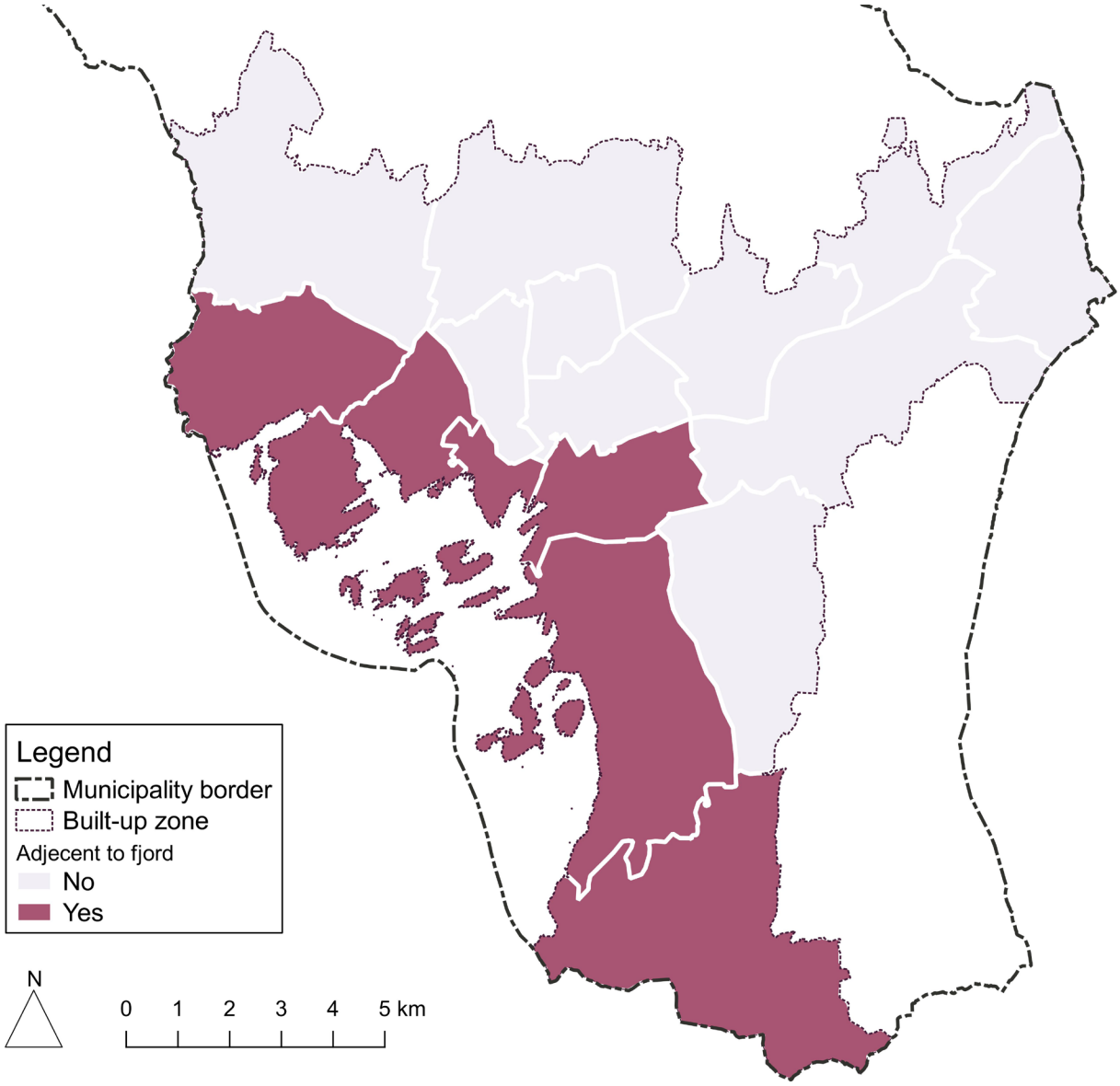


Figure 3.10. A map showing if a city district is adjacent to the fjord.

sibility to water is measured from each district, returning a value of 1 if it borders it or 0 if it does not. This is called a dummy variable in the econometrical analysis, which will estimate the price premium for a dwelling that is located in a city district bordering the fjord. It would also be possible to measure the distance from the city district, for example from the centroid in every district, to the fjord to get a continuous measure of the access. This could be considered to be unprecise, but the approach is not unusual (Heyman, Law, and Berghauser Pont 2019).

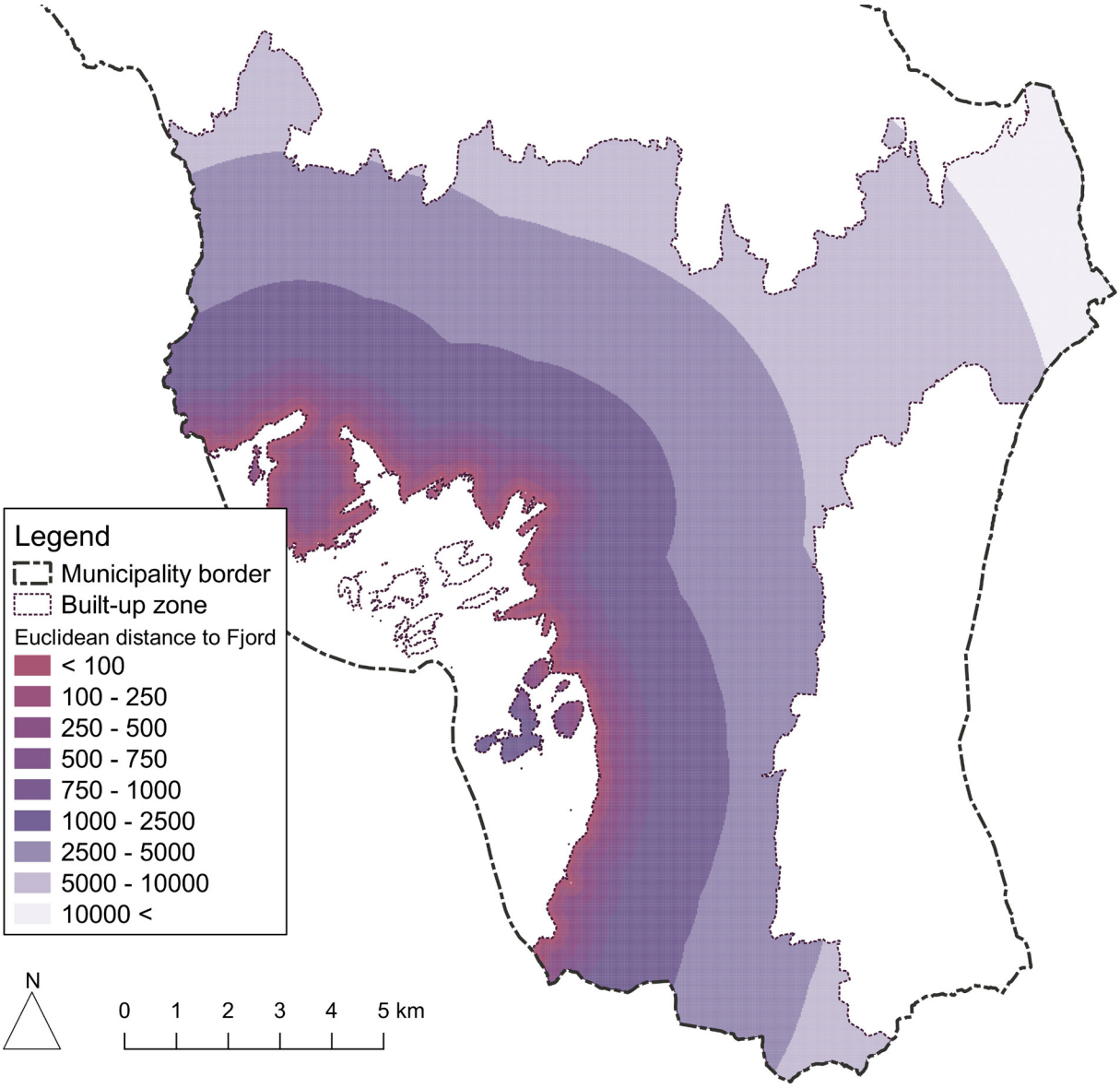


Figure 3.11. A map showing the Euclidean distance to the fjord.

In the next example, the measure consists of more fine-grained origins, either address points or polygons in a grid, and measuring the minimum distance between origin and fjord. This kind of accessibility measure is spatial separation, but it can be tuned very differently by using various impedances. Perhaps the simplest impedance is the Euclidean distance, or 'as the crow flies', which is illustrated in Figure 3.11 above. This answers how far a dwelling is located from the fjord on the map measured in Euclidean space.

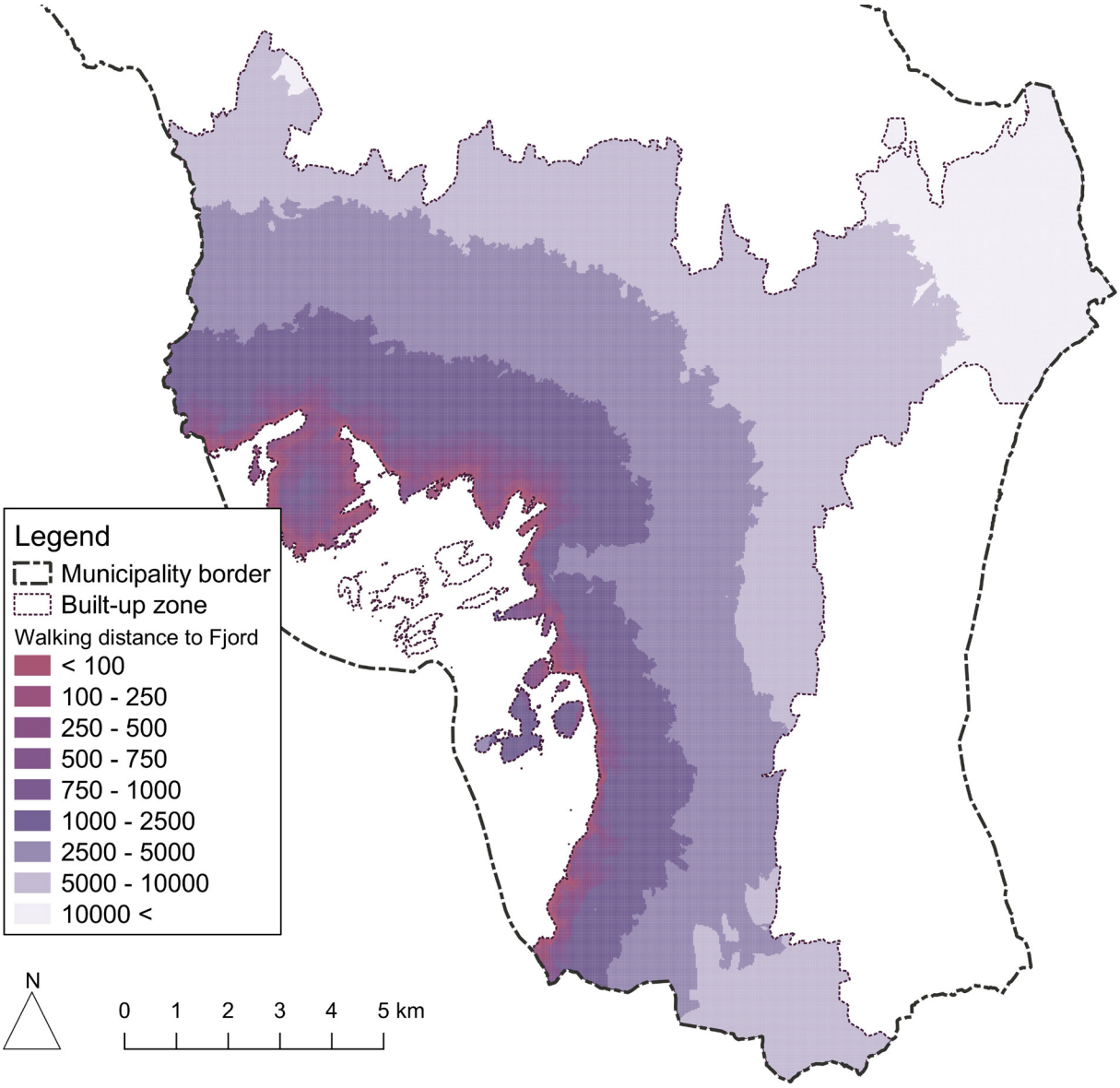


Figure 3.12. A map showing the network distance through the walkable street network.

Using the same type of measure, spatial separation, but with the impedance of network distance is shown in Figure 3.12. It is complicated to measure walking distance since pedestrians behave differently to each other as opposed to drivers, who, mostly, follow basic rules. For simplicity, the choice of impedance is metric distance through the axial network, which corresponds well to walking behaviour. This answers what the walking distance is from the origins to the fjord, but it does not answer how far it is for other modes that use other networks. By comparing Figure 3.11 and Figure 3.12, it becomes evident that for the valuation of a dwelling's location, the difference between walking and Euclidean distance might matter a great deal for the estimations.

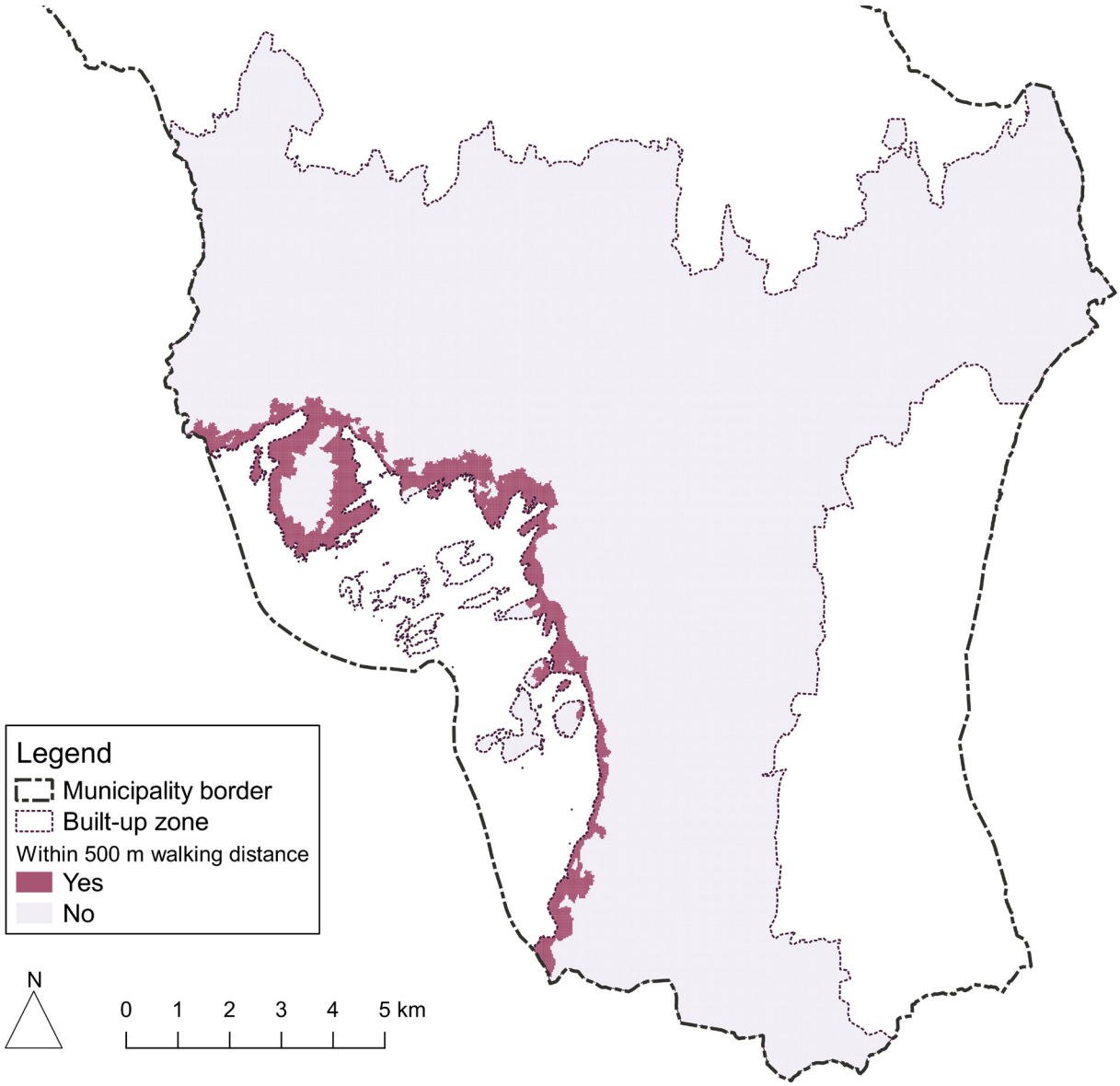


Figure 3.13. Places where the fjord is within 500 meters walking distance.

This example continues using the same origins as in Figure 3.11 and Figure 3.12 and the same impedance as in Figure 3.12, metric distance through the axial map. However, it measures whether the fjord is within 500 m walking distance from the dwelling, which is a cumulative opportunity measure that gives a yes or no answer, a dummy variable (Figure 3.13).

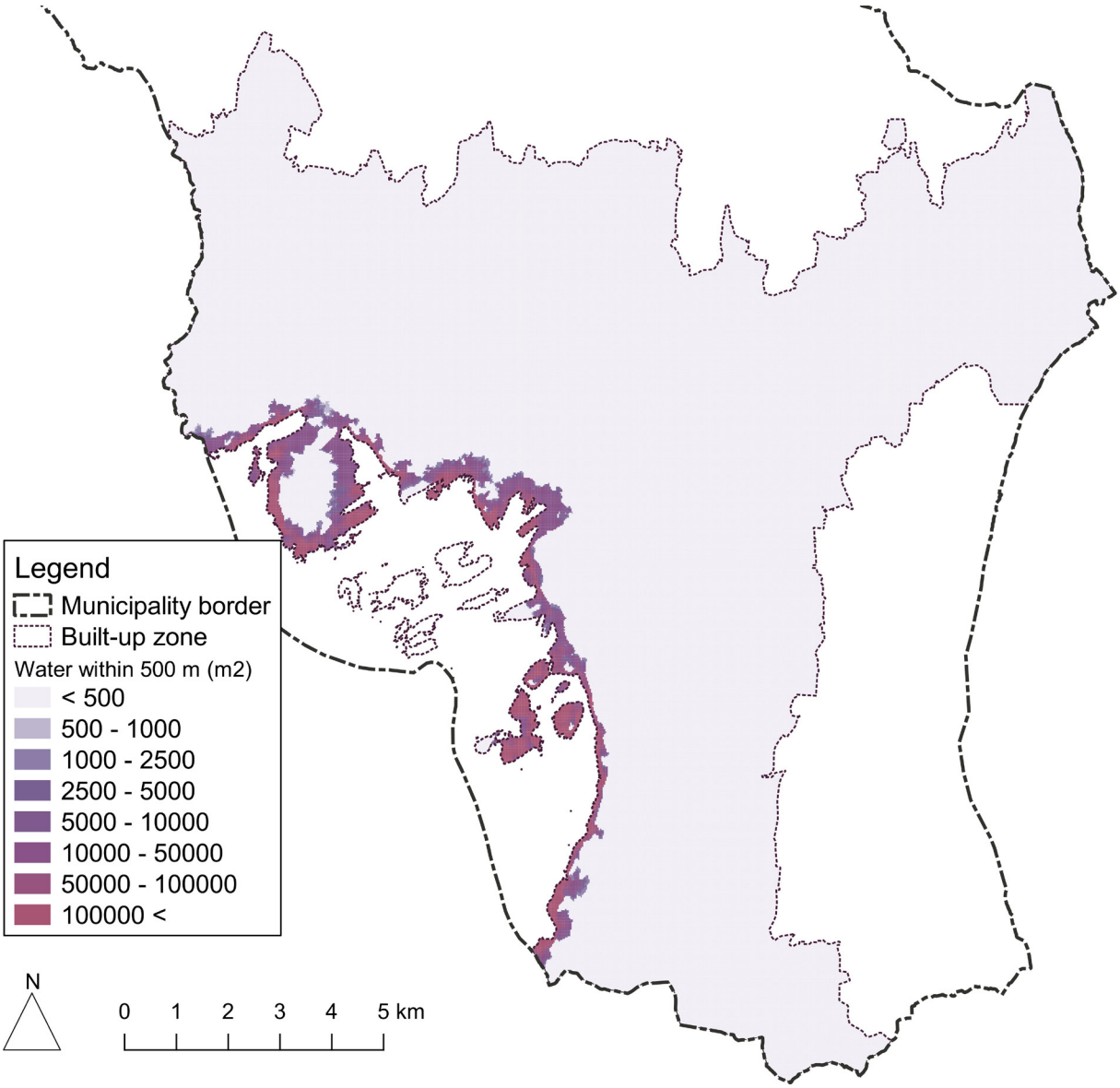


Figure 3.14. A map showing how many square meters of the fjord that is reached within 500 meters walking distance.

To exemplify how the type of accessibility measure can be used differently, the origins and impedance are kept constant from previous examples, and the information attached to the spatial object, the fjord, in the geographical model is used. In this example, the question is how much area of the fjord is accessible. This is done by measuring how many square metres of the fjord's area can be reached from the

dwelling (Figure 3.14). It might be more relevant to apply this on green space or to measure the number of restaurants within a walking distance from the dwelling, but this serves as a proof of concept.

3.3 ESTIMATING ATTRACTIVENESS – THE ECONOMIC MODEL

In this dissertation, housing is considered a commodity on a market, and simply put, the aim is to distinguish households' preferences for urban form through hedonic price modelling of housing. Due to the complexity of housing markets, considering, for example, property rights, state intervention, non-market housing sectors, tenure, transaction costs, and household mobility, a comprehensive model or approach is hard to fit into the format of a dissertation, if at all possible. The approach to how the economic model for this research was constructed is presented below.

Economic approaches on this matter are typically divided into fields of institutional economics and neo-classical economics, where institutional economics looks at certain aspects or 'institutions' in the market and to a greater extent builds on other theories and assumptions from disciplines apart from economics (Gibb, 2012). Depending on the issue studied, methods might shift. The neo-classical field, in contrast, has a more strict microeconomic approach that largely presupposes inter alia consumers' utility maximisation, no transaction costs, and homogenous goods. As Whitehand (2012) argues, this cannot hold on any housing market, but still this approach can give us the general picture. Hence, the method used should be judged on its predictions and not on whether or not this is how individuals behave – the idea being that all individuals in the market behave irrationally in separate ways, and therefore the model can hold (Pearce et al., 2006a).

For the statistical analysis in this research, the R language and RStudio software were used (R Core Team, 2015).

3.3.1 Hedonic price model

We know that housing prices vary over time and space. By relating aspects of urban form to housing prices, it is possible to estimate aspects in the urban environment that are considered attractive. Hedonic price models (HPMs) are tools for doing just that by estimating the price effects

of numerous relevant characteristics and treating them as explanatory variables in large samples (Baranzini et al., 2008). The method estimates the impact, the parameter estimate, of every statistically significant variable on the price variation and thereby infers people's marginal willingness to pay for particular characteristics of a dwelling. In this research, the HPM was chosen because of its advantage of being able to estimate the price effects on non-market goods, in this case urban form.

Dwellings have many characteristics that are consequently reflected in the price and theoretically can be said to be valued separately, even though they are bundled together in a specific dwelling and cannot be bought separately. The characteristics are traditionally categorised as presented in equation 1 structural, environmental, and locational (Freeman, 1979). Although this research is concerned with the latter two categories, the structural and environmental characteristics are an important part in the forming of housing prices and are vital to get a suitable economic model. Thus, other characteristics than locational that affect the price were also included, and their relationship with housing prices was estimated. The structural characteristics that were included in the models were, for example, size of the apartment, number of rooms, and floor number. They were partly restricted due to data availability and partly because of multicollinearity between some of the variables. Time dummy variables were included to control for time variation by adding a dummy variable for every period of time a sale was made to control for fluctuations over time. In addition, prices were adjusted according to the house price index for Oslo.

$$PSMPrice = \beta_0 + \sum \alpha_i Y_i + \sum \gamma_j S_j + \sum \delta_k A_k + \sum \phi_m I_m + \epsilon \qquad (1)$$

As for any model, what is not captured or included must be kept in mind before generalising the results (Maclennan, 2012). As Pearce et al. (2006b) mention, the model could suffer multicollinearity and consequently show corrupted estimates with a change of sign. This means that two or more explanatory variables vary very similar to the dependent variable, which can result in an estimation of a correlation to be negative even though it is positive. This was controlled for by looking at a correlation matrix between

the explanatory variables and by reviewing their variance inflation factor. Variables that had a too great tendency towards multicollinearity was excluded from the model.

The procedure of building a model, schematically illustrated in Figure 3.15, was complex and went through many iterations and modifications. The first complete version was published in Heyman et al. (2017) and was the point of departure for Papers III and IV. Partly due to the complexity and iterative work, there was a risk that the search for significance or explanatory power had a negative impact on the input variables or the model specifications (Gibbons & Overman, 2012b). To minimise this risk, the research aimed to keep the variables as simple as possible while still explaining the investigated phenomena. The iterative work included the remaking of locational variables when needed to fit the purpose.

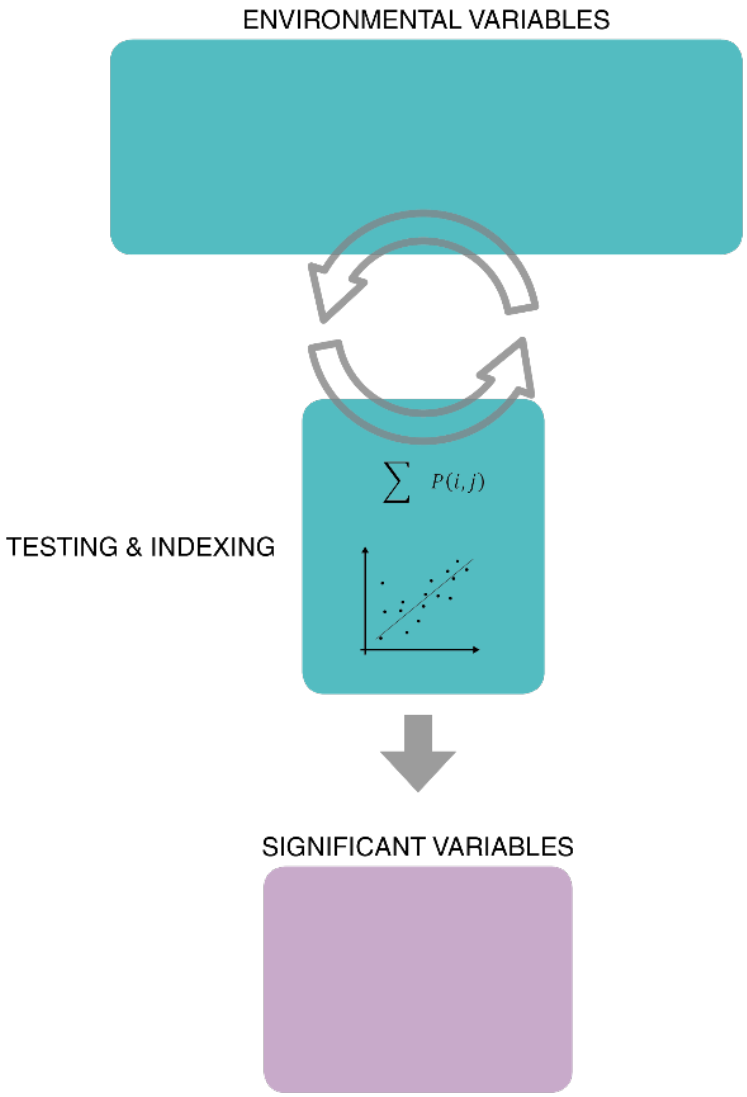


Figure 3.15. A schematic image of hedonic price model methodology.

3.3.2 Distance decay and PS-SEM

A fundamental part of accessibility is distance decay, not least in the framework of hedonic modelling. Whatever the mode of transport, the willingness to pay for access to an opportunity will vary with distance to it. Perhaps most apparent is the case with walking distance, where the distance to, for example, a school only matters up to a certain point, where people start taking a bike or car instead. The importance of distance is decaying. Typically, this is handled by transforming the variable, most often with a natural logarithm, or by dividing the variables into several buffer distances that are treated as dummies in the model – for example, dividing the distance to a metro school into 0–200 m, 200–500 m, 500–1000 m, etc. The former approach is effective for capturing distance decay but is dependent on an assumption of a fixed function, which usually is unknown. The latter is effective for finding significant relationships between the dependent variable and the dummies, but the cuts can play an important role for the parameter estimates and are not known a priori.

Paper III treats the variables with a combination of functional transformation and 'dummy cuts' to search for significant relations. However, in Paper IV, the distance decay function is estimated through the technique of a penalised spline spatial error model (PS-SEM) (Basile et al., 2014; Montero et al., 2018). This lets the model estimate the price

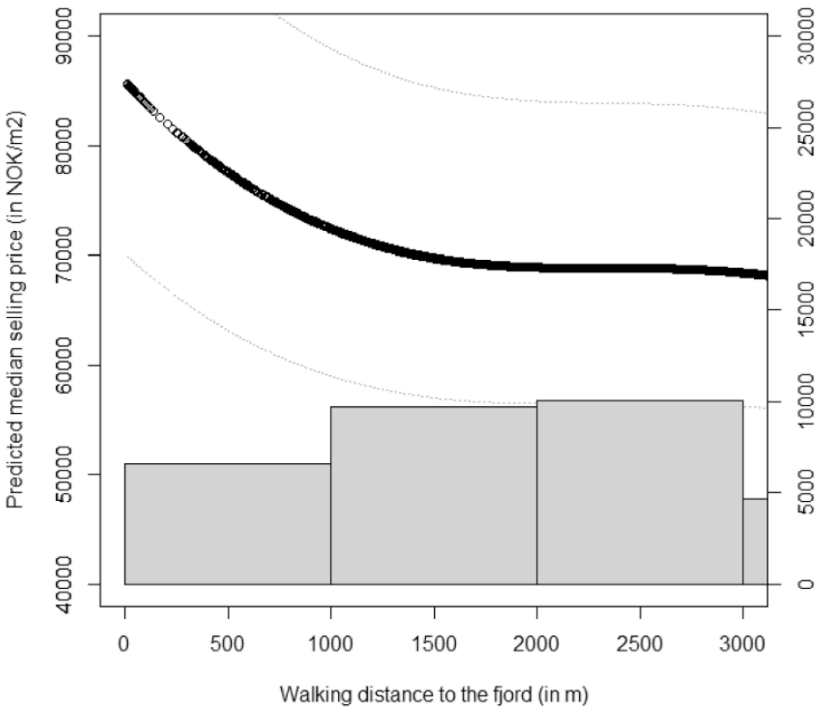


Figure 3.16. The estimated relationship between price per square metre of apartments and walking distance to the fjord in Oslo (Łaszkiewicz et al., 2022).

of apartments as a function of distance (also referred to as non-parametric modelling) by smoothing (Hastie & Tibshirani, 1990; Wood, 2017). Used for all variables, it gives insight into what the distance is from various opportunities at which the willingness to pay decays or increases. Figure 3.16 is an example from Paper IV of a distance decay graph where it becomes clear that prices decrease from right by the waterfront to about one kilometre but after that the price stabilises.

3.3.3 Spatial dependence

Hedonic price models for housing deal with spatial dependency. However, the approach to dealing with it varies in specification (Anselin, 1988; Kuminoff et al., 2010; LeSage, 2008; Ward & Gleditsch, 2008), which is expanded upon in Paper IV. In principle, spatial dependence is the phenomenon that observations are dependent in space. It is similar to temporal dependence, where a present observation is dependent on the past. The difference is that observations can be dependent in two directions in space instead of only one in time. Following Tobler's first law of geography (Tobler, 1970), closer things are more related, and consequently the methods for dealing with spatial dependence have to define where things stop spatially to depend on each other. Most approaches define neighbours in a spatial weights matrix, which in this case would be defining for the model which apartments are considered neighbours and therefore influence each other's price (Gibbons & Overman, 2012b). Insofar as the spatial weights matrix is defined correctly, the spatial dependence is controlled for, but if it is not, the parameter estimates in the model might be biased.

To test if a model suffers from spatial dependence the typical approach is to estimate the Moran's I. If there is spatial dependence, there are approaches to account for it by modelling it directly. The method used in Paper IV to control for spatial dependence was to use a well-established approach with a spatial weights matrix (Anselin & Arribas-Bel, 2013). To explain all spatial dependency in a model with explanatory variables is preferable, but when it is not possible, assumptions as to how this dependence is structured have to be made. In addition to the PS-SEM, other more well-established approaches, such as the spatial lag model, were used. The specifications and results of these approaches are presented in the electronic supplementary material to Paper IV.

3.3.4 Submarkets and ability to pay

A prerequisite for this kind of modelling on housing prices is that the sample is one market only. In general, this means that there should be few transactions between defined housing markets and that buyers generally do not consider two different markets at the same time (Palmquist 2005). Thus, the model results might be biased if the sample data consist of several markets. However, if the sample data are only considering a subsection of the market, the model will not be biased – albeit inference issues might occur if the sample data are taken from a very specific submarket.

Although a vast research field, briefly explained, submarkets can be defined either by geographical aspects, such as different city districts; social aspects, such as families with children; or structural aspects, such as detached houses or apartments. Research has also considered submarkets based on street network connectivity (Law et al., 2015; X. Yang et al., 2016). This thesis investigates the freehold apartment market in the geographical area of urban Oslo municipality.

The geographical delimitation of Oslo was a choice that was made in an effort to capture the willingness to pay in the whole city and cover the administrative border for the planning of Oslo municipality. It is possible to argue that there might be a difference in preferences for the central part and for the outskirts. However, as information for urban planning, this division does not serve the purpose of giving general conclusions of what is attractive urban form. If a difference in preferences between inner city and outer city was to be found, it would still not inform the planner about the general attractiveness in the city, only for smaller predefined parts of it. It is not an easy balance between saying something about everything or a lot about something. Furthermore, it is possible to argue that the market extends beyond the municipal border into the surrounding municipalities. The decision to limit the sample to the Oslo municipality was based on the fact that a smaller subsample of the market does not affect the result if the subsample is representative of the market (Palmquist, 2005).

Considering how housing markets work, different segments of the population of a city have different preferences. One example is the difference in preferences between empty nesters and families with small children, where the former might be more interested in a central location with access

to entertainment, and the latter might prefer a garden and fewer traffic-exposed bike routes to school. Hence, a consequence of the choice of market delimitation is that the analysis did not take differences in demographically separated groups into consideration. One important such demographical separation in the market is the ability to pay. Whereas the model estimates the marginal willingness to pay for the whole market, there is a segment of the population who has little choice in where to live. Instead, their concern is to pay as little as possible rather than making trade-offs between characteristics of the dwelling. On the other side of the spectrum is the segment of the population that has very little budget constraint. As a step to consider this in the model, the sample have omitted outliers in form of the top and bottom percent of the observations with regard to square metre price, as illustrated in Figure 3.17.

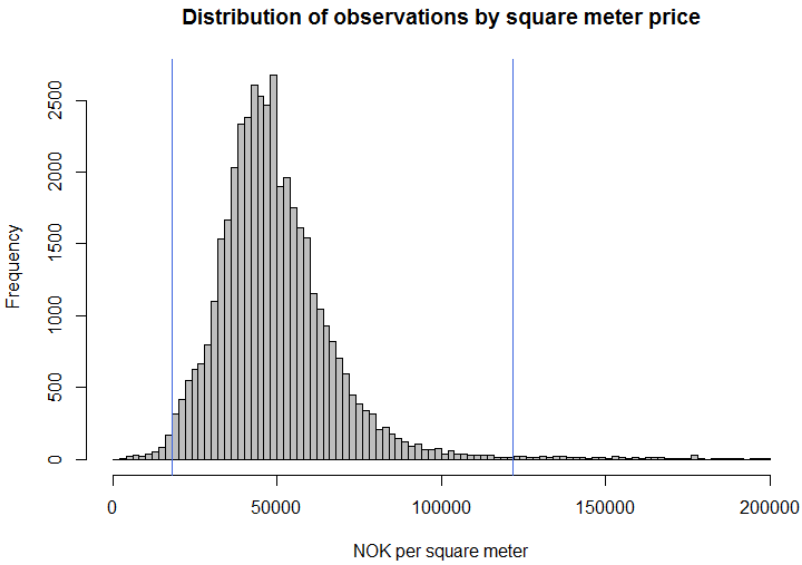


Figure 3.17. The cut-offs made in the sample to omit extreme values (Heyman and Sommervoll 2019).

There are two ways to own apartments in Norway – by freehold (selveiere) or through a housing cooperation (borettslag) – the latter meaning that you own a right to live in the apartment but legally you only own a percentage in the common property, which the cooperation owns collectively. In practice, there are typically some common mortgages and funds for maintenance of the property within the cooperation, which are paid for with a monthly fee. Generally, this means that the bidding price is lower for apartments in a housing cooperation since they are associated with higher monthly fees. Another important aspect that separates the two tenures is the right to sublet the apartment. With a freehold apartment, there are no restrictions, which makes

subletting quite widespread compared to the housing co-operation, where there are restrictions on whether and how one can sublet. With regard to these differences between the tenures, this research considers them to be two different submarkets in the Oslo housing market and only the free-hold market has been analysed. The geographical distribution of the two tenure types is presented in Figure 3.18.

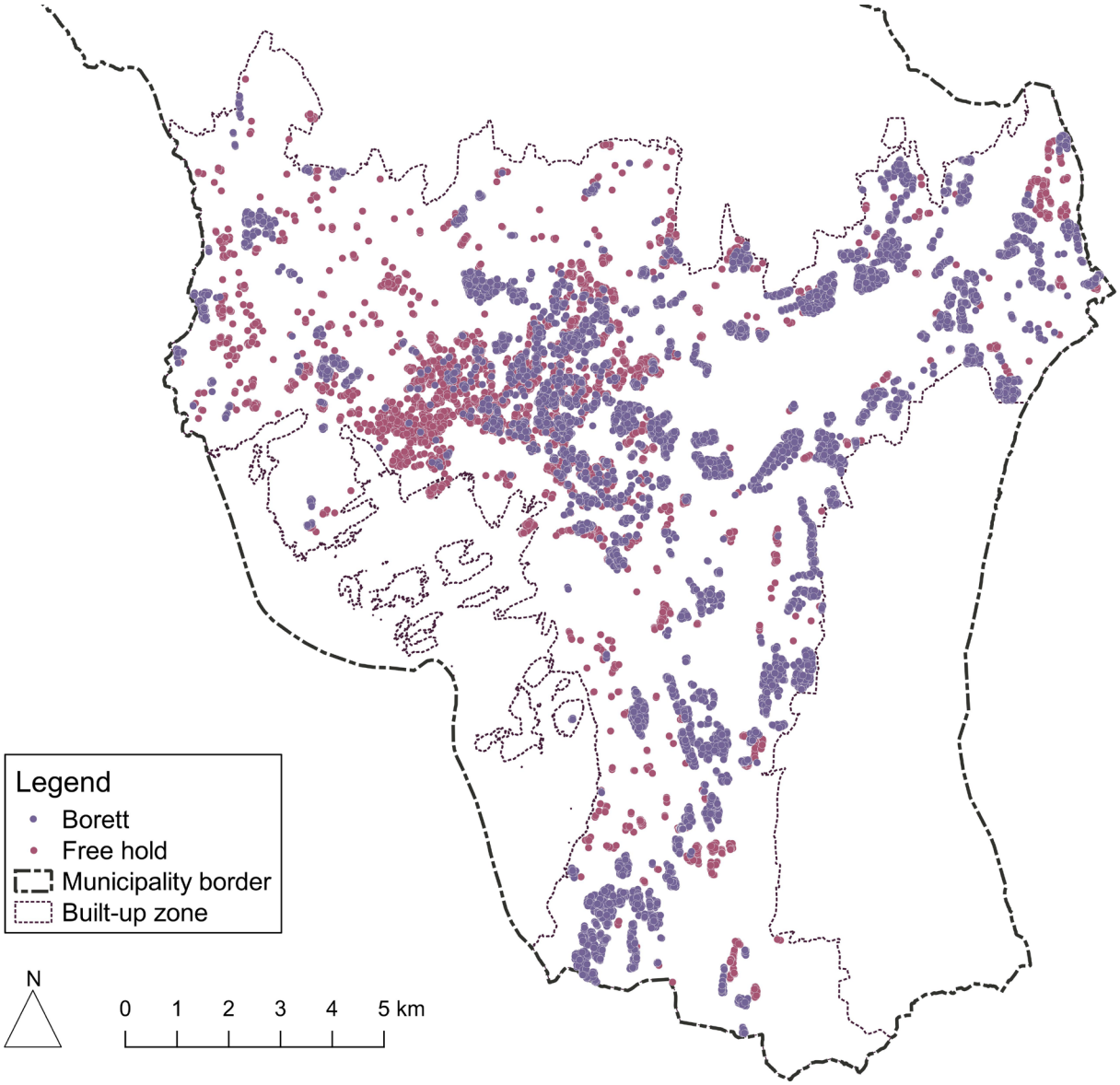


Figure 3.18. The geographical distribution of the two different tenure types of apartments in Oslo.

3.4 DATA DESCRIPTION

Papers I and II uses previous literature as data, and Papers III and IV use geographical and transaction data. Paper II is a systematic review of 54 peer-reviewed articles, collected through systematic database searches. The searches are thoroughly described in Paper II.

For the more empirical work in Papers III and IV, Table 3.1 shows the source and date for all the data used in the spatial analyses and the statistical work. The transaction data were bought from the company Ambita AS, and the geographical data were collected from Oslo municipality and Statistics Norway (SSB). The transactions were obtained on address point-level and multiple observations can occur on the same coordinates, either as different sales with same address or repeat sales.

Table 3.1: Sources of geographical data used in the research.

Data	Description	Year	Source
Apartment transactions	Transaction data for all condominium apartments sold between 2007 and 2015 with structural characteristics attached.	2007–2015	Ambita AS
Buildings with height	All buildings georeferenced and with laser scanned heights. The heights used were maximum heights, which presumably has an effect on the estimation of number of floors.	2016	Plan- og Bygningsetaten (PBE)
Parks	All parks georeferenced and defined by the municipality of Oslo.	2013	PBE
Green spaces	Graveyards, green areas, and sport fields georeferenced.	2013	PBE
Water	The fjord, rivers, and lakes georeferenced.	2013	PBE
Public transit	Stops and stations for the commuter train, metro, and tram.	2013	PBE
Businesses	All businesses registered at the Norwegian Tax Agency	2014	Statistics Norway (SSB)

In general, the municipality keeps its data for maintenance purposes, for example, regarding parks and light posts, and the data are frequently updated. SSB keeps data for research and governmental use. Ambita AS sells transaction data to various users and maintains a reliable and cleaned database based on data from The Norwegian Tax Administration and the Norwegian Mapping Authority. The data are originally compiled from tax declarations. The structural variables

included in the data set was size, floor level, number of rooms and number of bathrooms and kitchens.

The axial map was manually made by the author and is based on a previous version created by the consultancy Spacescape. The method was based on the logic of drawing the fewest and the longest lines in the network that cover the entire continuous open space (Hillier and Hanson 1989, pp. 91–92). As background data to help the drawing procedure, various maps, elevation curves and aerial photos were used in addition to site visits. In addition to the data presented in Table 3.1, Open Street Map[5] data, aerial photos from Microsoft Bing, and satellite images and street views from Google were used.

3.4.1 Data validation and analysis

All the data have gone through analysis and cleaning. First, when building the spatial model for Oslo, the geographical data were validated manually against updated aerial photos and online map services, such as Google maps, and supplemented where necessary. To some extent, site visits were also needed to validate some of the geographical data. Typically, data with less information attached needed less attendance and were easier to include in the spatial model. The more information-heavy data, especially the workplace registry, needed validation. Workplaces are based on tax declarations to the Norwegian Tax Administration with information on business branch, number of employees, and turnover. The registry also holds the address to all workplaces, which are the source for the geographical positioning. However, using the geographic position of an address should be handled with care as where the actual business is taking place is not always the same address included in the registry. For smaller businesses (e.g. self-employed), the home address is often used in the registry even though the work is performed elsewhere. For larger businesses (e.g. hotel chains), the address in the registry might be the address of the headquarters and not the individual branches. This causes some concern when using the information on employees or turnover, or on the micro businesses. In this research none of these parameters have been used, and thus large issues have been avoided, although some minor issues may still be present. However, the data have been completed by adding missing businesses manually from various other sources and site visits.

[5] Retrieved via the plugin QuickOSM on the QGIS platform (OpenStreetMap contributors, 2017).

The transaction data used were originally all registered transactions of properties from 1993. In this dataset, the structural information of the apartments was also included, such as number of rooms or the existence of an elevator. The transactions were filtered to obtain a sample that contained no empty fields or that could be used for the analysis. In addition to the choice of market and geographical delimitation (discussed in section 3.3.4), the filters presented in Table 3.2 were applied. No reason was found to believe that the observations filtered out had any structural bias that would influence the results in a profound way.

Table 3.2: Transaction data filtering (Heyman and Sommervoll 2019). Similar filtering was done in all empirical works in this thesis.

	Number of observations
Located in a multi-dwelling building (codes 141 to 146)	141,791
Categorised as a dwelling	129,529
Registered as an arms lengths sale	107,386
Geo coordinates	107,033
Larger than 10 m^2	92,299
At least one room	92,174
Sold in 2007 to 2015	48,912
Sold for more than 200000 NOK	48,907
Sold for less than 200000 NOK/m^2	42,825
No NA's for bathroom or WC	42,669
Transactions with building age	42,049
Transactions with size less than 200 square metres	41,886
Extreme observation removal[a]	40,019

[a] The top and bottom one percentile of sale price, square metre sale price and size removed.

4 Results

All four papers in this dissertation find, in one way or another, that urban form is part of people's preferences for housing. On one hand, the findings point towards the importance of including relative location description within hedonic pricing theory for strict methodological reasons. On the other hand, the results can inform urban planners about what aspects of urban planning and design are attractive, measured as preferences in the housing market in Oslo. It is furthermore suggested that relative location description, on a theoretical level, corresponds well to consumer perception, which is of great importance when analysing consumer behaviour. The first two papers provide results regarding problem identification and an overview of the field and methodology. The last two papers show novel empirical results of which aspects of urban form that are preferred in Oslo's housing market and how.

In Paper I, it is concluded that describing location as relative in economic modelling can give valuable insight to urban planning and fit well to the theory behind hedonic price modelling. This is followed up by empirical testing in Paper III, which shows that relative location description is more effective for estimating apartment prices than the more conventional method of controlling for location with postal code dummies and with a more informative description of location for urban planning and design. In essence, relative location variables, as specified in this research, account for a large part of the price variation of apartments in Oslo. However, in the case of walking distance variables, the influence on price also varies with distance, which is shown in Paper IV.

The systematic review in Paper II, where contemporary research is reviewed, concludes that the specifications of accessibility vary greatly in terms of level of detail and that a large share poorly relates to people's perception. Furthermore, it concludes that accessibility in HPM studies was

often measured within discrete zones, such as census tracts or neighbourhoods, or as a spatial separation (e.g. shortest route) using Euclidean distance. Accessibility was often reduced to aggregated values for city districts or the distance to the central business district (CBD). Network distance was a relatively rare measure for distance compared to Euclidean. Worth noting is that none of the studies reviewed used network distance for cumulative opportunity measures, meaning that in our sample of studies, no one has investigated the impact of number of opportunities within network distance on housing prices.

The results propose that there is much knowledge concerning which neighbourhoods are attractive but not as much about what makes them attractive. This argument and the notion that accessibility was sometimes not used at all in HPM studies frames the problem, on one hand, as the loss of precision using some specifications of accessibility and, on the other, the lost connection to the theory of HPM.

Walking distance is important but not to the same extent for different opportunities or over distance. Paper IV shows how the relation between apartment prices and walking distance to different destinations vary with distance, called distance decay. The novelty lies in the non-parametric estimation of the function, meaning that the relationship between distance and price is not set in advance but instead calculated from the sample. Furthermore, the willingness to pay for walking distance to destinations seems to coincide with the willingness to walk. That is, at the distance where people stop walking to a certain destination, their willingness to pay for walking access to the same destination decays. This suggests that housing prices to a degree are driven by walkability in terms of walking distance to key destinations.

4.1 ATTRACTIVE ATTRIBUTES OF LOCATION

The different aspects of location that are significant and robust throughout the papers are clear in what they represent, for example, access to green spaces or public transit. However, exactly what kind of accessibility is relevant is not as clear and differs between the different models. I argue that this result makes the case for my dissertation because most expectations about what impacted prices were found in the results. However, it was also evident that the specification

of the variables was highly important, which implies that urban planning and design must be considered in order to build accurate models.

Green spaces are considered differently in terms of type, size, and distance to dwellings. One cannot say that green space is attractive or unattractive as the relation to housing prices is much more complicated than that. What can be generalised about green spaces in Oslo is that they are estimated to affect prices to a large degree. They are one of the most important predictors of price variation in all the models tested. However, the variation is considerable as to how different greenspaces affect the housing prices at different distances.

Urban amenities follow the same logic, where they seem important in all models, but the preferred specification is different. It seems from Paper III that the number of accessible amenities is important, where few are better than many, but not too few. Another variable in the specification is the distance at which the amenities are preferred or not. Arguably the services that amenities in themselves contribute are appreciated, but the external effects, such as noise and traffic, might be unappreciated. The combination of different amenities seems to be more important for homebuyers than many of one kind.

Public transit has a correlation with housing prices throughout these studies. Different modes have been tested and have similar relations with prices, but due to multicollinearity among the modes, only access to metro station was included in the final models. Access to public transit in Oslo is overall good, and therefore the differences might not be picked up in the model since evenly distributed variables in a regression model tend not to show any significant relationship.

Access to regional and national roads was clearly associated with price variation in all models. Compared to many of the other variables, the distance to a motorway showed a stable positive relation to price in Paper IV, meaning that the closer the dwelling was located, the lower the price. The distance decay function supported this relation, where the prices increased with walking distance up to 500 metres where the prices plateaued.

Access to water was tested in many ways. Firstly, the different kinds of water (streams, lakes, and sea) were tested together and separately. Secondly, walking distance and Euclidean distance were both tested, with the latter as a crude proxy for sea view, given that Oslo is built up on slopes facing the fjord. In the end the walking distance to sea, the Oslo Fjord, was statistically the most fit and significant variable in combination with being theoretically most sound.

The configuration of space has a significant association with price variation. Considering that integration, in the sense of being close to much, is often associated with higher housing prices, the positive correlation between the global integration value of the closest street segment and price, shown in Paper III, comes as no surprise. The local integration value has the opposite relationship with prices, most probably because homebuyers are willing to pay for a central location in the city but on a calm street.

4.2 APPLICATIONS

One application of this research in general is the combination of spatial analysis and econometrics. The individual papers contribute to this in different ways, and their relevance lies mainly in two aspects: method development and informing urban planning practice. The contributions to method development are more concrete on the econometric side, where the spatial analysis helps to build better models, but there are prominent applications to urban planning and design that economic valuation gives.

4.2.1 Method development

One weakness in hedonic price models is the omitted-variable bias, meaning simply that relevant explanatory variables are left out of the model. Paper III strongly emphasises that by not using relative location description variables, relevant variables are omitted even though the explanatory power might be similar with other descriptions of location. In doing so, supplemented with theoretical argumentation in Papers I and II and further empirical confirmation in Paper IV, this research gives input to method development within hedonic pricing.

The penalised spline spatial error model (PS-SEM) used in Paper IV is a type of model not often used for explaining

the relationship between accessibility and housing prices but shows valuable contributions to the estimation of urban form in the form of distance decay estimations. By estimating the non-linear relationship between price and distance, the functional form of the relationship does not have to be specified a priori. Data mining, in the sense of looking for significant relationships by cutting variables into buffer dummies, also becomes obsolete. Alternatively, if data mining is necessary, this method can help inform the process.

Both contributions described above are to the econometric field. A contribution to method development for the urban planning practice is the notion that urban planning and design can be quantified. The different specifications of urban form and the different outcomes when analysed in relation to housing prices is also an important insight. Both contributions could potentially give planning authorities better tools to measure and evaluate urban development from a morphological perspective. It is also possible to see an opportunity to include economic value directly in the design process, which could open the possibility to increase feasibility in plans and design proposals as well as to increase aesthetical, social, and ecological value.

4.2.2 Information for urban planning

One of the main contributions from this research is the demonstration of inherent economic value in urban form. The other main contribution to the practise is that the economic value is very particular in the sense that it is not only more green or more transit that generates value. The relationship is much more complex than that, which has been estimated here. This insight could be used to generate more knowledge of how planning and design interventions affect the monetary value, in order to evaluate urban development, review proposals, or inform decision- and policymaking. The economic value of urban form, described as relative location, could potentially also help facilitate the communication with other actors in urban development. Economics can be understood and translated between several fields, which is not as easy with the description of urban planning and design in itself.

Enhancing walking is a recognised goal for many cities, and the effects of it has been widely researched. One way of enhancing walking is to make sure that there are services and shops at a walkable distance from residences. The suggest-

ed relationship between willingness to pay and willingness to walk, presented in Paper IV, is convincing information for urban planners and policy makers to use in practice. Not least is the estimation of the distance decay of willingness to pay interesting from an urban planning perspective. In a practice where distances are created and evaluated for different purposes, it becomes relevant to see the variation of impact over those distances.

This research also points towards an opportunity to be more concrete when planning a city with respect to economic value. Since urban development in most cases is executed by private actors, a method to evaluate urban plans could be a tool to use in urban planning practice to evaluate feasibility and informing processes of development agreements and property deals within the planning process.

5 Discussion

The results suggest that urban form has intrinsic monetary value. From a planning practice-perspective, this means that different designs are valued differently and that the difference in value could be argued to correspond to attractiveness. This research further argues that this holds as a quantitative measure of attractiveness in urban form. Given that the practice today has little knowledge of the intrinsic monetary value of what is created and regenerated in a time of rapid urbanization, this should be important input to the discourse around how to develop cities. That is not to say that other values, such as ecological or social values, are to be neglected, but that a quantitative measure of attractiveness in plans and designs could be guiding and assisting in the decision making. It is not within the scope of this thesis to appreciate the magnitude of the development, and what the potential economic effect could be when considering the monetary value of what is added or regenerated in the urban fabric. However, it seems safe to suggest that in Oslo alone, where the population have grown over 25 percent in the last 20 years (Statistics Norway, 2022), would benefit from estimating the attractiveness of such a vast development, preferably before the development is executed. For the reason of building knowledge, this topic of research should also be further developed, both in regard to investigating more geographies and different markets, as well as methodological advances.

5.1 ON THEORY

The way urban economics treats location makes at least the hedonic price model lose one of its theoretical fundaments: the consumer perception of housing characteristics. Without variables that correspond to how consumers perceive the characteristics, it is questionable whether it is willingness to pay that is measured. This research suggests that at least the hedonic modelling research of the econometrics

field, is preoccupied with the advancement of the statistical approach in the models, in support to Gibbons and Overman (2012),. Furthermore, it is suggested that, based on different points of departure, hedonic price models have the goal either to predict prices or to reveal preferences. To predict prices is strictly a statistical matter, and the search for robustness and explanatory power is the goal. The other point of departure is to try to reveal preferences. To do this, more caution to what the model is using to explain the price variation is introduced, as the explanatory variables need to be related to the initial question of preferences. Therefore, if one wants to know what aspects of location people in a market prefer, the variables describing location have to correspond to the consumer preferences, or they will be a proxy for something else, and the model will not be informative regarding the actual location that is preferred. In the specification of explanatory variables that describe location, urban planning and design, as an area of expertise, can help develop spatial econometrics.

The reverse relationship is also true in that urban economics can help develop urban planning and design. It is recognised through this research that the changes in urban form that urban planning and design generates also change economic value in housing. Setting property law and local economic restrictions aside, the mere notion that the relations between spatial elements in urban planning and design have economic value in themselves opens for an advanced discussion on how to develop cities and who benefits from the increase in value. This notion gives planners an incentive to think more about urban form in the urban development, and it gives a scale on which to measure how attractive it is.

It is worth emphasising that higher prices in the scope of this research, and how hedonic price models are used, correspond to preference. However, it is more complex than that to use the results as arguments for development strategies, where affordability and equality are strong counterweights. Higher prices cannot be directly translated as good. Furthermore, it should be recognised that the willingness to pay, which is what is estimated when housing prices stand as a proxy for preferences, is not equal in the population. It stands in relation to the ability to pay, making the willingness to pay a mean for the whole market, where some are unable to pay for anything but the cheapest

housing, and some do not need to consider the price at all. Equally important to recognise is that the housing market consists of submarkets, which can be both geographically and demographically defined. Which submarket an individual belongs to can also change over time due to, for example, family constellation.

Another interpretation of this thesis is that by putting monetary value on an intangible and somewhat abstract entity, such as urban form, the quality of it is translated into a universal language among disciplines. This has the potential to 'oil' the communication between actors in urban development, where there is often a difference in standards on which to measure accomplishment. Monetary value can more easily be measured and compared with other monetary values than other types of values. For example, deciding on whether to increase pedestrian access to parks or decrease travel time for cars could benefit from translating the changes in value into monetary terms for comparison and evaluation.

5.1.1 Consumer perception

Particularly Paper III makes a strong case for the advantages of using a description of relative location when estimating the marginal willingness to pay (MWTP) for housing. This has the advantage of having at least as high a level of explanatory power as the absolute description, relates to consumer perception more accurately, and display a better model fitness. The connection to consumer perception is important if the preferences of homebuyers, instead of price prediction, are of interest. Although it is not argued that a causal relationship between the attributes of location and apartment prices are found in this research, it can be argued that the possibility of such a relationship is plausible with a relative description of location. The reason for this is that the method used, hedonic price modelling, is based on how people value a good, and to be theoretically sound should therefore specify its explanatory variables as the buyers perceive them. In part, relative location is the answer to the better fit description of location although absolute descriptions of location are considered by consumers as well.

Another part is choosing the measures that correspond to what homebuyers prefer. This is hard and is referred to as omitted variable bias in the literature. It is hard since there are no bulletproof ways of knowing whether or not vari-

ables are omitted. However, focusing more on including variables that correspond to consumers' preferences and less on how well the variables perform in the model is arguably a good step. In many previous studies on the relationship between housing prices and location, some variables, which have also been estimated as highly significant, have less relevance for planning strategies or are in the worst case being used wrongly. One example is density, more specifically population density, which is generally considered to be an important factor in sustainable urban planning (Cervero & Kockelman, 1997). It has also been estimated to correlate with housing prices in Seoul and Stockholm (Kang, 2019; Ståhle & Bernow, 2011). Density is considered good for a number of reasons to reach sustainable urban life but is problematic to include in the estimation of preferences. It can be questioned whether homebuyers consider density at all when buying a dwelling. It is perhaps more plausible that they notice the effects of density, such as more restaurants and better public transport possibilities, which is what this research has included instead of density measures.

Connected to the perception of the consumer is distance decay, which is elaborated on in Paper IV. It is important to consider how the variables behave in different intervals. This, too, corresponds to consumer perception since the premium which they pay is different at different distances from the amenity. Again, to be able to infer preferences from hedonic modelling, how consumers perceive the attributes of location has to be considered. This research shows that this is highly non-linear, which means that often it is not more preferable to be closer to a certain amenity, such as a forest. Rather, the relationship between distance and willingness to pay is highly individual for different amenities. For some amenities, the distance does not matter as long as it is within a certain distance. For others it might not be preferable to be very close but better at a distance. Potentially, there are similar relationships for other types of variables as well, such as the number of restaurants within a certain distance. It might be important for homebuyers to have at least five restaurants within walkable distance, but after that it does not matter as much. The results from Paper IV should be viewed as a proof-of concept of this line of argument.

Another important issue to bear in mind is that variables which have little variance in the sample tend to have no significant effect in the model even though they might actually be valued by the consumers. If the distribution would be different, it would show in the market. A connected issue is whether a market lacks a characteristic that would be valued otherwise. For example, a hedonic model over a city without parks would not be able to value the willingness to pay for parks even though the people might prefer having access to parks.

5.1.2 Precise measures of urban form

A key contribution of this research is the inclusion of precise measures of urban form and the emphasis on the differences in results that different approaches bring. The origin of the contemporary lack of precise measures found in Paper II is manifold, where two main sources are identified as most frequent – the imprecise specification of location and location described only in absolute terms. The former can have many roots, such as lack of fine-grained geographical data or lack of knowledge on, or interest in, how to construct measures of location that are informative to the planner, which is often the case for fields distant from urban planning and design. The second source for less precise measures of urban form, describing location as absolute, might derive from culture. In many fields, the location of the dwelling is something to control for in order to get estimations for other aspects of the dwelling. This is in principle not a problem as long as the less-than-optimal descriptions of location are not inferred to planning and design practice.

Precision in this sense is not limited to having high spatial resolution of the data but to use accurate measures aligned with research questions and methods. To specify these is a comprehensive task, and this research does not present itself as a solution to doing so. However, this research presents a framework from which the kinds of questions that need to be answered can be defined and hopefully answered – one important part being the conceptualisation of accessibility measures into the components' origins, impedance, and opportunities, which is used and discussed in Paper II.

Using accessibility measures should include thorough consideration of the specification of all three components. One example is that green spaces in urban and suburban

Oslo, which are not perceived as parks, have been estimated to have a positive impact on housing prices in the central city but negative in the suburbs (Sjaastad et al., 2008). We cannot know if this is because the green spaces are of lesser quality in the suburban areas or because the preferences differ with location, which can be broken down into its components. The difference in quality would mean that the specification of opportunity should be improved, meaning that it is not green space itself that is less preferred in the suburbs but a certain kind of greenspace that might also be less preferred in the central city. Alternatively, it might be the origins that should be specified differently, in this case differences between suburban homes and central city homes. This gives less general knowledge to planners regarding what is preferred and not and could potentially be interpreted as adding less or even removing green space in the suburbs without knowing if or what kind of green space is actually preferred.

Equally important to consider is the component of impedance in the measure, which can be specified in many ways. Paper II categorises the impedance into an unspecified metric, Euclidean, network, travel time, cost, and zone. However, the principal difference is between network and Euclidean impedance since travel time and cost are derived from either a network or Euclidean distance but with further properties added to them. The network distance can furthermore be specified to be for children, for example by taking away crossings over larger roads that are not accessible to them, or for safe streets during the dark hours, for example by taking lighting into consideration. The specification of accessibility measures is fundamental information for planning, since planners can change all three of the components in order to change the accessibility.

The results from the use of the space syntax measure integration in this research show that the precision of the measures is important. Being a centrality measure, one could test whether or not it is preferred to live in a central location, but since integration can be calculated on different radii, it is also possible to see if there is a difference in preference in different kinds of centrality. From the results of Paper III, it is suggested that it is preferable to live centrally in the city as a whole, globally well integrated, but the opposite for local integration. This suggests that living close to much is good, but not too close. If the local inte-

gration can be argued to correspond to local highstreets, the logic of this result is that people prefer to live centrally in the city as a whole, but not on a busy street exactly. Hence, the specification is important when including centrality variables in hedonic price models.

5.2 DATA AND ANALYSIS

As such, the data and analyses used are described in the introductory chapter of this thesis and in the articles. However, there are two points of discussion on data and analysis that are useful to expand here. The first is repeat-sales observations in the data, which come from dwellings that are sold more than once during the time period of the data. No measures have been taken to control for this, and although there is little reason to believe that repeat-sales have caused systematic errors in the models, this could definitely be further investigated. A possibility is that smaller apartments, which tend to sell at a higher rate, are overrepresented in the sample and therefore some estimations could get more impact. However, this reasoning depends on the hypothesis that there is a difference in willingness to pay for different apartment sizes, whereas this thesis has clearly made the distinction that free hold apartments is a single market. An adjacent question is how multiple coordinates have been treated, that is multiple sales on the same address point but not sales of the same apartments, for example three sales on different floors in a building with the same gate. These have not been considered to cause any bias in the results.

The second discussion point is the one of endogeneity in the model. Omitted variable bias have been described and discussed in the background and theory chapter and the approach to deal with it has been to base the selection of variables on previous research and urban planning and design knowledge as much as possible. This is to avoid the trap of getting blinded by model fitness or explanation rate typical in econometrics. Another issue included in endogeneity is measurement errors, which cannot be excluded but are not likely to be significant in this case. The data on sales originally comes from the Norwegian tax agency and the geographic data for the most part originates from official sources, and there is little reason to believe that they are measured incorrectly. The data that does not come from official sources have been thoroughly verified. With this said, it is not possible to completely rule out measure-

ment errors, but it is possible to argue that since the sample is large, the eventual errors will matter to a very limited degree in the results. Besides omitted variable bias and measurement errors simultaneity can occur. It occurs when an explanatory variable correlates with the error term in the regression equation. This research has been observant towards this issue by choosing explanatory variables with care. One example of simultaneity was identified in Paper I where population density was found to significantly determine the square meter-price of apartments. Since higher prices in a place logically will incentivise property owners to build more apartments on that same place – densify – the explanatory variable and the dependent variable are jointly determined to a degree.

5.3 PLANNING ATTRACTIVE CITIES

Urban development happens constantly and is predicted to continue in a rapid pace due to urbanization. It is therefore interesting to note that the knowledge of the monetary value of urban form is so limited. There has been a tendency to treat location as a composite measure, described as absolute location, for example neighbourhoods. From those descriptions, relations to attractiveness are made, for example reputation or housing prices, and the conclusions for future urban planning and design, drawn from these relations, are often based on assumptions. A neighbourhood might be attractive and have much green space, and the assumption is drawn that new development should include as much green space as possible to be attractive. This thesis argues that this line of thinking is less than optimal. Even though the approach in this research does not pose to be the optimal solution for identifying a true answer to what attractive urban form is, since it might differ from place to place, from individual to individual, and from time to time, it is a step towards an understanding of what aspects in a location that could be considered attractive. By answering this simple question of what in a location that makes it preferable, we get insights that potentially can improve our accuracy regarding attractive urban development. It should however be emphasised that the definition for attractiveness in this research, the marginal willingness to pay for free hold apartments, is not argued to be used as a direct guide for planning strategies. There are other important goals, such as social and ecological sustainability, that are

becoming even more critical to address. The results from this research could, apart from a goal on its own to aim for attractiveness, also potentially be used as a mean to reach sustainability goals. The context in which urban planning and design takes place, at least in Scandinavia, is market driven – meaning that housing, office, and industrial spaces in principle have to be sold or rented out in order to be built. This means that to realise sustainable planning and design, the result in general must be appreciated in the market. Hence, it could be argued that the more information planners have of what is sought for in the market, the greater are the possibilities to include this in the planning strategies to make the strategies reach sustainability goals. The strategies become more feasible.

The hedonic literature proposes two stages in the methodology, which was mentioned in the Background and theoretical framework. This research has developed the first stage and a natural extension would be to approach the second stage. For the second stage, data on household economy is needed and although not easily accessible, there is data on income level and other information in Norway. This could potentially be connected to home buyers to model the second stage and estimate demand for urban form in the market.

Paper III argues that relative location descriptions are important factors when people chose where to live. It is surprising that the absolute description, in this case post codes, loses so much of its explanatory power when competing with the relative description. This result emphasises that it is not primarily a neighbourhood per se that is attractive, but how it is composed in terms of urban form. This is truly important when arguing for more attractive urban design. For planning it is fundamental to understand that how neighbourhoods are designed, and not merely where they are situated, plays a major role for attractive urban development.

In Paper IV it becomes evident that access to green spaces is important. It shows not only that the size and quality of the green space matters, but also that the distance to green spaces has a non-linear relationship to housing prices. This suggest that it is not simply higher prices closer to green space. Hence, planning strategies should adapt to these patterns rather than simply assuming that more and closer is

better. The non-linear relationship differs between different sizes of green spaces, which also is an important factor for strategic urban planning. Some patterns show that the preference is stable within the first kilometre from the green space, others show that the MWTP decrease rapidly only after a very short distance. Distance decay patterns deserves to be further analysed and may provide some missing key insights to inform planning.

In this research, access to green spaces have shown to have a positive relation to housing prices, which is expected in Oslo, but including crime data could differentiate the results. This connects to an issue of missing information in the model. In the case of green spaces this research has based its categorisation on size, drawing from the work of Czembrowski & Kronenberg (2016), but adding more information could possibly give more differentiated results. For example, studies have shown that parks associated with crime have the opposite effect on housing prices (Iqbal & Ceccato, 2015; Iqbal & Wilhelmsson, 2018). Beyond green spaces, there are more information to be added to for example amenities such as bars or restaurants, where there are potentially bars that are attractive to have close and others that are not.

Better access to highways, measured as network distance to entries and exits to highways, are shown to have a negative effect on housing prices. Because proximity to highways is associated with higher levels of noise, noise was included in the model. Since the negative effect persisted, it seems like other reasons than noise are in play. A hypothesis is that highways is a very space-consuming infrastructure that pushes out other land-uses that potentially are considered more attractive. This is a topic that could be extended to more types of car-dominated infrastructure, which consumes a lot of space compared to other modes of transport and make interesting additions to the discourse of how to plan cities regarding the consequences of priorities between different modes of transport.

The integration measures from space syntax analysis used in this research shows similar patterns with regard to housing prices as previous studies. It becomes clear that living in central parts of the city, also measured as global integration, is sought for. It is also suggested by the results that in a local scale, centrality is not sought for. This could be

interpreted as if people are willing to pay for having access to much but not right by the dwelling. It seems from this study that living in central parts of the city, but one or two blocks away from the main streets, is the most preferable location. This information is vital for street layout, but also for how land use is distributed on different streets. Given that it is more attractive to live centrally in the city, but off the most central streets, the aim should be to develop an as globally well integrated street network as possible and form the streets that are less locally integrated as good residential environments.

5.4 CREATING OR EXPLOITING ON LOCATION

As much research does, this thesis has shed light on an additional problem. It has become clear that the contributions from the planning and design of cities are not handled in a way that recognises the monetary value of urban form. This in turn clarifies that there are essentially two different ways to develop a city: creating location or exploiting on location (Marcus et al., 2019). Every change in urban form will change a place's relative location and consequently its attractiveness. These changes can either strengthen the attractiveness, creating location, or use the location without contributing to the attractiveness, exploiting on location. The results from this thesis are an important step to be able to express if a development is creating or exploiting on location, but the problem is also a legal one, which is not handled here.

In a scenario where a developer is considering a new place to build housing with an attractive location, the possibilities are either to find a property with an attractive location or a property with a less attractive location and somehow try to make it better. The issue in this scenario is that the relative location is decided by the composition of urban form, and hence to a very limited degree affected by a single property, but rather its surroundings. This means that the incentive to contribute to a more attractive location is rather low, since it will not benefit the single property very much. In most cases it will instead lead to the exploitation of location by building new or more apartments but not contribute to a more attractive location. This problem becomes even more pressing when thinking of the scarcity of attractive locations. It is true that land is finite, but at least in the Norwe-

gian context, it is difficult to argue that it is scarce. However, attractive locations in Oslo, one could argue, are scarce, and if not recognised as such, the exploiting on location might make it worse. The other possibility is the creation of location, which, since the incentives for this are arguably low, will be undertaken, and financed, by the public. To sharpen the argument, to a large degree the public creates location that private property owners can reap.

This research could help incentivise the creation of location due to the estimated value of relative location that is derived from urban planning and design. It could potentially be used as a way to shed light on the economic benefits developers and property owners can glean from creation of location.

5.5 FURTHER RESEARCH

Considering the urbanization on a global scale and the development needed to accommodate it, there would be clear benefits if this research was developed further. This thesis uses Oslo as a case study and although it is reasonable to believe that the results would look similar in other Scandinavian or even many European cities, it is not generalisable for most cities globally. Hence, a natural extension of this research would be to test the approach in more contexts to get a fuller view of the monetary value of urban form.

Another natural extension of this research would be to investigate more markets in Oslo to get a better understanding of the whole housing market. The housing association segment of apartments and the single-family house market are not included in the models in this research. These should be interesting to model to determine what coincides and what differs with the free hold market. Furthermore, more geographical and demographic submarkets should be investigated to analyse the diversity of preferences within the larger market. For example, if there is a difference in preferences in suburbs compared to inner city, or between empty nesters compared to young adults.

Looking at changes in preferences in a longitudinal study would strengthen the assumption that the relationship found in this thesis between relative location and housing prices is causal. This was also expressed as an aim in Paper I. If the changes in preferences are stable over time, even only

for a subset of variables, we have even more reason to believe that the variation in price is an effect of urban form. One could also start to reason about resilience in location with respect to housing prices by looking at price changes over time and particularly around exogenous impact, such as price bubbles. Is there a certain kind of location that is resilient to macroeconomic changes?

Of course, the specification of the locational variables can be further developed. It is greatly dependent on geographical data, but developing this side of the thesis could be fruitful for new knowledge about which attributes of location are preferred. One such development would be to investigate the accessibility with other modes of transport. In this research the network distance in urban spaces accessible by foot are used, which to a degree also works as a proxy for bicycling distance and in some respects also car distance. Testing separate networks for walking, bicycling and car travel should be interesting and complementary to these results, as well as investigating the more complex case of access with public transport. Another interesting development would be to investigate other space syntax-measures, such as network betweenness, to further deepen our understanding of the monetary value of configuration of space.

There are also a number of theoretical developments that could be considered. First is the public goods theory could perhaps be connected to sustainability in the property market. Although urban form and its composition is in some aspect intangible, it could be argued to be a good which is, although implicitly, traded. Second is the connection between gentrification and the results of this research. Developing more attractive neighbourhoods will according to microeconomic theory result in higher housing prices, which would probably spur gentrification. However, the solution to gentrification could not be to build less attractive neighbourhoods.

6 Conclusions

This thesis has investigated the nature of monetary value of urban form in Oslo, Norway. It has been done through a review part and through an empirical validation part.

The review part found that a commonly used valuation method, hedonic price modelling (HPM), can function as a tool to estimate monetary value to aspects of urban form, a non-market good. However, it is also found that the theoretical basis for the method, which relies on consumer behaviour, is not considered to a satisfactory degree in the academic work on this subject but could possibly be helped by better descriptions of location included in the models. Therefore, the descriptions of urban form in this thesis have been developed to take the abovementioned theoretical foundations into consideration and relate them to urban planning and design practice. To do this it was found that measuring and describing the relative location of dwellings was a fitting approach to quantify urban form.

The relative location descriptions were measured as various accessibility variables and related to housing prices empirically. Through the empirical analysis, it was found that urban form has intrinsic monetary value and that the advanced measures of location proposed in this research outperform the more commonly used measures in terms of explanatory power. This implies that not only does the relative location description fit better in theory, but also empirically.

A second empirical analysis examined how walking network distance to amenities in the city and the house price are related. Through approaches to identify how prices change with respect to distance, it can be concluded that the relationship is highly non-linear. This means that it is not as simple as saying that it is more preferable to live closer or further away; rather the preferences change and show different patterns with type of amenity. Furthermore, by reviewing research on willingness to walk, the non-linear

relationships found in this research suggest that there are clear similarities between the willingness to pay for and the willingness to walk to various amenities. Overall, this research has brought together two fields of research and shown that they can improve one another if handled correctly. The results can offer insight into and at least the start of a method to value urban form, which could be a powerful knowledge for urban planners and designers, and decision makers. It has also opened a good number of possible new theory and method development for transdisciplinary research within urban morphology and urban economics.

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