The Impact of Urban Public Transport on Residential Transaction Prices: A Case Study of Poznań, Poland

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Abstract: This study aims to determine the magnitude and nature of the impact of public urban transport accessibility on the value of residential properties in Poznań. The study was based on 2561 residential transactions completed within the study area in 2020. The input data obtained from the Board of Geodesy and Municipal Cadastre “GEOPOZ” were analysed statistically and spatially. The main part of both the spatial and the statistical analysis was performed using the hedonic pricing method (HPM)-OLS (ordinary least squares) and WLS (weighted least squares). The use of statistical tools enabled the finding of evidence to prove that the convenient accessibility of trams is positively related to housing prices. This has also been confirmed by previous research works conducted in other parts of the world. However, the collected data did not enable the identification of statistically significant relationships between housing prices and the distance from bus stops. The study also attempts to use spatial choropleth maps to clearly illustrate the mechanisms within the local housing market.

Keywords: hedonic regression; property market; public transport; price map

1. Introduction

1.1. Urban Public Transport

Public transport systems, due to their specificity, perform a basic function that is necessary for the business, economic, and social development of large urban centres [1]. Public transport directly affects both the reduction in traffic congestion and the quality of life of local communities. It also reduces social differences resulting from mobility constraints on a part of the population. Urban public transport managers should pay particular attention to the interests of poorer people, who often have very limited mobility. An important role of urban transport should be to bridge social divides [2–4]. Factors such as mobility and the widespread accessibility of urban public transport affect numerous aspects of daily life, and social interactions contribute significantly to the inclusion of people with reduced mobility such as, i.a., the elderly [5]. Moreover, it should be noted that the development of the public transport sector leads directly to a reduction in the environmental impact of the transport sector, i.a., because almost 20% of CO$_2$ emissions comes from road traffic [6,7]. From an economic perspective, the relationship between access to public transport and the competitiveness of economic entities, regardless of the economic sector in which the company operates, is of extreme importance. Factors relating to the accessibility of work for excluded people should be taken into account in the defining of a transport policy by the competent authorities [8,9]. Finally, the accessibility of high-quality urban transport systems also affects the property market and plays a fundamental role in the process of determining the value of properties. The urban transportation infrastructure can significantly impact the attractiveness of locating properties near stations and can improve the accessibility of these locations [10–12]. Due to its significance, the attribute related to the accessibility of the transport infrastructure in terms of the property market analyses has...
been a factor gaining in importance in recent years and has become the subject of many research works [13–18].

Apart from the many aforementioned advantages, urban transport networks also have certain limitations, mainly due to the high costs related to construction, operation, and maintenance. For instance, the total cost of the 3.3 km tram line in Poznań that is currently under construction (including reconstruction of the road system) from the Wilczak terminal to the Naramowice terminal stop is estimated by local authorities at PLN 430 million. According to the 2019 Annual Report of the Municipal Transportation Company, the total costs, including, but not limited to, operating expenses or financial expenses, significantly exceed total revenue, including, but not limited to, net revenue sales. As a consequence, urban public transport generates a loss that affects the ambiguous perception of the prospects for its development, especially by local communities. Usually, public officials and planners justify the development of investments related to the transport infrastructure by the possibility of compensating for the loss incurred through increasing the value of the residential properties located in the vicinity of the investment [19–21].

The vast majority of the existing studies that are related to urban transport concern the analysis of the direct costs that play a significant role in the urban planning process. Those studies usually concern pollutant generation, noise, and road congestion [22–25]. On the other hand, the issue related to the external benefit analysis is usually not addressed in the social and economic studies concerning such types of investment. From the perspective of the problem presented, the identification of the nature and magnitude of the impact of the transport infrastructure on the value of properties is an extremely important issue. Therefore, the most important research question of the study was formulated: How does public transport affect housing prices?

1.2. Residential Housing Market

The market value of a property depends on several individual and property-specific characteristics that can generally be divided into physical and economic factors. The first group includes attributes such as the dwelling size or the topography of the plot of land, while the second group includes attributes such as the demand and supply size and the employment structure within the local property market. An attribute of particular importance for residential properties located in urban areas is the location, accompanied by its derivative—the immediate neighbourhood [26–28]. Location is usually a highly significant attribute for potential buyers, and it is usually considered in terms of the accessibility of the service infrastructure (e.g., shopping centres and cultural facilities), the social infrastructure (e.g., kindergartens and nurseries), and the transport infrastructure (e.g., bus stops and tram lines) [29]. In terms of location, the factors that determine the quality of the immediate neighbourhood are also relevant. They include, among other things, the accessibility of biologically active areas that favour recreation and enable active leisure [30,31] as well as facilitate the reduction in pollution from road transport [32–34].

The analyses conducted on the level of the property market, related both to the process of property valuation and the analysis of mechanisms within this type of market, are performed using the statistical methods applied in mathematics [35–39]. Among the tools applied, two fundamental groups of methods can be distinguished: the basic and the advanced ones. The group of advanced methods, which constitute the basis for this study, include the following techniques: Artificial Neural Networks (ANN), the Contingent Valuation Method (CVM), the Hedonic Pricing Model (HPM), and the techniques related to spatial analyses that have become increasingly important lately [40]. Two methods that are most frequently used for the identification and assessment of non-marketable goods include the Hedonic Price Method (HPM) and the Contingent Valuation Method (CVM). The main difference between those methods stems from the fact that, as part of the CVM method, the values of factors that cannot be directly valued by the market mechanism are determined based on the results of surveys that define preferences in a detailed group of respondents [41]. Given the basic aim of the study and the reference literature, it can
be assumed that the market participants’ preferences are, as a rule, directly reflected in the housing price. This assumption is justified by the fact that potential buyers prefer apartments with convenient transport accessibility, which enables them to get to other parts of the city without too much trouble. Therefore, the HPM is an appropriate and necessary analytical technique to perform the property market analysis considering the selected attributes. It should be noted that this method additionally includes one of the most important attributes of property heterogeneity, which works very well in this type of analysis, and the obtained results can be considered to reliably reflect the actual situation on the market. Moreover, this study was conducted using spatial analysis, which guarantees a higher complementarity of the results obtained.

It should be noted that the HPM is used in many other scientific fields, such as that of the social [42–44] and the natural [45,46], as well as in the analysis of other types of markets [47–50]. The use of this method to determine the effect of transport accessibility on the value of housing units is an extremely important study, although there are many examples of the application of this method in property market analyses. Due to this method, this study may be a reference for comparable analyses that determine the impact of the proximity of developed transport infrastructure on property value, especially in Poland. Given the accuracy of the HPM characteristics in the literature, the study may not be considered novel or innovative; however, it may be key in determining the external benefits of transport infrastructure investments. The method of interpreting the results used in the study, based on spatial analysis combined with statistical analysis, may constitute an innovative approach to real estate market analyses and may find wide application due to the simplicity of interpreting the results.

2. Materials and Methods

2.1. Study Site and Data

The presented study was conducted in Poznań (the capital of the Wielkopolska Voivodeship), the area of which is 262 km². Poznań has fundamental importance for the neighbouring municipalities and directly determines their economic and social development. This city is located in the western part of Poland. According to the Statistics Poland data, Poznań is inhabited by 533,830 people, of whom the majority are women—284,587, and the number of men is 249,243 (as of June 2020). People of working age constitute a decisive advantage in the demographic structure (59%); 14% of the city population are people in pre-working age (below 15 years of age); and the remaining 26% are people in post-working age.

At the end of 2017, the total length of the communication lines was 1872.70 km. The length of all the tram lines was 229.33 km, while the bus lines amounted to 1118.14 km within the city and 754.56 km within the agglomeration. The total length of the routes was 768.90 km, of which the length of the bus routes within the city was 339.11 km and 429.79 km outside the city, while the length of the tram routes was 68.85 km. As a part of the urban transport, a special role is played by the Poznań Fast Tram (PFT) which is operated by 4 daily lines running at high frequency during rush hours (every 6 min for line nos. 15 and 16 and every 10 min for line nos. 12 and 14). The PFT route is also operated by one night line, no. 201. According to the Sustainable Development Plan of Public Collective Transport for the City of Poznań for 2014–2025 (as of November 2018), the public transport organised by Poznań has 20 tram lines, 53 daily bus lines, and 21 night bus lines within the city. Moreover, 55 suburban lines are operating in the agglomeration based on inter-municipal agreements. The participants of the public urban transport run by the Public Transport Authority can use 2232 bus stops—almost half of the stops (1162) are located within the city. Tram stops play a special role; there are 239 tram stops and 52 bus/tram stops within the city (Figure 1). According to data related to city statistics, the number of Poznań Electronic Agglomeration Cards (PEKA), which is a fee carrier, amounted to 714. There were four thousand at the end of 2020. The higher number of declared users of public transport than the total number of Poznań residents may indicate the additional
high importance of this form of transport for residents of neighbouring communes and people not registered in Poznań.

The source data obtained from the Board of Geodesy and Municipal Cadastre in Poznań are the basic group of data underlying this study. These data concern market transactions of housing units that were concluded in Poznań in 2020—2561 transactions in total (Figure 2).

As part of the initial analyses, the acquired data were reviewed for their usefulness. This process involved eliminating from the database the transactions that were concluded...
under specific, special, and non-market conditions (e.g., property transactions for purposes of bailiff auction or sale in enforcement proceedings). The transaction data obtained from the Board of Geodesy and Municipal Cadastre in Poznań are reliable and credible sources of information concerning the real and current situation on the property market because they come from notarial deeds. The characteristics of this type of data make them widely applicable in a variety of property market analyses.

The basic information gathered in this database includes information for each property regarding transaction price, transaction date, and area of housing unit, along with the area of the ancillary rooms and information on which floor the housing unit is in the building. A key problem of this type of data is the lack of their complementarity compared to the detailed characteristics of the basic attributes affecting the value of the property, such as the immediate environment, the technical condition of the building, or the standard of finish of the housing unit. An attempt to identify and specify the attributes that materially affect the value of housing units based solely on information collected in this register cannot be considered a presumptively acceptable approach given the unique nature of the property, whereby value is affected by several attributes that are not defined in the register. To alleviate this problem, the source data were supplemented with additional characteristics of the analysed residential properties, such as the location details or the characteristics of the immediate neighbourhood.

2.2. Methods

The breakthrough concepts related to the process of determining the characteristics of how selected factors affect the value of the property, the foundation of which is the HPM, appeared in the early 20th century. A pioneering study based on the HPM is a documented study in which G.A. Hass formulated an agricultural land price model in 1922 [51]. In the following years, this method gained more and more importance, and as a result, it was used, among others, for defining the relationship between air pollution reduction and residential property prices [52]. The theoretical framework of this method was specified and detailed by authors such as Lancaster [53], Rosen [54], and Maclellan [55].

Within local conditions, the HPM was the basic tool for determining, e.g., the nature of the impact of selected factors that are related to noise generated by air traffic or the accessibility of urban green areas on the value of residential properties in several major Polish cities, such as Warsaw [56,57], Krakow [58,59], or Poznań [60,61]. On the other hand, in terms of advantages (transport accessibility) or disadvantages (emitted noise) resulting from the accessibility of the public transport infrastructure on the value of residential properties, the analyses were conducted mainly in the United States [62–65], the southern European countries [66,67], and Asia [68–70].

The HPM is a method that investigates the relationship between the price of a given commodity, which in this type of market is property, and its most important characteristics. Market participants make investment decisions that are typically based on detailed property characteristics and an analysis of their utility. When it comes to a housing unit, the attributes that most frequently determine its investment attractiveness include the usable floor area, the number of rooms, including the associated premises, the age, and the technical condition of the building, as well as the availability of additional amenities, such as a parking space or access to a passenger lift [40,71]. Location is also a factor of extreme importance. It is usually considered in terms of the accessibility of, among others, public utility facilities, service facilities, and recreational facilities [56,72]. Moreover, other types of environmental and social factors that are defined by location and the condition of the immediate neighbourhood affect the price that a property can fetch during a market transaction [73,74].

The most important issue when using the model that was built using the HPM is to answer the question of how the selected factors adopted into the model affect the value of the residential property. The essence of the HPM model is the assumption that the property price is explained by several defined characteristics. The model obtained as a result of the statistical analysis makes it possible to specify the values of the analysed factors that
ultimately constitute specific components of the total price. The explanatory variables are characteristics included in the analysis that describe the property, e.g., the area and the transport accessibility \([40,41,75]\). According to the above assumption, the price of a housing unit can be determined in the form of a standard regression equation.

\[
p = \beta_0 + \sum_{i=1}^{K} \beta_i X_i + u
\]

where \(p\) is the housing price, \(\beta\) is the regression coefficient, \(\beta_0\) is the regression constant, \(X\) is the property attribute, and \(u\) is the standard error.

A regression function based on the natural logarithm is most frequently used during property market analyses using the HPM. This type of solution provides a reasonable solution to the problem that is related to the inability of the selected attribute to change in value in proportion to changes in the other factors in the case of a linear model. Consequently, the linear model only enables specifying the impact of the improvement or deterioration of a specific attribute, e.g., the technical standard, for all the residential properties in the adopted dataset. Unfortunately, these models do not identify the impact of increasing or decreasing the quality of an attribute for housing units with, for example, varying locations. The very process of interpreting the regression coefficients and addressing the problem of random component variation is also an important advantage of models that are based on the logarithmic function \([57]\). Regarding the conditions presented, the present statistical analyses were performed based on a logarithmic model.

In this study, two basic variants of hedonic regression were used: OLS (ordinary least squares) and WLS (weighted least squares). In the first stage, the OLS regression was performed, under which the WLS regression was performed in the following stages: performance of an auxiliary regression in which the squares of the residuals were dependent variables, while the input independent variables plus their squares were independent variables. In the next section of this article, a series of weights was created from the values derived from the hedonic regression. Finally, the original model was estimated using the WLS method \([40]\).

2.3. Variables

The most important aspect that is related to the analysis of the property market is the selection of the appropriate characteristics that have a decisive influence on the price of the residential property. Heterogeneity is one of the fundamental characteristics of the property; it results, among other things, in the fact that factors that are relevant to one type of property may be of marginal importance in a property of another type. For housing units, the variables can be grouped into four categories of attributes that relate directly to the characteristics of a dwelling, the neighbourhood, and the environment as well as to the social, economic, and planning conditions. Given the type of housing units and local conditions, each of the defined groups includes several specific attributes (Table 1).

Given the characteristics of the source data, the literature review, and the fundamental assumption of the conducted analysis within the first group (attributes of a dwelling), the following attributes should be distinguished: floor area, floor location, presence of a basement, number of rooms, height of a building. The most important variables that were adopted for the analysis among the other groups were attributes related to the accessibility of transport, schools, and recreational areas. Ultimately, the study did not include extremely important attributes that are related to housing characteristics, such as standard of finish or type of dwelling. For an attribute that is related to the standard of finish, the available data do not provide a way to determine the status of that attribute for each property listed in the database. On the other hand, the attribute referring to the type of dwelling was omitted because a vast majority of transactions concerned housing units located in multifamily buildings, while all other housing units, e.g., in single-family buildings, were of marginal significance within the local market. All the characteristics that can influence
the price cannot be included in the model because too many variables used during the model-building process can reduce its cognitive quality. On the other hand, however, an insufficient number of attributes may lead to a failure to take into account those factors that can significantly influence the price of the residential property. Additionally, as a result of constant cooperation with real estate agencies in Poznań, we were able to select a group of features that are extremely important for the local real estate market from the features presented in Table 1. According to the presented assumptions, the hedonic function of the housing price can be represented as follows:

\[
\ln(p) = f(\text{structural features, transport accessibility, location})
\]  

(2)

Based on the defined attributes that were adopted for the model, the characteristics of the analysed residential properties were performed; this constituted the next part of the study. The process of defining the variables was performed according to the adopted criteria. The property was specified based on the information collected in the acquired GEOPOZ database and the measurement of the actual distance for specific attributes using QGIS 3.16.1 software and our own analyses.

**Table 1.** Categories of variables created based on the literature on the subject.

| Category                          | Variable                                      | Author                        |
|----------------------------------|-----------------------------------------------|-------------------------------|
| Characteristics of a dwelling    | Surface area                                  | Čeh et al. [76]               |
|                                  | Number of rooms                               | Liu et al. [77]               |
|                                  | Type of a housing unit                        | Park et al. [41]              |
|                                  | Age of a building                             | Wu et al. [78]                |
|                                  | Parking space/garage                          | Ko et al. [79]                |
|                                  | Upper-floor location                          | Szczepańska et al. [80]       |
|                                  | Type of building construction                 | Ooi et al. [81]               |
|                                  | Form of ownership                             | Marano and Tajani [82]        |
|                                  | Accessibility of basement                     | Ottensmann et al. [83]        |
|                                  | Standard of finish                            | Tomal [84]                    |
|                                  | Energy efficiency                             | Zancanella et al. [85]        |
| Characteristics of neighbourhood | Distance to the centre                        | Jasińska and Preweda [86]     |
|                                  | Distance to the primary schools and kindergartens | Sah et al. [87]               |
|                                  | Access to public transport                    | Cordera et al. [88]           |
|                                  | Distance to shops                             | Heyman et al. [89]            |
|                                  | Distance to recreational areas                | Sikorska et al. [90]          |
|                                  | Bothersome neighbourhood (airport, etc.)      | Kopsch [91]                   |
|                                  | Distance to industrial zones                  | Wittowsky et al. [92]         |
| Characteristics of Environment   | Distance to lakes                             | Yuan et al. [93]              |
|                                  | Distance to green areas, parks                | Laszkiewicz et al. [94]       |
|                                  | Distance to legally protected areas           | Pearson et al. [95]           |
|                                  | Distance to other valuable natural areas      | Xiao et al. [96]              |
|                                  | (rivers, mountains, etc.)                     | Chen et al. [97]              |
|                                  | Air pollution                                 |                               |
| Characteristics of local social, economic and planning conditions | Amount of tax | Munro and Tolley [98] |
|                                  | Demographic structure                         | Lai [99]                      |
|                                  | Employment opportunities                      | Ding et al. [100]             |
|                                  | Prospects of economic development             | Perdomo [101]                 |
|                                  | Increase in revenue generated                 | Feng [102]                    |
|                                  | Dynamic business development                  | Md and Sheikh [103]           |
|                                  | Occurrence of planning barriers               | Hussain et al. [104]          |

**Number of rooms**

This is a characteristic that should be considered during property market analyses, along with the area of the housing unit. The number of rooms determines how the premises will be developed. Too many rooms in a relatively small usable area may lead to the
unfavourable arrangement of rooms, which usually results in the worsening of the living standard of the residents. On the other hand, a small number of rooms in a residential area may lead to underutilisation of the functional capabilities of the premises. In the analysed transaction dataset, the variable has varied values ranging from 1 to 8, while the average number of rooms is equal to 2.94.

**Surface area**

The surface area has a key role to play in the price of residential properties. It is assumed, in principle, that the unit price of a housing unit (per 1 m²) with a smaller surface area should be higher in relation to a comparable housing unit but with a larger surface area. As with other characteristics, however, this variable depends to some extent on local conditions. The abovementioned principle may not be correct under certain conditions. Information concerning the surface area of the property was obtained from the database of the Board of Geodesy and Municipal Cadastre “GEOPOZ”. With regard to the actual surface area of the residential properties within the analysed set, the variable takes different values ranging from 13.70 m² to 212.00 m², while the average surface area is equal to 54.14 m².

**Floor**

The location of a housing unit on a particular floor in a building plays a key role in terms of safety and accessibility. These factors are often of key importance to buyers, meaning that the floor determines the transaction price to some extent. For buildings of a relatively low height, higher prices are achieved by housing units located on the first and middle floors. However, this is not the case in high-rise buildings with passenger lift access. In this type of building, housing units located on higher floors are definitely more valued, i.e., they have higher prices. As with the surface area, the floor was determined based on information obtained from the acquired database. In the adopted transaction dataset, one of the housing units was located on the 17th floor. On the other hand, the minimum attribute value was 1 for one of the housing units located on the floor below the ground floor. In contrast, the average value across the dataset was 2.63. With respect to the characteristics of the variable, it should be investigated together with the height of the building in which the housing unit is located.

**Number of associated premises**

The presence of associated premises, such as a basement, storage room, or garage is an attribute that, together with, i.a., the height of the building or its technical condition, belongs to the group of variables that are directly related to the characteristics of a housing unit. A balanced comparison of two comparable housing units that differ in terms of the presence of associated premises may be unjustified, which is very frequently confirmed by the price. The number of associated premises was included in the analysis due to its significant importance within the local property market. The variable for each residential property was specified based on the transaction data collected. The average value of the attribute was 0.37; the maximum value of the attribute—4 associated premises—was identified for one housing unit.

**Access to public transport**

This is the most relevant variable in terms of this study. Public transport has many benefits; however, the most important one seems to be the ability of non-motorised users to travel to any part of the city. Moreover, this type of transport guarantees low travel costs and, in the case of cities with heavy car traffic, it reduces travel time. In the analysis, access to public transport was considered in two ways. Public transport in Poznań is operated by the city’s buses and by tram network. Therefore, the distance from the housing unit to the tram stop and bus stop was measured separately in the analysis. As a result of this type of division, two variables were distinguished within this attribute. The measured value of both variables represents the actual distance that an individual has to travel to get from the housing unit to the bus or tram stop using local pedestrian routes. For the analysed
transactions, the average distance to the nearest bus stop was 210.93 m, whereas to the nearest tram stop was 690.68 m. The minimum distance per housing unit was 15.07 m and the maximum distance was 7125.34 m for tram stops and 11.93 m and 1420.35 m for bus stops, respectively.

**Distance to the Warta River**

The natural landscape defined as a public good can significantly improve the perception of a highly urbanised urban space. As a result of the dynamic development of society, people in most social groups strive to emphasise the high quality of the environment, and they are willing to bear higher costs to preserve or enhance the natural aesthetic value of the urban landscape. Urban water objects, such as rivers or lakes, provide residents with clean and humid air that is necessary, especially when it is very hot. Furthermore, these objects guarantee a landscape with a low density of buildings, which is necessary to eliminate many of the stressors that play a harmful role in modern societies. The Warta River plays a special role in the study area and its accessibility was included in the analysis. The average actual distance to the river for the analysed residential properties was 2724.32 km. The maximum distance for one of the housing units was 9330.01 km, while the minimum value was 97.98 m.

**Distance to primary schools and kindergartens**

This is a key attribute, especially for young families with children. For older students attending secondary school, the location of their housing unit near their school is not as important because they can get to school using public transport. In the case of a group of younger students, the use of public transport is quite limited, with transport for them being provided with all the necessary precautions in place. Usually, however, parents choose to transport their children on their own, which determines the location of the housing unit within a convenient distance from the school. The analysis included the accessibility of a specific group of this type of infrastructure that is defined by primary schools and kindergartens. The actual average distance to the nearest educational institution measured using geo-information tools for all housing units was 673.55 m. The minimum distance was 6.09 m, and the maximum distance was 4387.43 m.

**Distance to the centre of Poznań**

This is a variable that is a component of a broader concept (location) of which it is also a derivative. It can be assumed that residential properties that are located in the very centre of big cities reach much higher prices compared to housing units located in the peripheral parts of the cities. For a certain type of potential buyers, this principle may not necessarily be true, as a certain part of the population prefers housing units that are far from the noise of the centre of most large cities. A particularly important role for this group of market participants is played by excellent public transport that guarantees convenient access to the city centre. The variable was determined by measuring the actual distance of the housing unit from the centre of Poznań. In the analysed dataset, the average value of the measured attribute was 3699.15 m; the housing unit located farthest from the city centre was at a distance of 11,311.75 m; and for one of the housing units located in the city centre, the minimum value of the attribute was 111.70 m.

**Distance to urban green areas**

In the case of large cities with high levels of urbanisation, such areas provide a range of benefits to residents in terms of important ecosystem services such as noise reduction, improved air quality, and the mitigation of extreme temperatures. Furthermore, they serve important functions in terms of their impact on the health and well-being of the residents. An additional advantage of such areas is the possibility of physical activity and recreation in nature in a highly urbanised landscape. Urban green spaces are a common social good that is especially valued in large urban centres by most social groups, especially the elderly, children, and physically active people. The average distance to the green area for the
analysed residential properties was 536.71 m; the minimum distance was 8.47 m; and the maximum value was 5539.09 m.

**Distance to the shopping centre**

Shopping centres appeared in Poland in the late 20th century, steadily gaining in importance throughout their operation. Large sales facilities have permanently entered the landscape of Polish cities, and during the last two decades, an intensive increase in the number of such facilities could be observed. Poznań is at the forefront of Polish cities in terms of both the number of facilities and the sales space. It is worth noting that shopping centres have evolved since their beginnings and in most cases have become almost self-sufficient facilities able to meet all the needs of customers and keep them entertained for many hours. Thanks to their characteristics, they are relevant to the immediate neighbourhood and condition the economic development and thus directly impact the property market. The average real distance to the shopping centre in the analysed set of properties was 899.49 m; the maximum distance was 7468.94 m; and the minimum distance was 31.97 m.

3. Results

To accurately determine how accessibility affects the value of housing units, the analyses were conducted in two stages. First, the collected data were subjected to preliminary verification based on spatial analysis, whose basic assumption was to define spatial regularities in relation to the analysed attribute. The most significant part of the study, which complements the spatial analysis, was based on multivariate statistical analysis performed using the HPM.

3.1. Spatial Analysis

The initial analyses were performed primarily using QGIS software and MS Excel, allowing for a straightforward interpretation of the results. Due to the way the analysed attribute was described in the study, this part of the analysis was divided into two groups. The accessibility of bus stops was considered in the first stage. The transactions accepted for analysis were classified into six groups defined by the distance one has to walk from a given housing unit to a stop of a given type. Considering the structure of the bus stops in Poznań, the following classification criteria were adopted: <100 m, 100–200 m, 200–300 m, 300–400 m, 400–500 m, and >500 m (Figure 3).

![Figure 3. Classification of transactions based on the distance to bus stops.](image-url)
Basic descriptive statistics, such as mean and standard deviation, were calculated for each of the groups in question. These statistics were formulated for both the explanatory variables and the dependent variable (Table 2).

**Table 2.** Descriptive statistics of dependent and independent variables across groups (bus stop).

| Group | Mean | σ | Mean | σ | Mean | σ | Mean | σ | Mean | σ | Mean | σ |
|-------|------|---|------|---|------|---|------|---|------|---|------|---|
| Price (PLN/m²) | 7170.05 | 1654.80 | 6993.44 | 1588.99 | 7120.34 | 1748.98 | 7602.56 | 1857.10 | 7207.53 | 1991.29 | 6225.96 | 1181.38 |
| Number of rooms | 2.81 | 1.01 | 3.07 | 1.04 | 2.92 | 1.08 | 2.79 | 1.15 | 2.87 | 1.12 | 2.87 | 0.92 |
| Surface area (m²) | 51.32 | 19.96 | 53.92 | 21.37 | 54.36 | 23.86 | 54.60 | 25.94 | 59.62 | 29.81 | 60.04 | 29.48 |
| Floor | 2.87 | 3.21 | 2.70 | 2.64 | 2.69 | 2.55 | 2.39 | 1.98 | 1.74 | 1.51 | 2.30 | 1.46 |
| Associated premise | 0.33 | 0.52 | 0.42 | 0.59 | 0.37 | 0.59 | 0.36 | 0.53 | 0.43 | 0.63 | 0.20 | 0.56 |
| Distance to tram stop-m | 671.42 | 984.93 | 628.04 | 830.56 | 527.55 | 583.27 | 743.34 | 924.17 | 1038.06 | 1085.99 | 1361.02 | 700.13 |
| Distance to bus stop-m | 65.31 | 23.86 | 151.72 | 28.31 | 241.98 | 27.21 | 340.58 | 27.49 | 442.11 | 30.47 | 591.21 | 104.88 |
| Distance to Warta River-km | 2910.11 | 1603.23 | 2756.53 | 1512.43 | 2661.50 | 1505.37 | 2530.20 | 1,56.42 | 3100.32 | 1848.53 | 2085.00 | 1865.95 |
| Distance to primary school and kindergartens-m | 644.38 | 513.46 | 634.70 | 471.93 | 663.77 | 480.42 | 652.85 | 415.33 | 877.30 | 807.86 | 1030.07 | 599.86 |
| Distance to the centre of Poznań-m | 3775.99 | 1888.13 | 3704.42 | 1642.72 | 3476.51 | 1663.07 | 3395.58 | 1916.00 | 4267.22 | 2100.28 | 4750.79 | 1358.66 |
| Distance to urban green areas-m | 562.37 | 493.44 | 468.43 | 408.75 | 536.72 | 474.93 | 535.80 | 495.32 | 861.46 | 795.77 | 659.87 | 733.93 |
| Distance to shopping centre-m | 965.35 | 959.75 | 867.99 | 771.47 | 777.30 | 594.73 | 845.71 | 643.93 | 1298.85 | 843.40 | 1255.08 | 595.23 |
| Number of observations | 491 | 943 | 593 | 306 | 119 | 109 |

The median prices of the residential units in the examined groups, determined by the distance criterion, changed significantly in the evaluated transaction dataset and reached the lowest value in the last group (Figure 4).

**Figure 4.** Median prices by group (bus stop).

The second stage of this section of the study was carried out in the same way. The only difference was the method of interpreting transport accessibility, this time defined by the distance to tram stops. Due to the significantly smaller network of tram stops compared to bus stops, the assumed classification criteria were modified and formulated in the following form: <200 m, 200–400 m, 400–600 km, 600–800 m, 800–1000 m, and >1000 m (Figure 5).

Basic descriptive statistics, such as mean and standard deviation, were determined for the groups analysed. These statistics were formulated for both the explanatory variables and the dependent variable (Table 3).
The median prices of the residential units in the examined groups, determined by the distance criterion, changed significantly in the evaluated transaction dataset and reached the lowest value in the last group (Figure 4).

**Figure 4.** Median prices by group (bus stop).

The second stage of this section of the study was carried out in the same way. The only difference was the method of interpreting transport accessibility, this time defined by the distance to tram stops. Due to the significantly smaller network of tram stops compared to bus stops, the assumed classification criteria were modified and formulated in the following form: <200 m, 200–400 m, 400–600 km, 600–800 m, 800–1000 m, and >1000 m (Figure 5).

**Figure 5.** Classification of transactions based on the distance to tram stops.

**Table 3.** Descriptive statistics of dependent and independent variables across groups (tram stop).

| Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|---------|---------|---------|---------|---------|---------|
| Mean    | σ       | Mean    | σ       | Mean    | σ       | Mean    | σ       | Mean    | σ       |
| Price (PLN/m²) | 7348.85 | 1893.52 | 7228.31 | 1777.02 | 6833.13 | 1546.40 | 7068.00 | 1482.24 | 7189.75 | 1731.14 | 6826.19 | 1420.52 |
| Number of rooms | 2.83    | 1.15    | 2.84    | 1.02    | 3.20    | 1.02    | 3.02    | 0.90    | 2.78    | 0.92    | 3.04    | 1.09    |
| Surface area (m²) | 54.19   | 25.90   | 51.69   | 19.16   | 54.37   | 17.87   | 48.07   | 15.23   | 48.06   | 19.83   | 61.46   | 29.54   |
| Floor | 3.03    | 2.98    | 2.73    | 2.48    | 2.80    | 2.93    | 2.71    | 2.96    | 2.73    | 2.73    | 1.89    | 1.63    |
| Associated premise | 0.35    | 0.56    | 0.39    | 0.59    | 0.43    | 0.61    | 0.33    | 0.51    | 0.33    | 0.56    | 0.34    | 0.56    |
| Distance to tram stop-m | 129.31  | 45.91   | 288.54  | 58.36   | 483.00  | 53.74   | 707.06  | 60.08   | 881.16  | 55.08   | 2014.34 | 1140.76 |
| Distance to bus stop-m | 161.84  | 98.37   | 214.71  | 98.98   | 200.36  | 113.40  | 182.61  | 112.47  | 201.57  | 111.62  | 277.81  | 191.17  |
| Distance to Warta River-km | 2196.24 | 1245.89 | 2319.43 | 1171.62 | 2787.24 | 1271.36 | 3560.04 | 1435.54 | 3546.87 | 1674.61 | 3390.80 | 2214.14 |
| Distance to primary school and kindergartens-m | 501.39  | 365.79  | 604.90  | 416.14  | 581.01  | 383.03  | 661.81  | 403.21  | 727.11  | 341.56  | 1023.27 | 718.19  |
| Distance to the centre of Poznań-m | 2561.90 | 1393.76 | 2919.39 | 1316.67 | 3783.15 | 1223.05 | 4608.42 | 1025.09 | 4484.23 | 823.31  | 5595.28 | 1626.24 |
| Distance to urban green areas-m | 384.58  | 282.37  | 472.16  | 314.84  | 506.54  | 328.00  | 519.57  | 313.75  | 539.32  | 315.69  | 831.14  | 860.26  |
| Distance to shopping centre-m | 753.38  | 541.69  | 803.69  | 516.97  | 864.68  | 560.55  | 886.69  | 524.86  | 773.16  | 511.02  | 1272.60 | 1280.58 |
| Number of observations | 567     | 812     | 350     | 178     | 138     | 516     | 567     | 812     | 350     | 178     | 138     | 516     |

The median prices of the residential units in the examined groups, determined by the distance criterion, changed significantly in the evaluated transaction dataset and reached the highest value in the first group (Figure 6).

The spatial analysis makes it possible to observe the initial relationship between the transaction price and the accessibility of the transport infrastructure. However, based on this type of analysis, no statistically significant conclusions can be drawn regarding the impact of the availability of the transport infrastructure on housing prices as it does not consider other important characteristics that can significantly determine the price of a housing unit in the local property market.
3.2. Statistical Analysis

The characteristic attributes analysed in this study included the structural features of the housing unit (number of rooms, floor area, floor, and the accessibility of associated premises) and the attributes related to the location of the housing unit (access to schools, access to urban green areas, distance to the centre of Poznań, distance to the shopping centre, and distance to the Warta river). Regarding the research objective, the model assumed a feature related to transport accessibility defined by two variables: distance to a tram stop and distance to a bus stop. The variables adopted were selected for the model based on the data availability and the local property market characteristics. In the first stage, the assumed variables were defined to enable their use in the model (Table 4).

Table 4. Characteristics of qualitative and quantitative variables applied in the model.

| Feature                        | Symbol | Feature Description                              |
|--------------------------------|--------|-------------------------------------------------|
| Price                          | p      | Housing price (PLN/m²)                           |
| Number of rooms                |        | 3 variables are used in the model; if the housing unit has a given number of rooms, it is assigned the value of 1; otherwise, it is assigned the value of 0. |
| Surface area                   | SA     | Surface area of the housing unit-m²             |
| Floor                          |        | 3 variables are used in the model; if the housing unit can be classified under one of the aforementioned floor level classes, it is assigned the value of 1; otherwise, it is assigned the value of 0. |
| Associated premise             | BT     | 1 variable is used in the model. If the housing unit had an associated premise, it is assigned the value of 1; otherwise, it is assigned the value of 0. |
| Tram stop                      | DT     | Distance to a tram stop (km)                     |
| Bus stop                       | DB     | Distance to a bus stop (km)                      |
| Warta River                    | DW     | Distance to the river (km)                       |
| Primary school and kindergartens | DS     | Distance to primary school and kindergartens (km) |
| City centre                    | DCC    | Distance to the centre of Poznań (km)            |
| Urban green areas              | DUGA   | Distance to urban green areas (km)               |
| Shopping centre                | DSC    | Distance to the shopping centre (km)             |

At first, the variables adopted into the model were analyzed for correlations between them. The purpose of this analysis was to check for multicollinearity between the analyzed features. Although some of the coefficients reached high values, the maximum value did not exceed 70%, which may indicate a lack of multicollinearity in the adopted database (Table 5).
Table 5. Correlation between variables.

|     | R1   | R2     | R3     | SA    | F1    | F2    | F3    | BT    | DT    | DB    | DW    | DS    | DCC   | DUGA  | DSC  |
|-----|------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| R1  | 1000 |        |        |       |       |       |       |       |       |       |       |       |       |       |      |
| R2  | −0.659 * | 1000   |        |       |       |       |       |       |       |       |       |       |       |       |      |
| R3  | −0.200 * | −0.330 * | 1.000  |       |       |       |       |       |       |       |       |       |       |       |      |
| SA  | −0.456 | 0.136 * | 0.579 * | 1.000 |       |       |       |       |       |       |       |       |       |       |      |
| F1  | −0.067 * | 0.023   | 0.081 * | 0.129 * | 1.000 |       |       |       |       |       |       |       |       |       |      |
| F2  | 0.052 * | −0.016 -0.065 * | −0.093 * | −0.630 * | 1.000 |       |       |       |       |       |       |       |       |       |      |
| F3  | 0.030  | −0.012 | −0.033 | −0.068 * | −0.355 * | −0.226 * | 1.000 |       |       |       |       |       |       |       |      |
| BT  | −0.164 * | 0.152 * | 0.011  | 0.018 | 0.015 | −0.045 | 0.050 | 1.000 |       |       |       |       |       |       |      |
| DT  | −0.074 * | 0.005  | 0.127 * | 0.209 * | 0.169 * | −0.114 * | −0.104 * | 0.003 | 1.000 |       |       |       |       |       |      |
| DB  | 0.007  | −0.013 | 0.012  | 0.091 * | 0.042 | 0.009 | −0.089 * | −0.044 | 0.192 * | 1.000 |       |       |       |       |      |
| DW  | −0.091 * | 0.036  | 0.098 * | 0.145 * | 0.129 * | −0.102 * | −0.054 * | 0.080 * | 0.382 * | −0.060 * | 1.000 |       |       |       |      |
| DS  | −0.068 * | −0.015 | 0.153 * | 0.229 * | 0.078 * | −0.086 * | −0.008 | −0.095 * | 0.286 * | 0.167 * | 0.100 * | 1.000 |       |       |      |
| DCC | −0.138 * | 0.072 * | 0.117 * | 0.188 * | 0.151 * | −0.138 * | −0.033 | 0.020 | 0.695 * | 0.080 * | 0.674 * | 0.384 * | 1.000 |       |      |
| DUGA| −0.022 | −0.042 | 0.121 * | 0.217 * | 0.141 * | −0.090 * | −0.096 * | −0.029 | 0.424 * | 0.118 * | 0.402 * | 0.275 * | 0.425 * | 1.000 |      |
| DSC | −0.047 | −0.025 | 0.135 * | 0.212 * | 0.166 * | −0.129 * | −0.072 * | 0.074 * | 0.572 * | 0.086 * | 0.368 * | 0.151 * | 0.417 * | 0.338 * | 1     |

* Correlation is significant at the 0.05 level.
In the next analysis stage, evaluation of the parameters adopted for the model was performed using IBM SPSS Statistics software. The natural logarithm of housing prices was the dependent variable, while the explanatory variables were the attributes adopted for the model. The analysis was performed using two regression variants: OLS and WLS (Table 6).

Table 6. OLS and WLS estimation results.

|                      | OLS          | WLS          |
|----------------------|--------------|--------------|
|                      | Coefficient  | Standard Error | p-Value | Coefficient  | Standard Error | p-Value |
| Constant             | 9.136        | 0.019         | 0.000   | 9.143        | 0.018          | 0.000   |
| 3 to 4 rooms         | -0.220       | 0.011         | <0.001  | -0.235       | 0.01           | <0.001  |
| More than 4 rooms    | -0.165       | 0.025         | <0.001  | -0.186       | 0.024          | <0.001  |
| Surface              | -0.235       | 0.000         | <0.001  | -0.224       | 0.000          | <0.001  |
| 3rd, 4th, 5th floor  | 0.025        | 0.010         | 0.169   | 0.016        | 0.009          | 0.385   |
| From 6th floor       | 0.025        | 0.017         | 0.168   | 0.017        | 0.014          | 0.338   |
| Associated premise   | -0.049       | 0.010         | 0.007   | -0.043       | 0.009          | 0.018   |
| Tram stop            | -0.104       | 0.000         | <0.001  | -0.149       | 0.000          | <0.001  |
| Bus stop             | 0.006        | 0.000         | 0.725   | 0.007        | 0.000          | 0.718   |
| Warta river          | 0.13         | 0.000         | <0.001  | 0.128        | 0.000          | <0.001  |
| Primary schools and  | 0.023        | 0.000         | 0.249   | 0.01         | 0.000          | 0.592   |
| kindergartens        |              |               |         |              |               |         |
| Town centre          | -0.246       | 0.000         | <0.001  | -0.234       | 0.000          | <0.001  |
| Parks                | -0.043       | 0.000         | 0.039   | -0.011       | 0.000          | 0.622   |
| Shopping centre      | -0.066       | 0.000         | 0.003   | -0.125       | 0.000          | <0.001  |
| R²                   | 0.521        |               | 0.701   |              |               |         |
| N                    | 2561         |               | 2561    |              |               |         |

Both in OLS and WLS, most variables used in the model were statistically significant. The difference between the two models occurred only in the case of the variable related to the distance of the property from urban green areas, which turned out to be statistically insignificant in the OLS model at probability values of \( p \) less than 0.05. F1 and R1 variables were excluded from both models due to the lack of variation in the variability in the analysed database. The vast majority of parameters had the expected signs of the coefficients (except for the attribute related to the associated premises) and the predicted order of magnitude. The model estimated by WLS demonstrated higher accuracy, explained 70% of the variability, and was therefore used to evaluate particular parameters and prepare cartograms related to these characteristics: the parameters of the accessibility of tram stops and average prices.

The structural parameters of the housing unit, which from the statistical point of view had a significant influence on the value of the property, are R2, R3, and area. It is worth paying attention to the last parameter. The analysis confirmed a relationship observed during the literature review that the larger the usable floor area of a given housing unit, the lower the unit price is likely to be during a market transaction.

The attributes directly related to the location of the housing unit have a significant impact on its value. Among the attributes belonging to this group of variables are DW, DCC, and DSC. Negative signs next to the DCC and DSC variables inform about the positive influence of this factor on value. In contrast, positive signs next to the DW variable inform about the negative impact of this feature. The greater the distance to the centre of Poznań and the shopping centre, the lower was the transaction price. The results confirm the average preferences of market participants in the case of larger cities, related to everyday life in the heart of the city in a place with convenient access to highly developed service infrastructure.

Turning to the most significant characteristic related to the purpose of this study, the variable related to the accessibility of the bus stop was found to be statistically insignificant \( (p\text{-value} = 0.718) \). Bus stops have a fairly even spatial distribution within Poznań, which can result in them not playing such an essential role in the investment decisions of market...
participants. In the case of the attribute related to accessibility, the variable related to the distance from a tram stop proved crucial in terms of market mechanisms. Based on the coefficient for this attribute, we may conclude that of the two comparable housing units, a significantly higher unit price (about 15% per 1 km) is achieved by a housing unit located at a shorter distance from a tram stop. The results obtained from the model partially confirm the conclusions of the preliminary spatial analysis, according to which the units belonging to Group 1 (less than 200 m to a tram stop) had the highest average unit transaction price. In the last stage of the analyses, the housing units were grouped based on the value of a parameter (distance to a stop (m) x value of the coefficient from the WLS model) against the background of the distribution of tramlines (Figure 7).

![Figure 7. Classification of housing units based on a parameter that is a component of the model.](image)

The housing units located in close proximity to tramlines had a lower value of the parameter, which directly affects their higher value. The model allowed the calculation of the average estimated values in particular districts of Poznań and, consequently, showing the distribution of average prices in a synthetic way for the entire city area (Figure 8).
4. Discussion

The property market shows several specific features, one of the most important of which is the imperfection, resulting in the market’s low efficiency and lack of transparency. As a result of this phenomenon, the average market participants have extremely limited access to information on current market trends. On the one hand, these limitations relate to the transaction prices themselves, which are usually recorded in closed databases, and, on the other hand, to the factors which significantly determine the price. The presentation of market analyses in the form of simple thematic cartograms, presenting the analysed issue in spatial terms, may provide market participants with a lot of reliable and necessary information helpful in making investment decisions. This information can be helpful not only to buyers and sellers but also to specialised professional groups operating in the property market, i.e., property valuers, agents, and property managers. Consequently, integrating simple mathematical operations and GIS tools can yield many tangible benefits.
Our study is one of the first to analyse the impact of public transport on the value of residential property in Poland. The choice of appropriate factors for analysis is often determined by local conditions and adequate knowledge of the local market. The analyses defined the impact of the accessibility of urban public transport on the value of housing units. The use of hedonic models (OLS and WLS) further determined the influence of the structural and other types of location characteristics. The map of average prices predicted based on the WLS model synthetically aggregates the nature of the impact of location and the spatial and environmental factors on the value. However, direct comparison of the results with the existing studies may be difficult due to the local character of the property market and the difference in research scale.

The results of our analyses made it possible to select statistically significant attributes, and a great advantage of this study is its reliability because the analyses concerned data coming directly from the market. This type of analysis may have much wider applications than studies based on data from the rental market [56]. However, despite the presented advantages of our analysis, the proposed solution is not entirely without some limitations, which occur firstly in connection with the availability of data reliably and accurately describing the given housing unit. In the context of the physical characteristics of the housing units, features such as the functionality and the standard of the finish play a decisive role. Typically, however, these variables cannot be included in this type of analysis due to the lack of real opportunities to record this information, even with specialised reports. Including all relevant attributes would certainly increase the accuracy of the constructed model to a significant degree. The limitations of the presented method may be related to the nature of the property market showing substantial local variations. Therefore, the results obtained in a given area may not apply to other research subjects. It is also worth noting that the size of a given market can often determine this method. In the absence of a sufficiently large number of transactions, difficulties may arise in estimating a model that reliably describes market mechanisms.

Regarding the limitations presented, analogous studies should be conducted and gradually updated in cities or larger regions of the country. The use of comparable methods and techniques simultaneously applied in several studies would provide an opportunity to compare results and draw more meaningful conclusions. In the case of transport accessibility, enrichment of the research methodology, i.e., including factors not accepted in our study in the analysis of additional aspects, such as, among others, the Transit Opportunity Index [105,106], could significantly increase the quality of the results.

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