# Evaluating and Analysing the Convenience of Property Location Based on 15-minute City Paradigm
# *a Case Study of London*

**Xianlai Yin**

August 2023

**Module**: Urban Spatial Science Dissertation

**Module Code**: CASA0010

**Student ID**: 22073407

**Supervisor**: Prof. Andrew Hudson-Smith

**Word Count**:10557

**GitHub Repository**: https://github.com/XianlaiYin/Convenience-of-Property-Location

*This dissertation is submitted in part requirement for the MSc in the Centre for Advanced Spatial Analysis, Bartlett Faculty of the Build Environment, UCL.*

# Abstract

As modern cities evolve and residents become more concerned with the quality of life that their neighbourhoods provide when making property decisions, the evaluation of location convenience needs to evolve with the times. The 15-minute city paradigm provides a framework for ideal urban living, ensuring that residents can walk to all daily-life amenities within 15 minutes, it is consistent with the pursuit of high quality of life in neighbourhoods when making property decisions.

Based on 15-minute city paradigm and property value perspective, this study establishes a replicable property location convenience evaluation system that considers regional differences, and develops a standardised evaluation tool that is adaptable to different cities. Taking Greater London as a case study, the convenience of various amenities is evaluated from perspectives of residents' demand and amenities supply, and by comparing the performance of OLS and MGWR regressions without zoning and spatial autocorrelation analysis, it is judged that residents' preferences for amenities are not consistent across different areas. Therefore, based on residents' characteristics using Spatially Constrained Multivariate Clustering to divide London into 20 regions, and using the feature importance obtained from Forest-based Regression to judge the weights of amenities preferences of residents in different areas, the model performance finds that amenities convenience explains 35%-40% of the property values variation. The results show that spatial distribution of convenience shows a monocentric, multi-node pattern, with areas of high convenience located mainly within Inner London, the monocentric area overlapping with CAZ, and the multi-node area being similar to the distribution of Metropolitan level town centres. The Bivariate analysis reveals a large difference in housing prices between east and west sides of the core zone at the same level of convenience.

This study enriches a new perspective for property location decision-making and provides valuable methodology and data support for future research.

# Acknowledgements

Firstly, I would like to express my sincerest gratitude to my supervisor, Prof. Andrew Hudson-Smith, whose excellent guidance and extensive knowledge are the basis for the successful completion of this dissertation.

Meanwhile, I would like to thank all the teachers and staff at CASA, from whom the knowledge I have learnt is the cornerstone of constructing this dissertation, and who have provided me with a new way of thinking as well as forward-looking knowledge of spatial analyses.

Afterwards, I would like to thank my girlfriend, Guanqi Liu, whose unwavering support and unconditional care, accompanied me through the road of writing the dissertation and sustained me every midnight to keep going.

In addition, I would like to thank my family and friends, who have been a solid foundation for me in completing the dissertation and have inspired me endlessly, both from academic and life perspectives.

Finally, I wish to thank the researchers and contributors behind the open data, whose efforts have constructed a wide range of high-quality data that underpin this dissertation and countless studies.

# Declaration

I hereby declare that this dissertation is all my own original work and that all sources have been acknowledged. It is 10557 words in length.

Signature: 尹光来

Date: 24 August 2023

# Contents

## List of Tables



## List of Figures



## List of Acronyms and Abbreviations

| | |
|---|---|
| **LSOA** | Lower Layer Super Output Area |
| **OLS** | Ordinary Least Square |
| **MGWR** | Multiscale Geographically Weighted Regression |
| **UK** | United Kingdom |
| **LR** | HM Land Registry |
| **POI** | Point of Interest |
| **CAZ** | Central Activities Zone |
| **IDW** | Inverse Distance Weighted |

# 1 Introduction

## 1.1 Background

With the transformation of modern society, technological, economic and cultural changes have had a profound impact on the values, lifestyles and daily demands of urban residents. These changes have permeated people's daily lives, reshaping their expectations about quality of life and living environments. The selection of where to live has become the critical key to carrying these expectations in urban life. As a result, when considering property decisions, urban residents are increasingly concerned not only with the physical characteristics and macro-location of the property, but also with their ability to achieve a higher quality of life in their neighbourhoods (Leyden, Goldberg and Michelbach, 2011) and higher sustainability (Dempsey et al., 2011). This implies that the locational value of a property is increasingly concerned with the quality of life that its environment and the community can offer its residents, and that the convenience of property location is being given a deeper meaning.

In this context, the traditional criteria for evaluating the convenience of a property's location are gradually becoming not comprehensive enough, and it is necessary to establish indicators that are more reflective of the comprehensive amenities that a property's surrounding community could offer to evaluate the quality of life that the location could provide. At the same time, the 15-minute city paradigm presents an ideal framework for urban living, the core idea of which is to optimise the urban configuration and improve the infrastructure so that the residents can achieve the basic demands of their daily lives within a 15-minute walk (Pozoukidou and Chatziyiannaki, 2021). This paradigm not only addresses the problems of traffic congestion and environmental pollution in modern cities, but is also highly compatible with modern city residents' desires for quality of life, community belonging and sustainability (Khavarian-Garmsir, Sharifi and Sadeghi, 2023). Combining the 15-minute city paradigm with property location value evaluation, evaluating the convenience of various categories of amenities available to residents within a 15-minute walking radius, and evaluating resident preferences based on feedback from local residents on the property value of different categories of conveniences, in order to construct a comprehensive evaluation index of the convenience of a community-based property location that takes into account regional differences, and provide a more comprehensive and in-depth reference perspective for property decision-making.

### 1.2 Hypothesis and Research Questions

The core hypothesis of this dissertation is:

***Is it possible to develop a replicable system for evaluating the convenience of property location that takes regional differences into account, based on 15-minute city paradigm and property value perspectives?***

Meanwhile, this study uses Greater London as a case study to carry out the evaluation, which leads to the following 3 questions and aims to address them through the research findings:

- Based on the 15-minute city paradigm, how convenient are the various categories of amenities within Greater London?
- Do residents across Greater London have consistent preferences for different categories of amenities? If not, how can Greater London be divided into regions based on resident characteristics, and what are the preference weights for amenities for residents in each region?
- What is the spatial distribution of the convenience of property locations within Greater London? What are the similarities and differences with the distribution of property values?

### 1.3 Research Area: Greater London

Greater London, located in the South East of England, is the administrative and economic centre of the United Kingdom and has a rich historical and cultural background. Greater London consists of the 'City of London' in the centre of the city and its 32 surrounding boroughs, and according to 2021 data, the area of Greater London is approximately 1,572 square kilometres (Office for National Statistics, 2023), with a population of approximately 8.8 million people (London Datastore, 2023). London is known for its multiculturalism, attracting immigrants and tourists from all over the world, creating a metropolitan area with a mix of languages, religions, and cultural traditions (Eade, 2000). This dissertation will study Greater London at the LSOA level.

# 2 Literature Review

## 2.1 Property Location Convenience and Property Value

Location theory has conventionally been regarded as an important element of property value research, and research in this area is constantly developing and refining. On the one hand, scholars want to measure and analyse more precisely; on the other hand, with the speedy changes in modern society and economy, the content of evaluating the convenience of a property's location is also transforming.

In the mid-20th century, the German economic geographer Alonso suggested that the distribution of urban land values is determined by the efficiency of land use and distance from the city centre (Alonso, 2013). Later, the Hedonic Pricing Model provided a useful tool for analysing how the various attributes of a house could be converted into its total value (Rosen, 1974), including the location of the property, as Geoghegan, Wainger and Bockstael (1997) and Des Rosiers et al. (1996) have applied this model to explore how various types of location accessibility affect property values.

As urban development and the needs of residents change, aspects such as the quality of community life (Leyden, Goldberg and Michelbach, 2011) and sustainability (Dempsey et al., 2011) are beginning to be taken into account in location evaluations, and residents' values for property are becoming more associated with the quality of their daily existence ( Kuminoff, Smith and Timmins, 2013). In addition, differences in preferences for location convenience have been observed for areas with different residential characteristics (Brueckner, Thisse and Zenou, 1999), and based on the Multiscale Geographically Weighted Regression (MGWR) to study the impact of amenity convenience on house prices at the spatial scales, provides insights into the spatial heterogeneity of convenience (Liu et al., 2022).

## 2.2 15-minute City Paradigm and Convenience Evaluation

The 15-minute city paradigm, an urban planning concept that focuses on promoting accessibility and livability, advocates that residents should be able to access the services they need in their daily lives within a 15-minute walking or cycling distance (Moreno et al., 2021). This concept has a significant effect on improving the urban ecological environment, enhancing the quality of life of urban residents, strengthening community cohesiveness, and promoting economic progress (Pozoukidou and Chatziyiannaki, 2021). The paradigm has gradually gained attention in recent years in cities around the world. Portland, United States of America has been promoting 20-minute neighbourhoods since 2012 and plans to make it easier for 90% of the population to walk or bike to fulfill all basic, daily, non-work needs (Wiewel and Kafoury, 2012). Shanghai, China launched the Planning Guidance of 15-Minute Community-Life Circle in 2016 to guide the promotion of the central urban area to achieve full coverage of basic security-type services within a 15-minute walking distance, creating a basic unit of community life (Shanghai Urban Planning and Land Resources Administration Bureau, 2016). Melbourne, Australia, proposed in 2017 to become a 20-minute neighbourhood, allowing people to meet most of their daily needs within a 20-minute walk from their homes, creating healthier and more liveable communities (Planning Implementation, Department of Transport and Planning, 2023). Barcelona's Superblock, which improves the availability and quality of public space for leisure and community activities, as well as for pedestrians and cyclists, by revamping the city's street network (Ayuntamiento de Barcelona, no date). Paris Mayor Anne Hidalgo's plan to implement the 15-minute city paradigm during her 2020 re-election campaign (Willsher, 2020) attracted widespread public attention and popularised the concept worldwide.

However, there are some concerns and opposition to the 15-minute city, with Edward (2021) arguing that cities will be fragmented into 15-minute segments, that urban mobility would be reduced, and that the gap in wealth between neighbourhoods would lead to further social inequality. Tim and Julia (2021) argue that the accompanying gentrification would disrupt neighbourhoods through price rises and inequality. In London, UK, the Royal Town Planning Institute (no date) argues that the 15-minute city paradigm is likely to challenge the existing paradigm of agglomeration planning, which is capable of increasing productivity, and that a unilateral overemphasis on localism may limit the diversity and variety of opportunities in cities (Monika and Shivani, 2020).

Evaluations targeting the 15-minute city have also been carried out extensively around the world. In Liverpool, UK, Calafiore et al. (2022) developed a methodology to identify the location of potential 20-minute neighbourhoods within urban areas and to evaluate how their presence relates to socio-spatial inequalities. In Ferrara and Bologna, Italy, Olivari et al. (2023) and others have built a set of NExt proXimity Index (NEXI) based on open data to measure proximity to local services by walking, based on the principle of 15-minute cities. In Barcelona, Spain, Vich, Gómez-Varo and Marquet (2023) developed an evaluation of the 15-minute city paradigm through three approaches: grid-based, building-based, and mobility-based, respectively. In Shanghai, China, Weng et al. (2019) established a more precise method for evaluating the accessibility of 15-minute walkable community amenities considering different walking groups, amenity attributes, and real transportation conditions, and introduced attenuation curves to judge the travelling intentions of different groups of people. In Utrecht, the Netherlands, Knap et al. (2023) developed a metric (CSx), based on the analysis of travel data from the Netherlands Mobility Panel, to determine the accessibility of community amenities using a Standardised gravity-based 2-step floating catchment area (2SFCA) to weight and aggregate accessibility scores into a composite metric.

Apart from widely used accessibility analyses, ways of designing and evaluating 15-minute city are also being explored. Lima, Brown and Duarte (2022) developed an approach called 15-minute Neighbourhood Configuration by exploiting the potential of coupling shape grammars and computational optimization to find 15-minute neighbourhood configurations that minimize infrastructure costs and maximize pedestrian accessibility to urban services. Chen and Crooks (2021) developed an agent-based model called "D-FMCities" to simulate the bottom-up development of diverse communities. bottom-up development of diverse communities and estimates the size of such local communities to depict the scale of a 15-minute city. Zhang et al. (2023) propose a network-based framework based on mobile phone signalling data and point of interest data to evaluate the 15-minute city by taking into account the mobility patterns of people. Barbieri et al. (2023) investigated the structure of 15-minute cities by measuring service distances on a spatial map based on graph theory.

### 2.3 London's vision and Convenience Evaluation based on the 15-minute City Paradigm

London, as one of the world's important cities, its mayor proposed to regard the 15-minute community as part of London's recovery (Sadiq and Caroline, 2020), and solicit opinions from residents to the mission "Thriving, inclusive and resilient high streets and town centres in every London borough with culture, diverse retail and jobs within walking distance of all Londoners." (Talk London, 2020).

However, despite a diverse public service system and advanced infrastructure, a number of surveys and evaluations based on the 15-minute city paradigm have shown that London residents are dissatisfied with the accessibility of their current amenities in comparison to other European cities, with the average length of time it takes to satisfy the 15-minute city paradigm in London being 23.5 minutes, and nearly half of Canadians complaining that amenities are spread too far (Malcolm, 2020). Bartzokas-Tsiompras and Bakogiannis (2023) constructed a comparable 15-minute Walking City (15-MWC) index evaluating the walking performance of 121 European metropolitan areas and seven amenity types, and found London to be one of the worst performing cities.

Whilst London's property market and property location has been a popular urban research topic, the significant impact of location accessibility on property values has also been confirmed (Chiaradia et al., 2013). Law (2017) carried out a study in London through the analytical methods of Network Science and Spatial Syntax, and found that region has a significant impact on property values and suggests that analysis results are better using Street- based Local Areas than using Region-based Local Area, which also suggests that property value analysis in London tends to be a more localised evaluation and that an evaluation based on the 15-minute city paradigm would provide a more precise indicator of the convenience of a property's location.

### 2.4 Summary

Generally speaking, scholars have carried out extensive research on the convenience of property location and the 15-minute city paradigm, but with the development and changes of the times, there are gaps that still need to be filled. On the one hand, although existing evaluations of property location convenience have developed in a more refined and life-oriented direction, and have also taken into account the influence of spatial heterogeneity, few scholars have linked them to the 15-minute city paradigm, which can adequately represent the quality of local life. On the other hand, most evaluations based on the 15-minute city paradigm are limited to evaluating the model itself, but the benefits of the 15-minute city paradigm are very extensive, including economic, environmental, health, social, etc. (Tim and Julia, 2021), and it is evident that the organisational patterns and weighting preferences of the evaluation should be varied for different purposes. However, the question of "what effects should be evaluated based on the 15-minute city paradigm" seems to have received little consideration.

Meanwhile, there is a wide range of evaluation methods currently proposed by scholars for both property location accessibility and the 15-minute city paradigm. However, few scholars have constructed a replicable evaluation tool that could be widely used, and most evaluations are limited to the region. There are also very few evaluations of London as a globally prominent city, mostly from a macro perspective, but not in a refined way. In addition, as a human-centred concept, previous evaluations have mostly focused on the distribution and coverage of amenities, and less on the needs of residents. While the ability and willingness to access amenities on a walking basis varies among residents (Town and Country Planning Association, 2023), the characteristics of the population in different areas can also cause a wide range of needs.

Therefore, this study combines the evaluation of property location convenience with the evaluation of the 15-minute city paradigm. Taking property location convenience as the purpose of evaluation, using property value as a mapping of residents' recognition of property location convenience, establishing an evaluation system based on the 15-minute city paradigm that takes into account both the residents' demand and amenities supply, and at the same time developing a standardised evaluation tool that can be used in different cities, the study takes London as a case study to carry out a fine-grained evaluation and analyse the property location convenience evaluation's spatial distribution characteristics of property location convenience evaluation.

# 3 Methodology

There are two core elements in evaluating the convenience of a property location. On the one hand, it is necessary to evaluate the convenience of various types of amenities around the property under a uniform scale, and on the other hand, it is necessary to understand the preference of local residents for the convenience of different amenities when considering the property location, and then combine the two and assign the weight of the preference to the convenience of various types of amenities, to quantify the comprehensive degree of convenience of the location of the property. Therefore, this evaluation will start from these two directions, firstly, from the perspectives of residents' demand and amenities supply, the convenience of each category of amenity will be quantified by Closest Facility Analysis and Service Area Analysis respectively; Afterwards, the analysis area is divided into several clustered areas with the similar residents' characteristics through Spatially Constrained Multivariate Clustering, and through Random Forest Regression to understand the degree of influence of different amenities on the property value in each area, and then to determine the preference of the residents in the area for various categories of amenities, and finally to get the comprehensive property location convenience. During the research process, a standardised property location convenience evaluation tool based on Arcpy was developed for use in the UK or even worldwide, to help researchers with a similar orientation to quickly carry out their research, and to replicate the analysis across different cities in the future to compare and contrast the differences between cities or regions. The tool is open source on my GitHub (Yin, 2023).

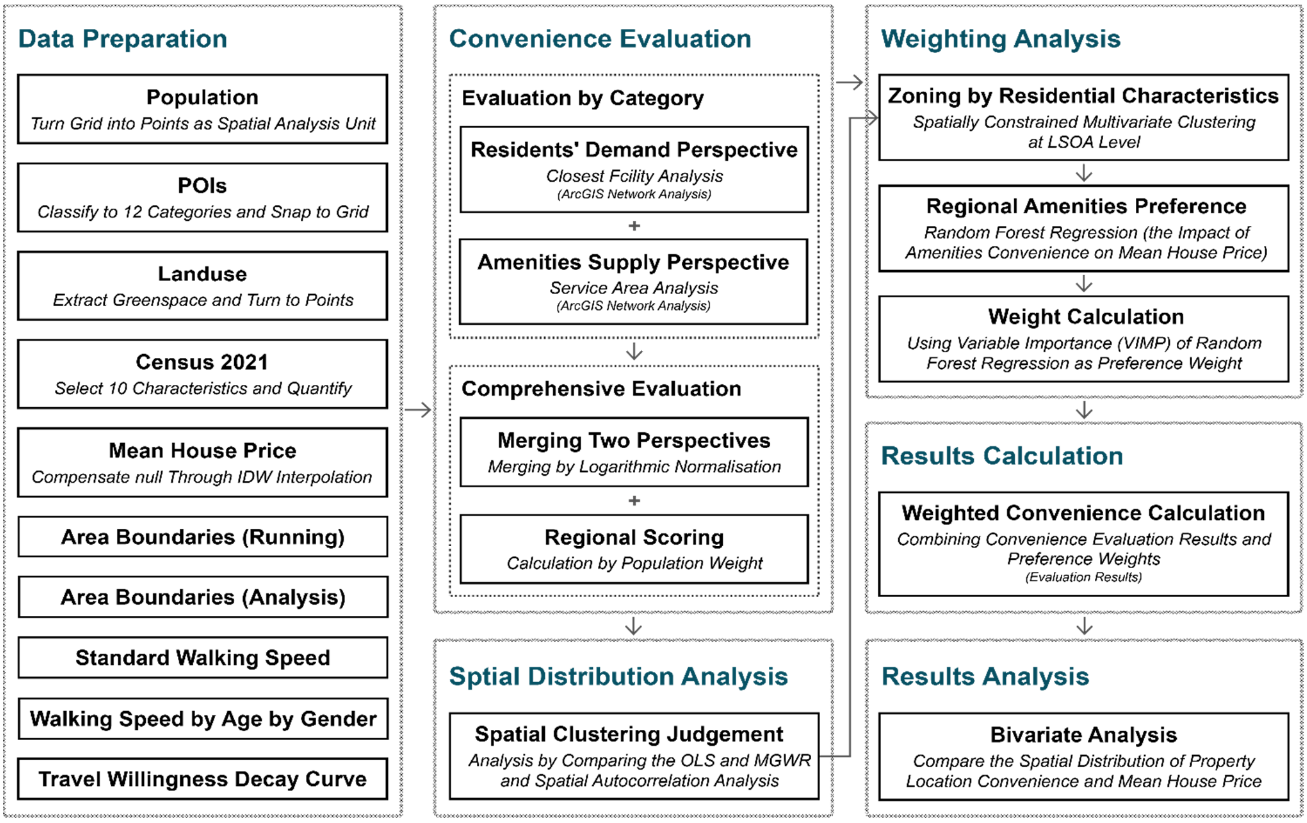


***Figure 1**. Evaluation System Workflow Diagram*

### 3.1 Data Preparation

Data need to be acquired and pre-processed before the evaluation can be carried out. The data used in this study are all publicly available, with low research ethical risk and reproducibility worldwide. The boundary data and socio-economic data are only usable within the UK and landuse data is only available in parts of Europe, but it is not difficult to find alternative data in other countries. In addition, population size data may have spatial resolution that is not available at the case level in some countries, and resampling or finding alternative data sources could be considered. The following is an example of Greater London to present the data and to illustrate the preparations for analysing it.

***Table 1***. *Data Source Information*

| DATA | DATA SOURCES |
|---|---|
| ***Population Data*** | The Spatial Distribution of Population in 2020 with Country Total Adjusted to Match the Corresponding UNPD Estimate, United Kingdom (Bondarenko et al., 2020) |
| ***POI Data*** | OpenStreetMap data - Greater London (Geofabrik GmbH and OpenStreetMap, 2023) |
| ***Landuse Data*** | Urban Atlas 2018 (Copernicus Land Monitoring Service, 2021) |
| ***Area Boundaries (Running)*** | Wards (May 2023) Boundaries UK BFE (Office for National Statistics, 2023) |
| ***Area Boundaries (Analysis)*** | Lower Layer Super Output Areas (2021) Boundaries EW BFE (Office for National Statistics, 2023) |
| ***Census 2021*** | Census 2021 data (Office for National Statistics, 2023) |
| ***Mean House Price*** | House price statistics for small areas QMI (Office for National Statistics, 2023) |
| ***Standard Walking Speed*** | The Planning for Walking Toolkit (Transport for London, 2023) |
| ***Walking Speed by Age by Gender*** | Normal walking speed: a descriptive meta-analysis (Bohannon and Williams Andrews, 2011) |
| ***Travel Willingness Decay Curve*** | Walking Distance by Trip Purpose and Population Subgroups (Yang and Diez-Roux, 2012) |

#### *3.1.1 Population: Spatial Analysis Unit*

The spatial resolution of this data is 3 arc (approximately 100m at the equator), where each raster value represents the number of population residing in this raster range (approximately 100m*100m), and the original data is estimated based on the Census data by mapping through methods such as Random Forest, and based on United Nations population estimates to adjust and match the population size of the whole country (Stevens et al., 2015; Nieves et al., 2020). Therefore, this data might have some bias, but it does not affect our relatively more macroscopic study. In the analysis, rasters were converted to points representing the location of the area and used as spatial units of analysis, with each spatial unit of analysis (point) referring to a resident within the corresponding range.

#### *3.1.2 POIs Data: Amenities*

This data consists of various categories of amenities point data, classified into 12 categories based on the 15-minute city paradigm by the classification experience of relevant studies (Calafiore et al., 2022; Olivari et al., 2023) and Geofabrik's OpenStreetMap classification guide (Frederik, 2022), while discarding some of the amenities that do not fall within the requirements of the 15-minute city paradigm. As the 15-minute city paradigm focuses more on whether a certain category of function can be accessed, and to simplify the amount of calculation, POIs will be automatically captured to the nearest spatial analysis unit during the analysis and calculation, and only one point of the same category of amenity will be retained in the same analysis unit, representing that the category of service can be provided in that spatial analysis unit.

***Table 2**. Classification of Amenities by Category*

| SERVICE | INCLUSION AMENITIES |
|---|---|
| ***Health*** | pharmacy, hospital, clinic, doctors, dentist, nursing_home |
| ***Leisure*** | theatre, nightclub, cinema, attraction, museum, art, zoo, theme_park, arts_centre |
| ***Parks*** | park, playground, dog_park |
| ***Sports*** | sports_centre, pitch, swimming_pool, tennis_court, golf_course, stadium, ice_rink |
| ***Catering*** | restaurant, fast_food, cafe, pub, bar, food_court, biergarten, bakery |
| ***Shopping*** | clothes, florist, chemist, bookshop, butcher, shoe_shop, beverages, optician, jeweller, gift_shop, sports_shop, stationery, outdoor_shop, mobile_phone_shop, toy_shop, newsagent, greengrocer, beauty_shop, video_shop, bicycle_shop, doityourself, furniture_shop, computer_shop, garden_centre, hairdresser, laundry |
| ***Supermarket*** | supermarket, kiosk, mall, department_store, general, convenience, market_place, vending_machine |
| ***Financial*** | bank, atm |
| ***Education*** | school, kindergarten, |
| ***Worship*** | place_of_worship |
| ***Transportation*** | railway_halt, railway_station, tram_stop, bus_station, bus_stop, taxi_rank |
| ***Facilities*** | police, fire_station, post_office, library, community_centre |

### *3.1.3 Landuse Data: Greenspace*

Extraction of green space-related data from landuse data (Green urban areas, Forests, Herbaceous vegetation associations, etc.) points are generated by lines at 200-metre intervals according to the edges of the elements and added to the parks category of the POI data to make up for the shortcomings of the original POI data, which represented vast green spaces with a single point, and to improve the accuracy of the analysis in this category.

### *3.1.4 Area Boundaries (Running): Tool Running Unit*

This data is used to divide the analysis area as the running unit of the evaluation tool. Due to the maximum number of points for single processing of the network analysis tool in ArcGIS Pro (ArcGIS Pro 3.0, 2023), and taking into account the operational efficiency, the running unit is set to be borough, i.e., all spatial analysis units within a borough are calculated at a time, and the final results are obtained by combining the results of all the running units at the end. In addition, as the area of a borough varies greatly, for borough data that are too large (greater than 50 square kilometres), The evaluation tool will automatically split it into several units by ward according to the upper limit of a single processing of the network analysis.

The borough-based Tool Running Unit is too large an area to support the subsequent need for accurate spatial clustering and result analysis, so LSOA will be used as the Result Analysis Unit to improve accuracy. Since the evaluation results are output in the spatial analysis unit (points), the Result Analysis Unit extracts the evaluation results within the range and weights them by the population of the point to produce the evaluation data for that Result Analysis Unit, so the difference between the Tool Running Unit and the Result Analysis Unit does not lead to any conflict.

### *3.1.6 Census 2021: Resident Characteristics*

Based on the clustering effect and neighbourhood effect, people tend to live in similar areas by connecting and interacting with those who are similar to them (McPherson, Smith-Lovin and Cook, 2001), and the characteristics of the neighbourhood also affect the characteristics of the local population (Durlauf, 2004), so residents in different areas tend to present different characteristics and have different preferences for amenities in different areas. Therefore, to divide different areas in the analysis area to understand more precisely the preference of local residents for various amenities, this study is based on the 15-minute city paradigm and LSOA-level Census data, from ten dimensions highly related to amenity demand Resident characteristics are quantified and linked to outcome analysis units for spatial clustering.

***Table 3***. *Data Sources and Calculation for Residential Characteristics (Office for National Statistics, 2023)*

| DIMENSION | CALCULATION | DATA SOURCE |
|---|---|---|
| ***Age*** | Average age | England and Wales Census 2021 - RM200: Sex by single year of age |
| ***Household*** | Average household size | England and Wales Census 2021 - TS017: Household size |
| ***Housing*** | Average number of rooms | England and Wales Census 2021 - TS051: Number of rooms |
| ***Commuting*** | Average working distance | England and Wales Census 2021 - TS058: Distance travelled to work |
| ***Ethnicity*** | Shannon Diversity in Ethnicity | England and Wales Census 2021 - TS021: Ethnic Group |
| ***Economics*** | Proportion of working population | England and Wales Census 2021 - TS066: Economic activity status |
| ***Internationalisation*** | Proportion of non-UK births | England and Wales Census 2021 - TS004: Country of birth |
| ***Religion*** | Proportion of people with faith | England and Wales Census 2021 - TS030: Religion |
| ***Mobility*** | Proportion of population with less than 5 years of residence | England and Wales Census 2021 - TS016: Length of residence |
| ***Transportation*** | Proportion of households with car | England and Wales Census 2021 - TS045: Car or Van Availability |

### *3.1.7 Mean House Price*

This data is based on the statistics of HM Land Registry (LR) transaction and price data, and since this indicator only counts LSOAs with more than five transactions per quarter (Office for National Statistics, 2019), there are some areas with missing data. As a result, this study calculates the average of the last two years (eight quarters) of the original data and performs IDW spatial interpolation to obtain the raster data of average housing prices, counts the mean values of the corresponding rasters in the areas where vacant LSOAs are used, and also identifies the average price of the property in each spatial analysis unit location by collecting samples to the point.

### *3.1.8 Walking Speed by Age by Gender*

Based on walking speeds derived from relevant studies (Bohannon and Williams Andrews, 2011), walking distances within 15 minutes were calculated for different age and gender groups to accurately analyse the extent of access to services and amenities based on the 15-minute city paradigm at different walking capacities. However, due to limitations in computing capabilities (Estimated evaluation of Greater London will require 2023 standard configuration computers running uninterrupted for more than a month), only the standard walking speed (120 cm/second) provided in The Planning for Walking Toolkit (Transport for London, 2023) was used in the case study to avoid massive calculations. However, the analysis methodology of using different walking speeds weighted by different population sizes is well established and the functionality of traversing different walking speeds has been reserved in the Standardised Evaluation Toolkit, although it is currently set to not run, it is expected that this functionality will be reinstated in the future after optimisation of computation times.

***Table 4**. Walking Speed by Age by Gender (Bohannon and Williams Andrews, 2011)*

| STRATA GENDER (AGE IN YEARS) | GAIT SPEED (CM/SECOND) | AVERAGE DISTANCE IN 15 MINS (KM) |
|---|---|---|
| ***Men (20 to 29)*** | 135.8 (127.0 to 144.7) | 1.222 |
| ***Men (30 to 39)*** | 143.3 (131.6 to 155.0) | 1.29 |
| ***Men (40 to 49)*** | 143.4 (135.3 to 151.4) | 1.291 |
| ***Men (50 to 59)*** | 143.3 (137.9 to 148.8) | 1.29 |
| ***Men (60 to 69)*** | 133.9 (126.6 to 141.2) | 1.205 |
| ***Men (70 to 79)*** | 126.2 (121.0 to 132.2) | 1.136 |
| ***Men (80 to 99)*** | 96.8 (83.4 to 110.1) | 0.871 |
| ***Women (20 to 29)*** | 134. 1 (123.9 to 144.3) | 1.207 |
| ***Women (30 to 39)*** | 133.7 (119.3 to 148.2) | 1.203 |
| ***Women (40 to 49)*** | 139.0 (133.9 to 141.1) | 1.251 |
| ***Women (50 to 59)*** | 131.3 (122.2 to 140.5) | 1.182 |
| ***Women (60 to 69)*** | 124.1 (118.3 to 130.0) | 1.117 |
| ***Women (70 to 79)*** | 113.2 (107.2 to 119.2) | 1.019 |
| ***Women (80 to 99)*** | 94.3 (85.2 to 103.4) | 0.849 |

### *3.1.9 Willingness-to-Travel Decay Curve Based on Walking Time*

As the willingness to travel decreases with the increase in walking time, it is not possible to consider all the amenities that can be accessed within 15 minutes to get the service as equally useful. According to the relevant research, the longer the travelling time people walk to the less likely, the probability distribution of travelling time is a negative exponential function (Yang and Diez-Roux, 2012), so the distance decay function derived from the regression of the study is cited, and the travelling probability of the time spent when arriving at the amenity is regarded as the travelling willingness of residents to go to the amenity as basic scoring criteria for convenience, and its formula is as follows:

$$P(t) = e^{-0.073t} \tag{1}$$

In Eq. (1): $P(t)$ is the probability of travelling on foot when time is equal to the value of $t$, $t$ is the time spent walking, and the value of -0.073 is derived using a non-linear ordinary least squares regression model ($R^2$ =0.99).

### 3.2 Evaluation of Convenience for Each Category of Amenity

To objectively evaluate the level of convenience of a location, it is necessary to evaluate it through different dimensions under a uniform scale. Based on the requirements of the 15-minute city paradigm, residents can access most of the amenities needed for daily life on foot within a relatively short period of 15 minutes (Pozoukidou and Chatziyiannaki, 2021). Based on this vision, this study divides the amenities needed for daily life into 12 categories and analyses the extent to which various types of amenities are satisfied within 15 minutes of walking distance of a location from the perspective of residents' demand and from the perspective of amenity supply, respectively, which can be regarded as the various types of convenience degrees of the location.

#### *3.2.1 Convenience Calculations from the Perspective of Residents' Demands*

Using Closest Facility Analysis in the Network Analyst toolset of ArcGIS (ArcGIS Pro 3.0, 2023), the travelling distance and travelling time between each spatial analysis unit and the nearest amenity can be solved in a real geographic location through a real road network. In this study, the time taken to reach the nearest amenity point is calculated based on the standard walking speed, and the willingness to travel when arriving at the point is calculated according to the willingness to travel decay curve as the ease of reaching the amenity. At the same time, the truncation time was set to 15 minutes, and if the amenity could not be accessed within 15 minutes, the rating of the category was automatically set directly to 0. The following is the methodology for quantifying the convenience of individual amenities from the residents' demand perspective for a single spatial unit of analysis:

$$C_{demand,i} = \begin{cases} e^{-0.073t_i} & \text{if } \mathrm{t_i} \leq 15 \\ 0 & \text{if } \mathrm{t_i} \geq 15 \end{cases} \tag{2}$$

In Eq. (2): $C_{demand,i}$ is the convenience of travelling to the $i$ type of amenity for this spatial analysis unit, and $t_i$ is the time taken to reach the nearest $i$ type of amenity.

The walking speeds of people of different ages and genders have significant variations (Bohannon and Williams Andrews, 2011), so the areas they can visit within a 15-minute walk have significant variations, and the amenities they can access can also vary. At the same time, the gender and age distribution of the population in different areas are also distinctively different (Office for National Statistics, 2023), so theoretically, this study needs to calculate the amenities for people of different ages and genders at each node based on the walking speed of age and gender. Based on the regional demographics, the proportion of different genders and ages in the region was used as weights to calculate the average convenience of each spatial analysis unit. Unfortunately, for the reasons described in the previous section, however, there is no computational capacity to conduct that analysis at this time. The analysis methodology has been clarified, nevertheless, and it is hoped that a more refined analysis can be carried out in future studies. The following is the methodology for quantifying the population-weighted convenience of a single amenity from the resident demand perspective for a single spatial unit of analysis:

$$C_{demand,i,avg} = \frac{\sum_{a,s} w_{a,s} C_{demand,i,a,s}}{\sum_{a,s} w_{a,s}} \tag{3}$$

In Eq. (3): $C_{demand,i,avg}$ represents the average convenience of $i$ type of amenities based on different walking speeds of people of different ages and genders from the residents' demand perspective, $w_{a,s}$ represents the proportion of population of age $a$ and sex $s$ in the region, and the other meanings are the same as in Eq. (2).

### *3.2.2 Convenience Calculations from the Perspective of Amenities Supply*

Using Service Area Analysis in the Network Analyst toolset of ArcGIS (ArcGIS Pro 3.0, 2023), it is possible to solve for the coverage of services that each amenity can provide at different travelling times in a real geographic location with a real road network. In this study, based on the standard walking speed, the minute-level walking coverage of each amenity within 15 minutes is calculated, and based on the travel decay curve, each minute-level isochronous circle is assigned a value, which is used as the intensity of the service that a single amenity can provide in different areas, while the range exceeding 15 minutes is regarded as not having the service capability, and the service area is not generated. As each spatial analysis unit can often be covered by more than one amenity of the same type within 15 minutes, and multiple amenities increase convenience by increasing the variety of choices available to residents and complementing each other. Therefore, the service intensity values of similar amenities can be superimposed in the same spatial analysis unit to obtain the sum of the service intensities of the spatial analysis unit that can be accessed by all the amenities of that type. The following is the methodology for quantifying the convenience of a single amenity from the amenity supply perspective for a single spatial unit of analysis:

$$C_{supply,i} = \sum_{n=1}^{N_i} e^{-0.073 t_{i,n}} \tag{4}$$

In Eq. (4): $C_{supply,i}$ denotes the sum of the service intensity of this spatial analysis unit from all $i$-type amenities, $N_i$ denotes the number of $i$-type amenities that can cover the current spatial analysis unit, and $t_{i,n}$ denotes the time from the $n$th $i$-type amenity to the current spatial analysis unit.

Since the gain of amenity overlay is continuously decreasing and there is no longer any significant gain after reaching a certain level (Kung and Liao, 2018), it is necessary to quantify the boundary where there is no longer any significant gain. After calculating the service intensity of all categories, the outliers of all evaluated values are calculated through the Z-score method, and the triple standard deviation is used as the basis for judging the outliers, and higher than the triple standard deviation is regarded as having saturated the supply of the service of that type of amenity, so the evaluated values higher than the threshold are changed to the value of the triple standard deviation, to facilitate the subsequent normalisation within a reasonable range. The formula is as follows:

$$C'_{supply,i} = \begin{cases} 3\sigma + \mu & \text{if } C_{supply,i} \geq 3\sigma + \mu \\ C_{supply,i} & \text{otherwise} \end{cases} \tag{5}$$

In Eq. (5): $C'_{supply,i}$ represents the revised evaluation value of $i$ amenity supply perspective, $C_{supply}$ represents the original supply perspective evaluation value of $i$ amenity, $\mu$ represents the mean of all evaluation values (including all types of amenities) from the perspective of supply, and σ represents the standard deviation of all evaluation values (including all types of amenities) from the perspective of supply.

### *3.2.3 Comprehensive Convenience Evaluation*

Once the demand and supply perspectives have been evaluated, they need to be aggregated into one evaluation indicator. Not only is it necessary to ensure that the two perspectives are reasonably combined, but it is also necessary to ensure that there is a uniform scale between the different categories, so that the indicators in the different categories can be integrated and compared. Although both categories are derived from a uniform scoring system (travelling intention decay curves), the resident demand perspective only calculates the score for the nearest amenity, which represents the ease of access to the nearest amenity for the spatial unit of analysis. The amenity supply perspective calculates the sum of the ratings of all accessible amenities and represents the total amount of corresponding services available to the spatial unit of analysis.

Therefore, the evaluation value from the perspective of demand has been limited to the interval from 0 to 1 based on the travel willingness curve, but the evaluation value from the perspective of supply is much larger than the interval from 0 to 1, and normalization is required to synthesize the two indicators. Due to the ever-decreasing superposition gain of amenities, a nonlinear transformation of logarithmic normalization is used for the evaluation value of the supply perspective. After that, the two dimensions are the same, and the final result can be obtained by averaging the evaluation values of the two perspectives, which comprehensively represents the convenience degree of the nearest certain type of amenity that the spatial analysis unit can access, and the total amount of such amenity that can be obtained in the area, as the comprehensive convenience degree of this type of amenity. The formula is as follows:

$$C_i = \frac{log_{1+3\sigma+\mu}\left(1 + C'_{supply,i}\right) + C_{demand,i}}{2} \tag{6}$$

In Eq. (6): $C_i$ represents the combined convenience of $i$ types of amenities, $3\sigma + \mu$ represents the triple standard deviation of all evaluated values of the supply perspective described earlier, and the base and truth of the logarithm are +1 to ensure that the regression result of the logarithmic function is in the interval from 0 to 1. The other values have the same meanings as those described earlier.

At the same time, in order to more accurately reflect the needs of regional residents, it is also necessary to weight the results of the spatial analysis units in combination with the number of populations to obtain a more accurate convenience at the regional level. The calculation at the regional level is performed at the LSOA level, covering all spatial analysis units within each LSOA, with the formula:

$$C_{i,area_k} = \frac{\sum_{j=1}^{u}\left(C_{i,point_j} \times Population_j\right)}{\sum_{j=1}^{u} Population_j} \tag{7}$$

In Eq. (7), $C_{i,area_k}$ represents the $i$ class of amenity convenience of Lower Layer Super Output Area $k$, $C_{i,point_j}$ represents the $j$ spatial analysis unit of the $k$ area, $Population_j$ represents the population of the $j$ spatial analysis unit, $u$ represents the number of all spatial analysis units in the $k$ region.

### 3.3 Weighting Analysis and Calculation of Convenience Based on Regional Differences

In the case of this study, London is a city with a rich history and culture, gathering different people from all over the world, so the various areas of London show significant differences, and residents also have corresponding characteristics (Davidson and Wyly, 2012). Therefore, residents in different areas have different preferences for various amenities, and their perceptions of property value will also differ (Kang et al., 2023), based on which the comprehensive evaluation of the property location convenience is more accurate and meaningful. Therefore, this study divides the study area into different regions based on demographic characteristics, analyses the influence of various categories of amenities on the value of the property in each region, and then uses this as the weight to aggregate the evaluation indicators of each category to obtain the final convenience score of the property location.

#### *3.3.1 Zoning Based on Differences in Demographic Characteristics*

According to the description of the data preparation phase, in order to accurately measure the characteristics of the residents of each area and their needs for various amenities, this study refers to the categorisation methodology of other studies (Kienast-von Einem, Panter and Reid, 2023), selected ten dimensions from the Census 2021 data to describe London's diverse group of residents, which reflect the daily habits of different residents from various perspectives, and in turn, to determine their needs for different services and amenities.

- Age: The average age can reflect the age distribution of an area, and residents of different ages will have different needs for health, leisure and culture.
- Household: Average household size can reflect the type of household and affects the demand for housing, shopping and educational amenities.

- Housing: The average number of rooms can reflect the type and quality of housing in the local area and a sidebar to the income level of the area.
- Commuting: Average working distances can reflect the extent to which residents rely on transportation and public amenities, while those with short working distances are likely to rely more on local services and amenities.
- Ethnicity: Measuring ethnic diversity through the Shannon Diversity Index for Race gives an idea of how culturally integrated an area is, which has implications for the demand for food, cultural and religious amenities.
- Economics: The proportion of working people reflects the economic vitality of an area, with a high proportion meaning more occupational demand and business activity.
- Internationalisation: The proportion of the population that is not British born is a reflection of how cosmopolitan an area is, and people in highly cosmopolitan areas have more diverse needs for all types of services and amenities.
- Religion: The proportion of the population with religious affiliation can influence the demand for religious amenities and related services.
- Mobility: The proportion of people who have lived in the area for less than five years reflects the mobility of an area's population, with highly mobile residents likely to have a higher reliance on amenities such as shopping and transportation, and less need for relatively local amenities.
- Transportation: The proportion of households owning a car influences residents' reliance on private and public transportation and is a proxy for regional income levels.

Ten dimensions of LSOA-level resident features are placed for clustering through Spatially Constrained Multivariate Clustering. The advantage of this clustering method is that it not only analyses multidimensional multivariate datasets, but also incorporates spatial constraints in the formation of clusters to ensure that the results are geographically adjacent and continuous, preventing the generation of a large number of mutually dispersed clusters with no practical significance (ArcGIS Pro 3.0, 2023). As a result, London is divided into several contiguous regional clusters with different characteristics by this method.

### *3.3.2 Random Forest Regression Based on Regional Amenities Preference Analysis*

After dividing the region, it is necessary to understand the preference of the residents in the region for different types of amenities and how this quantification of such preference plays a role in the value judgement of residents for properties. To this end, this study uses the Forest-based Regression tool, which is based on the Random Forest algorithm, to regress and analyse the impact of the convenience level of each type of amenity on the average price of houses in different regions. Random forest algorithms use randomly selected training samples and feature subsets to construct multiple decision trees and integrate their results, which can estimate the feature importance while improving the accuracy and robustness of predictions (Ishwaran and Lu, 2019). Therefore, based on this, we can understand the feature importance of the convenience of different amenities to the change in the average price of houses, analyse the preference of residents in each region for various amenities based on the judgement of the value of the property, and use the ratio of the importance of a single characteristic to the importance of the total characteristic as the weight of the overall evaluation of the evaluated value of each type of amenity integrated in each district, which is calculated by the formula:

$$W_{i,area_k} = \frac{R_{i,area_k}}{\sum_{i=1}^{m} R_{i,area_k}} \tag{8}$$

In Eq. (8), $W_{i,area_k}$ represents the weight of $i$ category of amenities in $k$ area, $R_{i,area_k}$ represents the feature importance of $i$ category of amenities obtained from the Random Forest algorithm in $k$ area, and $m$ represents the category number of amenities.

### *3.3.3 Property Location Convenience Comprehensive Calculation*

The final weighted score for each outcome analysis unit is calculated integrally based on the previously described scoring and weighting methods, using the formula:

$$C_{area_k} = \frac{\sum_{i=1}^{m} \left( C_{i,area_k} \times W_{i,area_k} \right)}{\sum_{i=1}^{m} W_{i,area_k}} \tag{9}$$

In Eq. (9), $C_{area_k}$ represents the property location convenience level of the resultant analysed unit $k$, and $C_{i,area_k}$ represents the convenience score of the $k$ unit for $i$ type of amenities, and the other meanings are the same as in Eq. (8).

# 4 Results: Case Study in London

## 4.1 Results of Convenience Evaluation of Each Category of Amenity


***Figure 2****. Evaluation Maps for Each Category of Amenities*

The results of the 12 individual convenience evaluations obtained show that the vast majority of amenities tend to be concentrated in the CAZ area, but there are differences in the way different categories of amenities are distributed and where they are concentrated. Health, Catering, Shopping, Supermarket, and Transportation, as relatively basic categories, are widely distributed within Greater London and are therefore widely distributed, so although accessibility is highest in the centre of the city, it remains high in other areas. Amenities such as Sports, Facilities, and Worship, on the other hand, as more widely served and relatively less frequently used amenities, have a relatively lower overall level of coverage and convenience, but are located throughout Greater London. In addition, Leisure amenities are only distributed with high intensity in the central city and very little in Outer London, and the Parks category has a high level of convenience across the whole area, and is only lower in some certain zones (e.g. airports, industrial areas).

### 4.2 Correlation Analysis Results Between Various Amenities and Average House Price

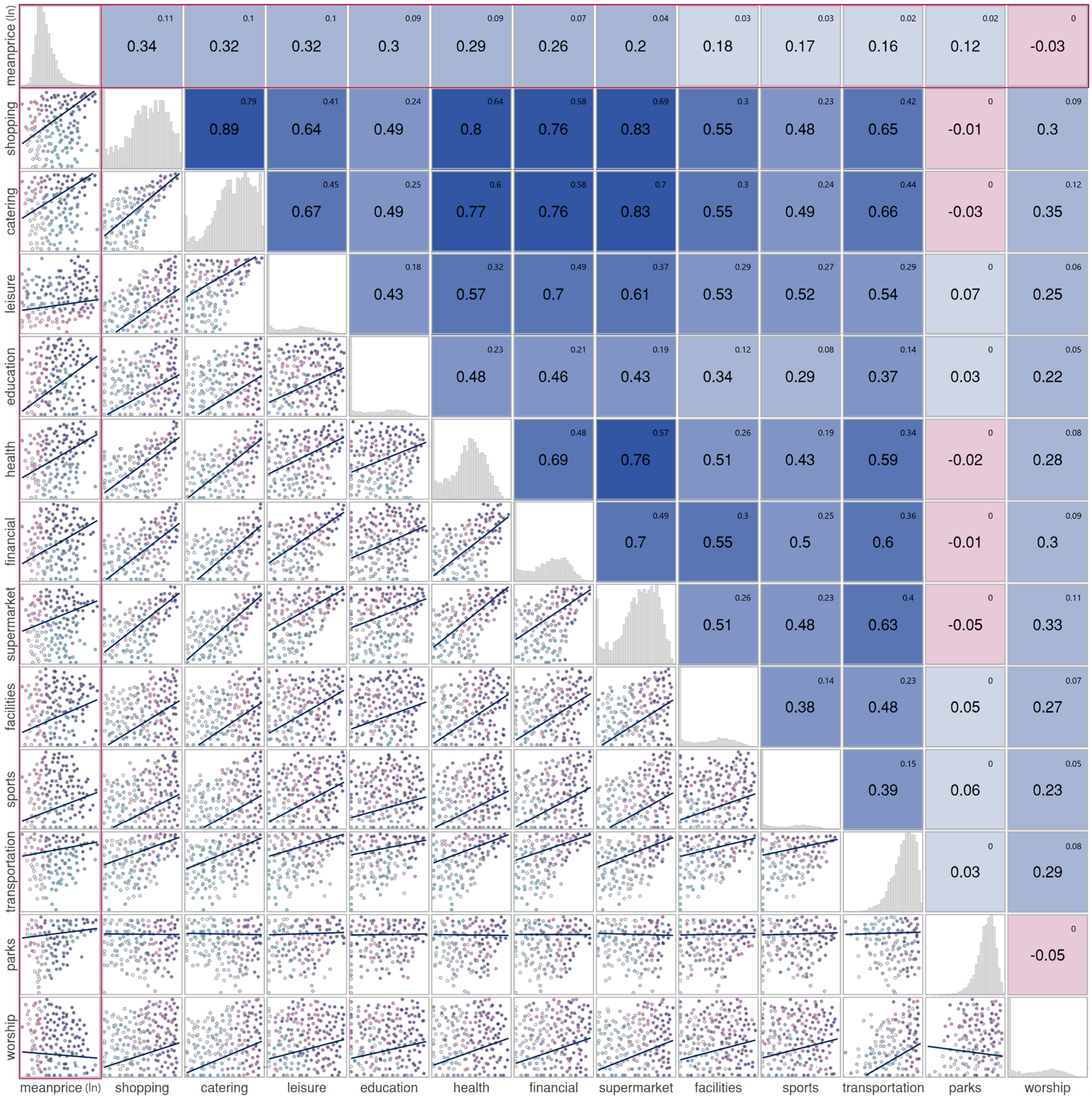


***Figure 3***. *Correlation Analysis of Various Convenience of Amenities on Property Mean Price*

The correlation analysis reveals that the relationship between all categories of amenities and the average price of houses is positive for all categories except the Worship category, which can indicate that the various types of services and amenities have a positive correlation with the average price of property, and in the subsequent weighting analysis it can be judged that these categories of amenities have positive weights. However, contrary to intuition and experience, there is a negative correlation between the Worship category of amenities and the average price of housing. However, their Pearson's correlation coefficient is only -0.03 and $R^2$ is 0. The negative linear correlation between the two at the global level is very weak. Therefore, this study still adopts the widely accepted view from other studies (Carroll, Clauretie and Jensen, 1996; Brandt, Maennig and Richter, 2014) and the popular perception that the convenience of Worship category amenities has a positive impact on the average price of houses, and regards the weak negative correlation derived from the correlation as an error caused by not considering spatial differences, and still considers the weight of Worship as a positive value.

Meanwhile, lower $R^2$ of all categories indicates on the one hand that the degree of explanation of the impact of amenities of various types of amenities on property value is not high without considering spatial differences, and on the other hand, it suggests that there are many other factors besides amenities that can affect property value. Since the purpose of this study is to evaluate the convenience of amenities and not to predict property values, in other words, this study mainly considers the difference in importance between different types of amenities based on the property value perspective. Therefore, other factors that can affect property values are not considered here, but rather the analysis focuses on the impact of spatial differences.

***Table 5**. Analysing the Performance of OLS and MGWR Regressions Without Zoning*

| OLS | | | | MGWR | |
|---|---|---|---|---|---|
| ***Statistic*** | ***OLS Result*** | ***Statistic*** | ***OLS Result*** | ***Statistic*** | ***MGWR Result*** |
| Number of Observations | 4992 | Akaike's Information Criterion (AICc) | 143555.1 | AICc | 8257.873 |
| Multiple R-Squared | 0.179087 | Adjusted R-Squared | 0.177108 | Adjusted R-Squared | 0.756 |
| Joint F-Statistic | 90.51634 | Prob(>F), (12,4979) degrees of freedom | 0.000000* | R-Squared | 0.7979 |
| Joint Wald Statistic | 487.215615 | Prob(>chi-squared), (12) degrees of freedom | 0.000000* | Sigma-Squared | 0.244 |
| Koenker (BP) Statistic | 178.958735 | Prob(>chi-squared), (12) degrees of freedom | 0.000000* | Sigma-Squared MLE | 0.2021 |
| Jarque-Bera Statistic | 519717.4477 | Prob(>chi-squared), (2) degrees of freedom | 0.000000* | Effective Degrees of Freedom | 4135 |

Through the spatial clustering analysis of the standardised residuals of the Ordinary Least Squares (OLS) results, the result of Moran's I is 0.534963, which has an obvious tendency to cluster. z-score is 64.630646, which is greater than 99% of the possibility of clustering. This can indicate that the impact of each type of amenity on the change of property value in different regions is vastly different, which can lead to obvious bias in the prediction of property value in specific regions under the uniform regression coefficients. In addition, by comparing the results of the OLS and Multiscale Geographically Weighted Regression (MGWR), it is found that the MGWR, which considers spatial differences, has a much higher explanatory degree ($R^2$: 0.7979>0.1791) and performance (AICc: 8258<143555) than the OLS model. This suggests that the impact of amenities on property values varies significantly across different regions, and that it is necessary to divide London into multiple regions based on the characteristics of the residents, to determine the extent to which the convenience of each type of amenity affects the change in property values, and thus to evaluate the preferences of the residents of different regions for different types of amenities.

### 4.3 Weighting Results of Convenience Based on Regional Differences

#### *4.3.1 Zoning Results Based on Differences in Demographic Characteristics*

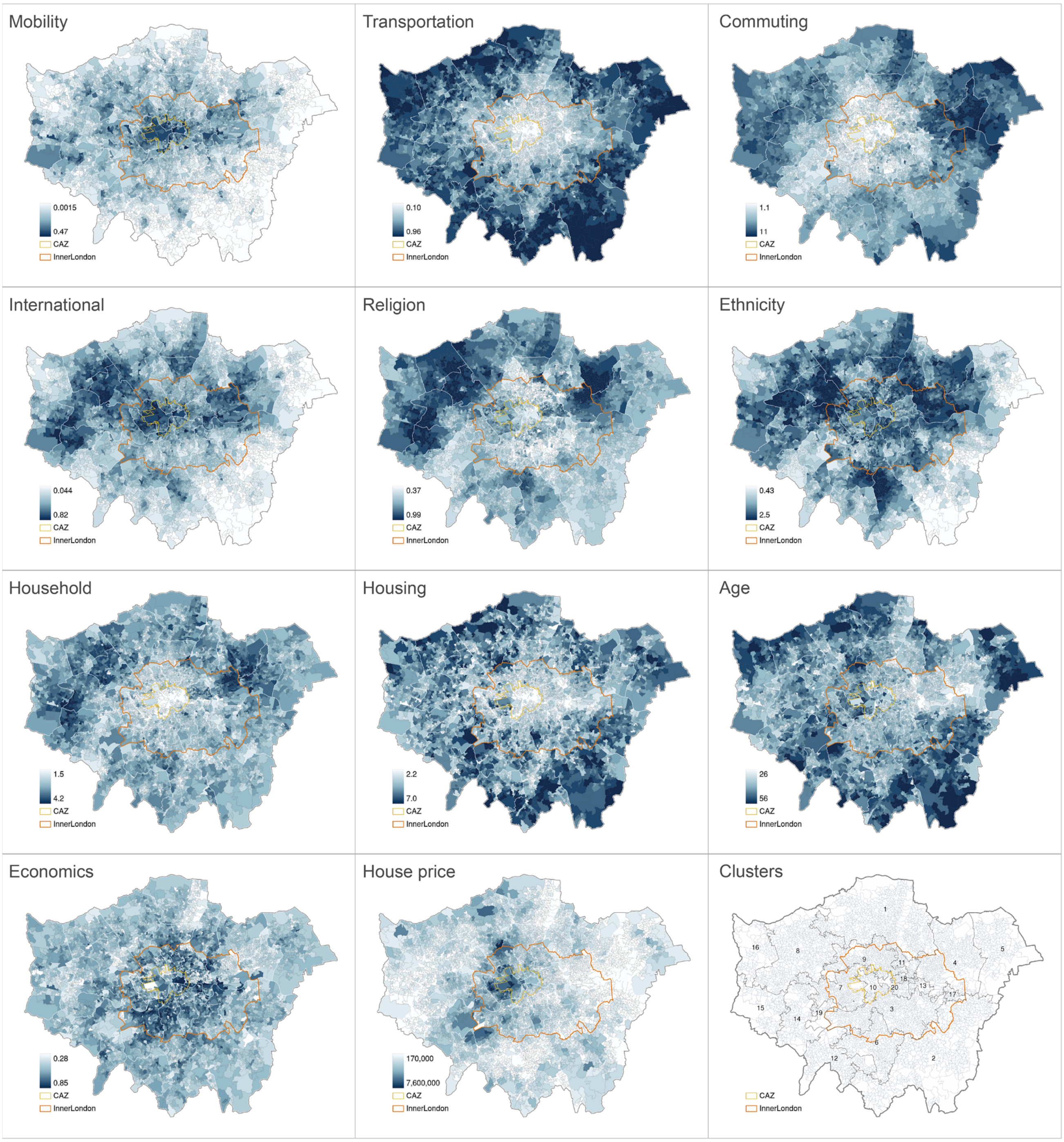


***Figure 4,5,6.*** *Maps of Residential Characteristics, Map of Mean House Prices, Map of Clusters*

Calculating the Census data to obtain ten categories of resident characteristics reveals that each category has a spatial distribution. High values for population mobility and the proportion of people who own a job are concentrated in the central area; high values for the proportion of people who own a car, commuting distance, household size and average age are higher the further away from the centre of the city; it is worth noting that ethnic diversity, proportion of faiths owned, and cosmopolitanism have similar distributional characteristics, with high values clustered in the north-west and north-east of Greater London, but lower values for proportion of people who own a faith in the central area. While the other two have higher values further towards the centre. Average house prices are clustered with high values to the west of the central city. This information provides a depiction of the differences in the characteristics of residents in the London area.

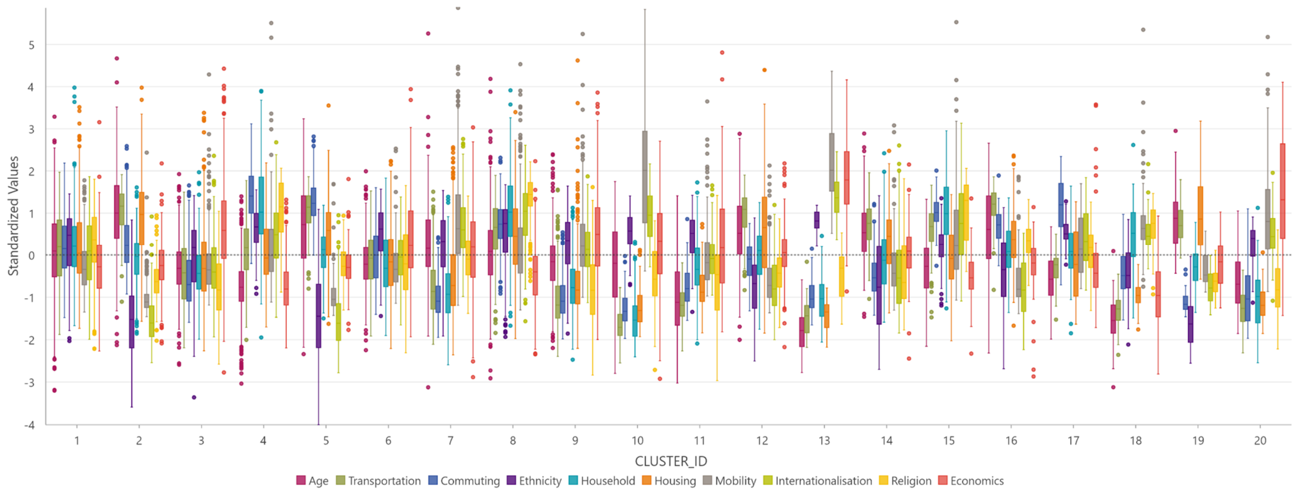


***Figure** 7. Chart of the Characteristics of Residents in Each Clustered Areas*

Spatially Constrained Multivariate Clustering is performed by placing ten categories of resident characteristics, and the number of clusters needs to be selected by iterating. Based on the existing research (Davidson and Wyly, 2012), clustering performance and analytical needs, this study concludes that, when London is divided into 20 categories, the regions have a better clustering performance while conforming to the mainstream cognitive divisions, and each region also has enough data to support the subsequent Forest-based Regression, and the 20 clusters after division also have different characteristics of residents.

### *4.3.2 Random Forest Regression Results Based on Regional Amenities Preference Analysis*

The weights of residents' preferences for each type of amenities in different regions are obtained by Forest-based Regression of amenities and the average price of houses in each region after division. The performance of the random forest model varies from region to region, but the $R^2$ of the training set mostly fluctuates around 0.4, and that of the testing set mostly fluctuates around 0.35, so it can be assumed that the convenience of amenities explains 35%-40% of the changes in property values.

At the same time, different regions have different preferences for each type of amenity: Leisure, Transport, and Supermarket all account for more than 10% of the average weight, which is the relative preference of the majority of regional residents; Facilities, Worship, and Sports have less than 6% of the average weight, indicating that these amenities are not the most frequently used amenities for the majority of residents in their daily lives; Transport, Health, and Parks have a standard deviation of more than 0.05, with large differences among regions.

***Table 6**. Preferences for Convenience of Each Categories of Amenities in Each Clustered Area*

| CLUSTER ID | LEISURE | TRANSPORT | SUPERMARKET | HEALTH | PARKS | FINANCIAL | SHOPPING | CATERING | EDUCATION | FACILITIES | WORSHIP | SPORTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 4.78% | 19.90% | 10.63% | 5.94% | 8.35% | 5.06% | 6.92% | 10.66% | 7.73% | 7.53% | 3.28% | 9.22% |
| *2* | 4.41% | 23.47% | 7.37% | 9.71% | 14.70% | 6.72% | 14.98% | 7.01% | 1.91% | 4.82% | 3.06% | 1.83% |
| *3* | 8.61% | 13.36% | 7.28% | 7.14% | 9.54% | 8.79% | 9.14% | 6.20% | 5.02% | 11.47% | 4.91% | 8.55% |
| *4* | 3.47% | 5.79% | 10.65% | 13.58% | 5.32% | 9.14% | 11.68% | 12.83% | 8.89% | 5.22% | 7.45% | 5.99% |
| *5* | 7.90% | 18.98% | 4.76% | 5.90% | 9.56% | 14.73% | 5.00% | 6.04% | 9.98% | 5.44% | 6.89% | 4.83% |
| *6* | 12.54% | 10.21% | 7.07% | 7.05% | 6.47% | 17.53% | 9.28% | 8.15% | 7.56% | 6.33% | 5.08% | 2.74% |
| *7* | 18.17% | 5.32% | 11.98% | 3.95% | 25.48% | 4.50% | 9.32% | 3.81% | 5.04% | 3.90% | 5.30% | 3.25% |
| *8* | 9.03% | 12.34% | 14.83% | 7.14% | 7.93% | 9.80% | 5.81% | 7.65% | 3.57% | 6.78% | 12.40% | 2.72% |
| *9* | 15.47% | 10.14% | 11.43% | 4.41% | 10.35% | 12.94% | 7.36% | 6.91% | 6.02% | 4.22% | 8.26% | 2.49% |
| *10* | 19.33% | 4.28% | 4.51% | 29.61% | 9.49% | 6.44% | 7.92% | 2.33% | 4.28% | 3.04% | 4.42% | 4.34% |
| *11* | 15.85% | 12.43% | 9.20% | 8.67% | 7.06% | 8.34% | 4.89% | 5.12% | 6.35% | 5.04% | 4.30% | 12.75% |
| *12* | 5.65% | 16.34% | 6.69% | 6.49% | 9.50% | 9.84% | 7.52% | 14.09% | 5.64% | 3.26% | 7.06% | 7.93% |
| *13* | 12.48% | 3.30% | 3.21% | 12.18% | 8.09% | 12.85% | 5.99% | 12.31% | 12.22% | 7.42% | 3.32% | 6.63% |
| *14* | 11.36% | 5.94% | 11.45% | 5.65% | 6.54% | 6.93% | 4.49% | 5.27% | 18.98% | 3.61% | 5.48% | 14.31% |
| *15* | 8.20% | 8.02% | 9.54% | 7.04% | 16.43% | 5.92% | 17.66% | 7.71% | 4.96% | 4.96% | 4.95% | 4.62% |
| *16* | 5.26% | 12.67% | 15.22% | 8.41% | 8.05% | 4.42% | 10.17% | 14.21% | 4.21% | 5.33% | 8.39% | 3.68% |
| *17* | 10.32% | 7.89% | 18.91% | 9.04% | 3.40% | 5.19% | 9.96% | 6.28% | 6.81% | 8.54% | 9.76% | 3.92% |
| *18* | 8.79% | 3.66% | 7.23% | 19.61% | 2.58% | 18.97% | 13.58% | 6.32% | 4.63% | 6.85% | 3.01% | 4.77% |
| *19* | 12.05% | 5.23% | 19.47% | 17.47% | 15.11% | 8.12% | 8.43% | 4.25% | 4.88% | 4.38% | 0.01% | 0.61% |
| *20* | 19.33% | 5.64% | 12.41% | 9.36% | 3.37% | 4.97% | 10.17% | 15.59% | 2.22% | 5.77% | 4.56% | 6.63% |
| *Mean* | 10.65% | 10.25% | 10.19% | 9.92% | 9.37% | 9.06% | 9.01% | 8.14% | 6.54% | 5.70% | 5.59% | 5.59% |
| *Std Dev* | 0.048 | 0.057 | 0.044 | 0.06 | 0.052 | 0.042 | 0.034 | 0.037 | 0.037 | 0.02 | 0.027 | 0.034 |

### 4.4 Property Location Convenience Comprehensive Calculation Results and Analysis

The final results of the Convenience of Property Location within Greater London were obtained through the integrated calculation, and it can be found that: the evaluation results are normally distributed, the areas with high convenience are mainly located in Inner London, and the areas with the highest convenience almost coincide with Central Activities Zone (CAZ), distributed in the whole of City of London, most of City of Westminster, Islington and the south of Camden, these places have the most convenient property location; in addition, in Canary Wharf, Stratford, Greenwich etc., which have a secondary core of convenience; and the more peripheral the lower the convenience, but there are some high convenience nodes along the main transport routes, such as Bromley and Croydon.

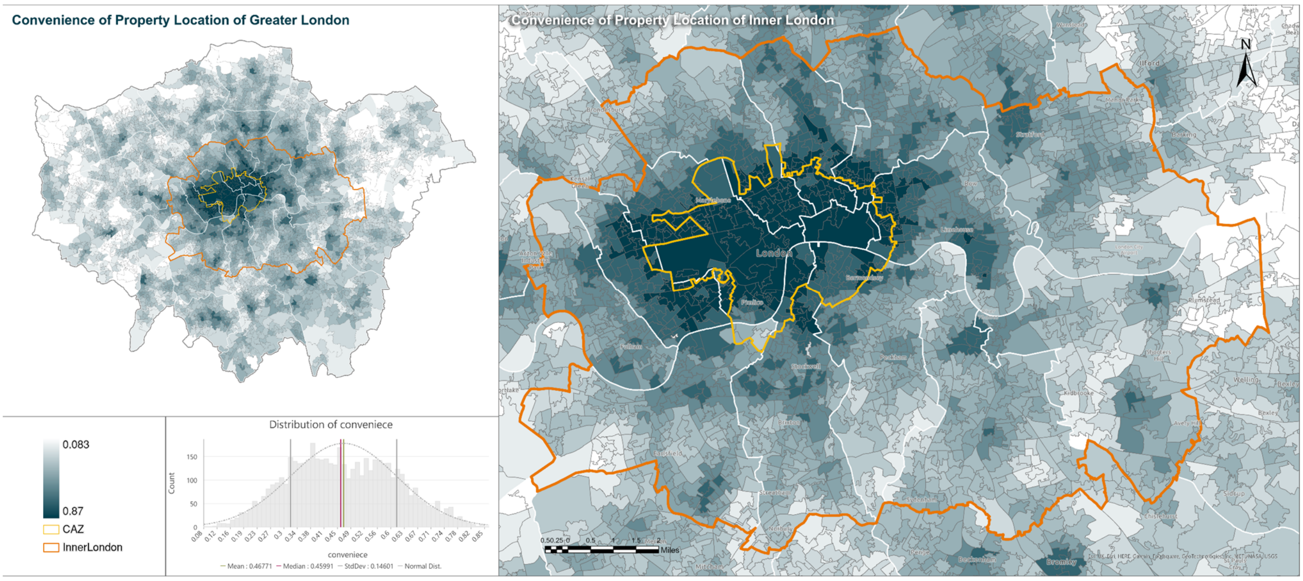


***Figure 8****. Convenience of Property Location in Greater London and Inner London*

Spatial Autocorrelation Analysis shows that there is a clear case of spatial clustering of property location convenience (Global Moran's I = 0.7099, z-score = 227.064), and Local Indicators of Spatial Association suggests that there is a wide range of high-value clusters and low-value clusters. Meanwhile, Hot Spot Analysis (Getis-Ord Gi*) shows that high-value clustering is mainly concentrated in the central city area, which is roughly the same extent as Inner London, while low-value clustering is mainly in the Outer London area in the west, north, and east, and in the Outer London area in the south, where numerous nodes with a high degree of accessibility are present but with low convenience beyond that, so there is no clear high or low-value concentration.

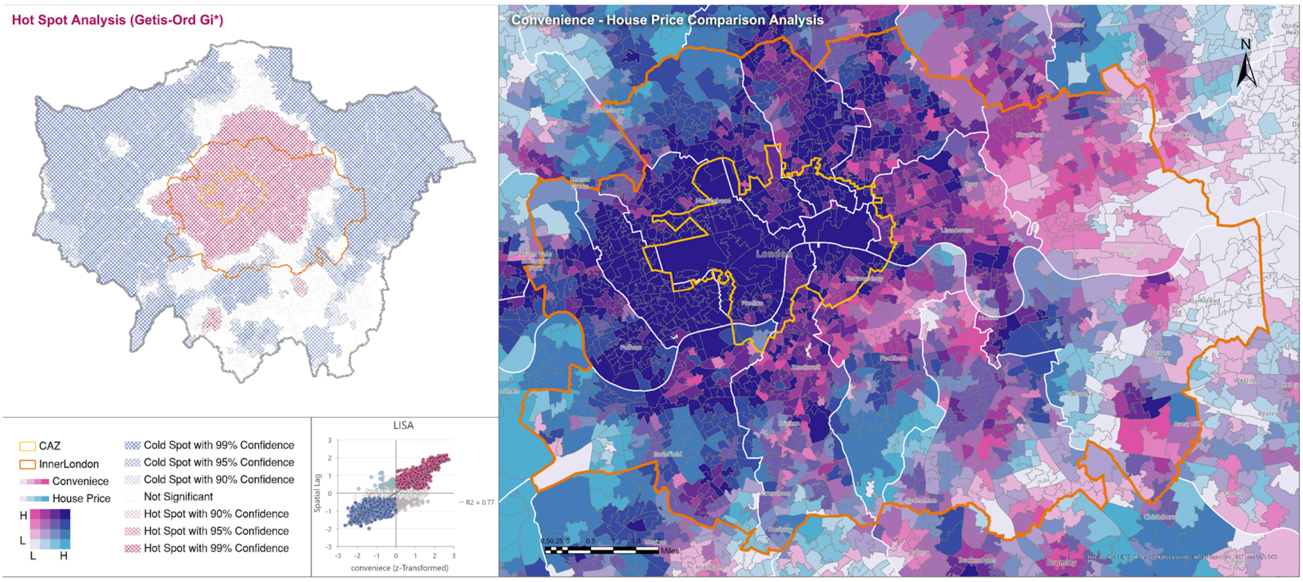


***Figure 9****. Hot Spot Analysis (Getis-Ord Gi*) & Convenience - House Price Comparison Analysis*

A Bivariate analysis of convenience and average property prices shows clear regional differences in Inner London. City of London, City of Westminster, Kensington & Chelsea have the highest convenience and housing prices, while the areas further west have higher average property prices despite lower convenience, but the areas east of the City of London and south of the Thames Despite the high convenience, the average house price is not high. On the one hand, this shows that there are extensive factors other than convenience that affect housing prices, and on the one hand, it also provides a reference for real estate decision-making.

# 5 Discussion

## 5.1 Results Discoveries and Reflections

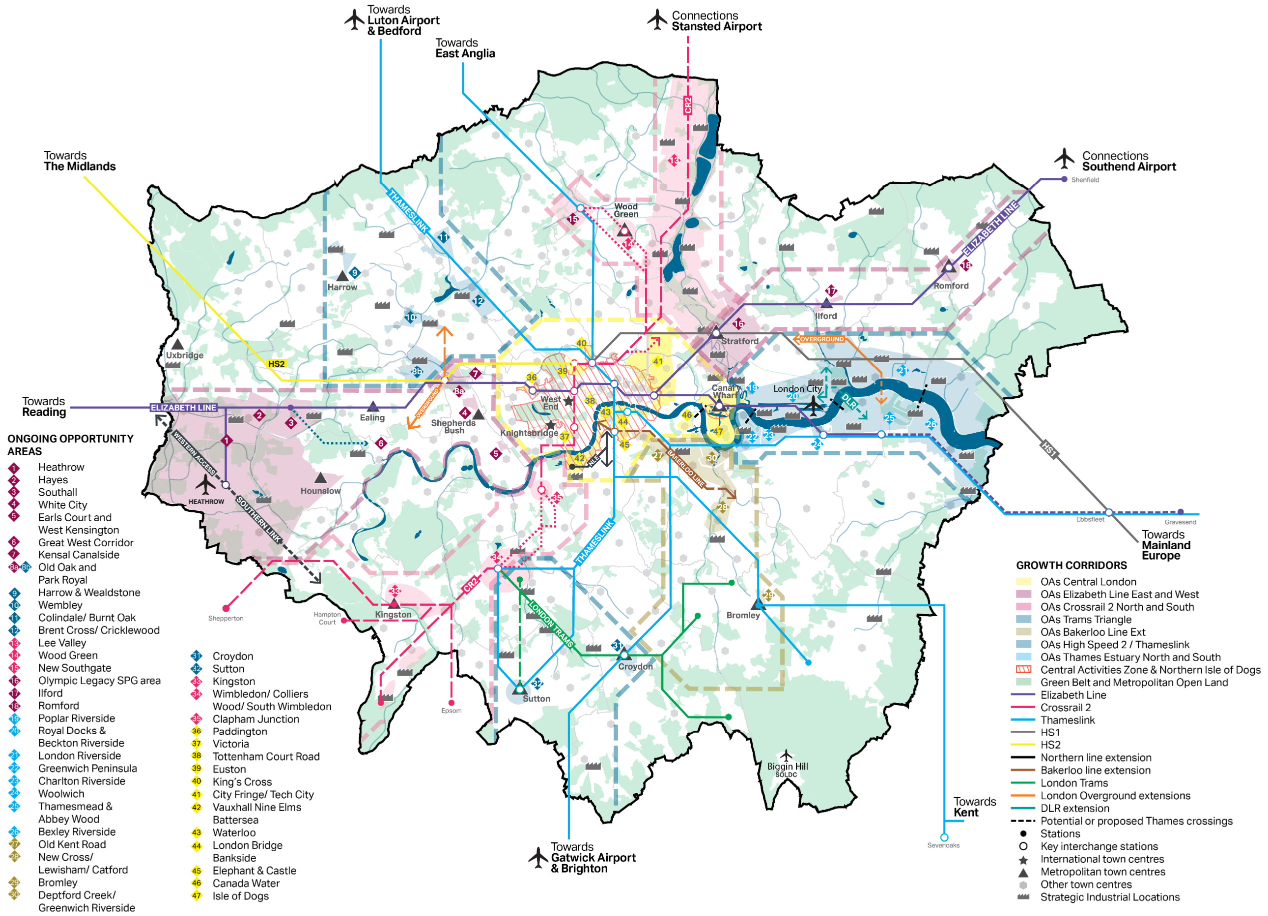


***Figure 10***. *Spatial Development Patterns Diagram, The London Plan 2021(Greater London Authority, 2021)*

The results of the evaluation reveal that the distribution of property location convenience shows a monocentric and multi-nodal distribution pattern, which also depicts the urban structure of London and validates the Spatial Development Patterns proposed in The London Plan 2021 (Greater London Authority, 2021). The monocentric area overlaps with the Central Activities Zone (CAZ), the vibrant heart and globally iconic core of London, one of the most attractive and competitive business locations in the world, renowned for its culture, night-time economy, tourism, shopping and heritage (Greater London Authority, 2021), which area exhibits the highest and centrally connected convenience. Multi-nodal areas, similar to the distribution of Metropolitan level town centres, are at the heart of Londoners' lives and provide a focal point for local communities (Greater London Authority, 2021) and are located in regional-level cores along key transport routes, which have close to the convenience of the central area but are much smaller in scale, can provide comprehensive services to the local area. However, this indicator is primarily concerned with the local amenity content, and it may be possible to derive a more accurate spatial structure of the city by including a wider range of amenities.

Bivariate analysis reveals that there is a huge difference in prices between the east and west sides of the heartland at the same convenience level, and implies that there are other important factors affecting housing prices other than convenience. It can be verified through relevant research (Hamnett, 2009) that London's growth in financial and business services as one of the world's financial centres has spawned a large and relatively well-paid professional and managerial middle class, whose purchases of properties in Kensington and other high-priced areas have pushed house prices astronomically high. Therefore, this indicator can also be analysed in comparison with other factors to explore the influence of other factors behind areas of similar life service capacity.

The application of the property location convenience evaluation tool developed based on the 15-minute city paradigm in London in this study reveals the spatial distribution pattern of property location convenience, and provides quantitative data with an precision at the LSOA level, which is of significant importance for the evaluation of the property location and the progression of the 15-minute city paradigm in London. Meanwhile, the good match between the spatial distribution of the results and the spatial structure of the city suggests that this data can be used as part of a study of the spatial structure, and the evaluation tool provided in this study allows scores to be calculated quickly in different cities, which is also useful for the study of spatial structure at the regional level. In addition, by comparing this data with other data, more exploratory studies can be conducted.

### 5.2 Limitations and Future Work

This study has several limitations due to various subjective and objective conditions, which we hope to remedy in future research.

Limitations due to research focus: The main research direction of this study is to evaluate convenience. However, due to the consideration of inter-regional differences, this study divides London into regions based on the characteristics of residents, but since there is no mature research in London as a basis, this study carries out a relatively simple division study on its own through Spatially Constrained Multivariate Clustering. However, spatial clustering is a very complex area of research with many clustering methods (Grubesic, Wei and Murray, 2014). Knowledge of residents' preferences is also limited to objective data analyses, whereas understanding residents' subjective preferences through questionnaires may provide a more accurate determination of differences in residents' lifestyles (Frenkel, Bendit and Kaplan, 2013). In the future, this could be remedied by more in-depth research in the various segments.

Limitations of data collection: This study decided to use OpenStreetMap's POI data after considering the reproducibility of the tool and the openness of the data, but for the case's regionality, Ordnance Survey's POI data would have been more accurate and informative in London (Ordnance Survey, 2023). In addition, differences between the same type of amenities were not considered in this study, and differences between the quality, size, and type of amenities may have important implications for quality of life, as well as for the evaluation of convenience of location. In the future, incorporating the fine-grained division of POIs into the research work could provide a higher reference value for property location convenience.

Limitations of computational capacity: This study simplified some of the functions that should be available when creating and running the evaluation system after weighing the running time and computational accuracy. For example, it was planned to divide residents into different groups according to age and gender, and calculate the access capacity of different groups within 15 minutes based on their walking speed, but it was abandoned due to tens of times of calculation time. In addition, due to the excessive number of POIs, and considering that the mainly focus on regional access capacity, similar POIs within the same area were simplified and snapped, thus reducing the accuracy. Both of these are due to the limitations of running the network analysis tool in ArcGIS Pro, and there may be a possibility that some of the functions that were originally required to be run only once when the tool was developed will be repeated when calculating different categories of amenities. In the future, there is a need to continuously optimise the evaluation tool, and explore the use of other methods to replace the network analysis tool of ArcGIS Pro to reach a faster running speed so as to calculate more accurate evaluation results.

Based on this study, richer research can be carried out in the future. This paper provides a replicable methodology for evaluating the convenience of property location, which on the one hand can be used as a scoring result to provide data for other studies that cover convenience evaluation but do not focus on it, and on the other hand can be used to conduct a quick comparative study in different cities. The tool could also be further developed to incorporate other influences on property choice and combined with a service area analysis from commuting/study locations, to become a quick tool for generating reference information on property choice. Of course, future work is not limited to this, and this study amounts to providing a data source and platform for property location convenience, on which a very wide range of future work can be based.

# 6 Conclusion

The hypothesis of this study is if it is possible to establish a replicable property location convenience evaluation system based on the 15-minute city paradigm and property value perspective that takes into account regional differences, and through the study, it is agreed that the hypothesis is valid, and based on this, a standardised Arcpy-based evaluation tool that can be used in different cities is developed. The three ensuing research questions are answered in the evaluation results using Greater London as a case study.

The analysis firstly started from the perspectives of residents' demand and amenity supply, and calculated the individual convenience of 12 categories of amenities through the Closest Facility Analysis and Service Area Analysis. It was found that most of the amenities tend to be concentrated in the CAZ area, but the range of the values, distribution mode and concentration location of the convenience of different amenities are different. Afterwards, by comparing the performance of OLS and MGWR regressions without dividing the regions and spatial autocorrelation analysis of the standardised residuals of the OLS predictions, it was concluded that the residents of the various regions of Greater London have different preferences for amenities. Therefore, ten categories of resident characteristics were calculated and placed, and Spatially Constrained Multivariate Clustering was used to divide London into 20 regions, and the feature importance of Forest-based Regression was used to obtain the weights of residents' preferences for each category of amenities in different regions. Based on the performance of the model in each region, it is found that the convenience of amenities can explain 35%-40% of the variation in property prices. By weighting the regional preferences, the comprehensive convenience of property location is obtained, and it can be found that the convenience within Greater London is basically normally distributed, and the spatial distribution shows a single-centre and multi-node distribution pattern, and the areas with high convenience are mainly located in Inner London. The monocentric areas overlap with the Central Activities Zone (CAZ), and the multi-nodal areas are similar to the distribution of Metropolitan-level town centres. Further Bivariate analyses of property location convenience and average house prices reveal large house price differences between the east and west sides of the central zone with equal convenience.

Overall, this study provides a new way of thinking about property location convenience that is in line with the current trend, combines the concept of the 15-minute city paradigm to carry out the evaluation, and constructs a set of complete and feasible evaluation system and tools to carry out a case study in London, which has a wide range of future expandability, while the results of the study and the methodology can provide a source of data and methodological support for other studies.

# Reference


Alonso, W. (2013) 'Location and Land Use: Toward a General Theory of Land Rent', in *Location and Land Use*. Harvard University Press. Available at: https://doi.org/10.4159/harvard.9780674730854.

ArcGIS Pro 3.0 (2023a) *Find Closest Facilities (Ready To Use)—ArcGIS Pro | Documentation*. Available at: https://pro.arcgis.com/en/pro-app/3.0/tool-reference/ready-to-use/itemdesc-findclosestfacilities.htm (Accessed: 22 August 2023).

ArcGIS Pro 3.0 (2023b) *Generate Service Areas (Ready To Use)—ArcGIS Pro | Documentation*. Available at: https://pro.arcgis.com/en/pro-app/3.0/tool-reference/ready-to-use/itemdesc-generate-service-areas.htm (Accessed: 22 August 2023).

ArcGIS Pro 3.0 (2023c) *How Spatially Constrained Multivariate Clustering works—ArcGIS Pro | Documentation*. Available at: https://pro.arcgis.com/en/pro-app/3.0/tool-reference/spatial-statistics/how-spatially-constrained-multivariate-clustering-works.htm (Accessed: 22 August 2023).

Ayuntamiento de Barcelona (no date) *Bienvenido a Superilles | Superilles*. Available at: https://ajuntament.barcelona.cat/superilles/es/ (Accessed: 23 August 2023).

Barbieri, L. *et al.* (2023) 'Graph Representation of the 15-Minute City: A Comparison between Rome, London, and Paris', *Sustainability*, 15(4), p. 3772. Available at: https://doi.org/10.3390/su15043772.

Bartzokas-Tsiompras, A. and Bakogiannis, E. (2023) 'Quantifying and visualizing the 15-Minute walkable city concept across Europe: a multicriteria approach', *Journal of Maps*, 19(1), p. 2141143. Available at: https://doi.org/10.1080/17445647.2022.2141143.

Bohannon, R.W. and Williams Andrews, A. (2011) 'Normal walking speed: a descriptive meta-analysis', *Physiotherapy*, 97(3), pp. 182–189. Available at: https://doi.org/10.1016/j.physio.2010.12.004.

Bondarenko, M. *et al.* (2020) 'Census/projection-disaggregated gridded population datasets, adjusted to match the corresponding UNPD 2020 estimates, for 183 countries in 2020 using Built-Settlement Growth Model (BSGM) outputs'. University of Southampton. Available at: https://doi.org/10.5258/SOTON/WP00685.

Brandt, S., Maennig, W. and Richter, F. (2014) 'Do Houses of Worship Affect Housing Prices? Evidence from Germany', *Growth and Change*, 45(4), pp. 549–570. Available at: https://doi.org/10.1111/grow.12066.

Brueckner, J.K., Thisse, J.-F. and Zenou, Y. (1999) 'Why is central Paris rich and downtown Detroit poor?: An amenity-based theory', *European Economic Review*, 43(1), pp. 91–107. Available at: https://doi.org/10.1016/S0014-2921(98)00019-1.

Calafiore, A. *et al.* (2022) 'The 20-minute city: An equity analysis of Liverpool City Region', *Transportation Research Part D: Transport and Environment*, 102, p. 103111. Available at: https://doi.org/10.1016/j.trd.2021.103111.

Carroll, T.M., Clauretie, T.M. and Jensen, J. (1996) 'Living next to godliness: Residential property values and churches', *The Journal of Real Estate Finance and Economics*, 12(3), pp. 319–330. Available at: https://doi.org/10.1007/BF00127540.

Chen, Q. and Crooks, A.T. (2021) 'Delineating a "15-minute city": an agent-based modeling approach to estimate the size of local communities', in *Proceedings of the 4th ACM SIGSPATIAL International Workshop on GeoSpatial Simulation*. New York, NY, USA: Association for Computing Machinery (GeoSim '21), pp. 29–37. Available at: https://doi.org/10.1145/3486184.3491080.

Cheshire, P. (2014) *Turning houses into gold: the failure of British planning*, *British Politics and Policy at LSE*. London School of Economics and Political Science. Available at: http://blogs.lse.ac.uk/politicsandpolicy (Accessed: 23 August 2023).

Chiaradia, A. *et al.* (2013) 'Compositional and urban form effects on residential property value patterns in Greater London', *Proceedings of the Institution of Civil Engineers - Urban Design and Planning*, 166(3), pp. 176–199. Available at: https://doi.org/10.1680/udap.10.00030.

Copernicus Land Monitoring Service (2021) *Urban Atlas 2018*. Available at: https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018 (Accessed: 22 August 2023).

Davidson, M. and Wyly, E. (2012) 'Class-ifying London', *City*, 16(4), pp. 395–421. Available at: https://doi.org/10.1080/13604813.2012.696888.

Dempsey, N. *et al.* (2011) 'The social dimension of sustainable development: Defining urban social sustainability', *Sustainable Development*, 19(5), pp. 289–300. Available at: https://doi.org/10.1002/sd.417.

Des Rosiers, F. *et al.* (1996) 'Shopping centres and house values: an empirical investigation', *Journal of Property Valuation and Investment*, 14(4), pp. 41–62. Available at: https://doi.org/10.1108/14635789610153461.

Durlauf, S.N. (2004) 'Chapter 50 - Neighborhood Effects', in J.V. Henderson and J.-F. Thisse (eds) *Handbook of Regional and Urban Economics*. Elsevier (Cities and Geography), pp. 2173–2242. Available at: https://doi.org/10.1016/S1574-0080(04)80007-5.

Eade, J. (2000) *PLACING LONDON FROM IMPERIAL CAPITAL TO GLOBAL CITY JOHN EADE CONTENTS*. Available at: https://doi.org/10.13140/2.1.2513.8242.

Edward, G. (2021) 'The 15-minute city is a dead end — cities must be places of opportunity for everyone', *LSE COVID-19*, 28 May. Available at: https://blogs.lse.ac.uk/covid19/2021/05/28/the-15-minute-city-is-a-dead-end-cities-must-be-places-of-opportunity-for-everyone/ (Accessed: 23 August 2023).

Frederik, R. (2022) 'OpenStreetMap Data in Layered GIS-Format'.

Frenkel, A., Bendit, E. and Kaplan, S. (2013) 'The linkage between the lifestyle of knowledge-workers and their intra-metropolitan residential choice: A clustering approach based on self-organizing maps', *Computers, Environment and Urban Systems*, 39, pp. 151–161. Available at: https://doi.org/10.1016/j.compenvurbsys.2012.09.001.

Geofabrik GmbH and OpenStreetMap (2023) *Geofabrik Download Server*. Available at: https://download.geofabrik.de/europe/great-britain/england/greater-london.html# (Accessed: 22 August 2023).

Geoghegan, J., Wainger, L.A. and Bockstael, N.E. (1997) 'Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS', *Ecological Economics*, 23(3), pp. 251–264. Available at: https://doi.org/10.1016/S0921-8009(97)00583-1.

Greater London Authority (2016) *Central Activities Zone Supplementary Planning Guidance*. Available at: https://www.london.gov.uk/sites/default/files/caz_spg_final_v4.pdf (Accessed: 23 August 2023).

Greater London Authority (2021) *Chapter 2 Spatial Development Patterns | The London Plan 2021*. Available at: https://www.london.gov.uk/programmes-strategies/planning/london-plan/the-london-plan-2021-online/chapter-2-spatial-development-patterns (Accessed: 23 August 2023).

Grubesic, T.H., Wei, R. and Murray, A.T. (2014) 'Spatial Clustering Overview and Comparison: Accuracy, Sensitivity, and Computational Expense', *Annals of the Association of American Geographers*, 104(6), pp. 1134–1156. Available at: https://doi.org/10.1080/00045608.2014.958389.

Hamnett, C. (2009) 'Spatially Displaced Demand and the Changing Geography of House Prices in London, 1995–2006', *Housing Studies*, 24(3), pp. 301–320. Available at: https://doi.org/10.1080/02673030902814580.

Ishwaran, H. and Lu, M. (2019) 'Standard errors and confidence intervals for variable importance in random forest regression, classification, and survival', *Statistics in Medicine*, 38(4), pp. 558–582. Available at: https://doi.org/10.1002/sim.7803.

Kang, C.-N. *et al.* (2023) 'A service facility location problem considering customer preference and facility capacity', *Computers & Industrial Engineering*, 177, p. 109070. Available at: https://doi.org/10.1016/j.cie.2023.109070.

Khavarian-Garmsir, A.R., Sharifi, A. and Sadeghi, A. (2023) 'The 15-minute city: Urban planning and design efforts toward creating sustainable neighborhoods', *Cities*, 132, p. 104101. Available at: https://doi.org/10.1016/j.cities.2022.104101.

Kienast-von Einem, C., Panter, J. and Reid, A. (2023) ‘A longitudinal area classification of migration in Great Britain: Testing the application of Group-Based Multi-Trajectory Modelling’, *Population, Space and Place*, n/a(n/a), p. e2694. Available at: https://doi.org/10.1002/psp.2694.

Knap, E. *et al.* (2023) ‘A composite X-minute city cycling accessibility metric and its role in assessing spatial and socioeconomic inequalities – A case study in Utrecht, the Netherlands’, *Journal of Urban Mobility*, 3, p. 100043. Available at: https://doi.org/10.1016/j.urbmob.2022.100043.

Kuminoff, N.V., Smith, V.K. and Timmins, C. (2013) ‘The New Economics of Equilibrium Sorting and Policy Evaluation Using Housing Markets’, *Journal of Economic Literature*, 51(4), pp. 1007–1062. Available at: https://doi.org/10.1257/jel.51.4.1007.

Kung, L.-C. and Liao, W.-H. (2018) ‘An approximation algorithm for a competitive facility location problem with network effects’, *European Journal of Operational Research*, 267(1), pp. 176–186. Available at: https://doi.org/10.1016/j.ejor.2017.11.037.

Law, S. (2017) ‘Defining Street-based Local Area and measuring its effect on house price using a hedonic price approach: The case study of Metropolitan London’, *Cities*, 60, pp. 166–179. Available at: https://doi.org/10.1016/j.cities.2016.08.008.

Leyden, K.M., Goldberg, A. and Michelbach, P. (2011) ‘Understanding the Pursuit of Happiness in Ten Major Cities’, *Urban Affairs Review*, 47(6), pp. 861–888. Available at: https://doi.org/10.1177/1078087411403120.

Lima, F.T., Brown, N.C. and Duarte, J.P. (2022) ‘A Grammar-Based Optimization Approach for Designing Urban Fabrics and Locating Amenities for 15-Minute Cities’, *Buildings*, 12(8), p. 1157. Available at: https://doi.org/10.3390/buildings12081157.

Liu, L. *et al.* (2022) ‘Multiscale Effects of Multimodal Public Facilities Accessibility on Housing Prices Based on MGWR: A Case Study of Wuhan, China’, *ISPRS International Journal of Geo-Information*, 11(1), p. 57. Available at: https://doi.org/10.3390/ijgi11010057.

London Datastore (2023) ‘Demography’. Available at: https://data.london.gov.uk/demography/ (Accessed: 22 August 2023).

Malcolm, S. (2020) *Future proofing our cities with the 15 minute concept*. Available at: https://www.arup.com/en/perspectives/the-fifteen-minute-vision-future-proofing-our-cities (Accessed: 23 August 2023).

McPherson, M., Smith-Lovin, L. and Cook, J.M. (2001) ‘Birds of a Feather: Homophily in Social Networks’, *Annual Review of Sociology*, 27(1), pp. 415–444. Available at: https://doi.org/10.1146/annurev.soc.27.1.415.

Monika, J. and Shivani, B. (2020) ‘Unravelling the Concept of the 15-Minute City – Could it Render an Equitable, Healthy and Sustainable London?’ Available at: https://www.futureoflondon.org.uk/wp-content/uploads/2022/09/Unravelling-the-concept-of-the-15-minute-city.pdf (Accessed: 23 August 2023).

Moreno, C. *et al.* (2021) ‘Introducing the “15-Minute City”: Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities’, *Smart Cities*, 4(1), pp. 93–111. Available at: https://doi.org/10.3390/smartcities4010006.

Nieves, J.J. *et al.* (2020) ‘Annually modelling built-settlements between remotely-sensed observations using relative changes in subnational populations and lights at night’, *Computers, Environment and Urban Systems*, 80, p. 101444. Available at: https://doi.org/10.1016/j.compenvurbsys.2019.101444.

Office for National Statistics (2019) *House price statistics for small areas QMI*. Available at: https://cy.ons.gov.uk/peoplepopulationandcommunity/housing/methodologies/housepricestatisticsforsmallareasqmi (Accessed: 22 August 2023).

Office for National Statistics (2022a) *Economic activity status*. Available at: https://www.ons.gov.uk/datasets/TS066/editions/2021/versions/1 (Accessed: 22 August 2023).

Office for National Statistics (2022b) *Ethnic group*. Available at: https://www.ons.gov.uk/datasets/TS021/editions/2021/versions/1 (Accessed: 22 August 2023).

Office for National Statistics (2022c) *Religion*. Available at: https://www.ons.gov.uk/datasets/TS030/editions/2021/versions/1 (Accessed: 22 August 2023).

Office for National Statistics (2023a) *Car or van availability*. Available at: https://www.ons.gov.uk/datasets/TS045/editions/2021/versions/1 (Accessed: 22 August 2023).

Office for National Statistics (2023b) *Census 2021*. Available at: https://www.ons.gov.uk/census (Accessed: 22 August 2023).

Office for National Statistics (2023c) *Country of birth*. Available at: https://www.ons.gov.uk/datasets/TS004/editions/2021/versions/3 (Accessed: 22 August 2023).

Office for National Statistics (2023d) *Distance travelled to work*. Available at: https://www.ons.gov.uk/datasets/TS058/editions/2021/versions/3?showAll=workplace_travel (Accessed: 22 August 2023).

Office for National Statistics (2023e) *Household size*. Available at: https://www.ons.gov.uk/datasets/TS017/editions/2021/versions/3 (Accessed: 22 August 2023).

Office for National Statistics (2023f) *Length of residence*. Available at: https://www.ons.gov.uk/datasets/TS016/editions/2021/versions/3 (Accessed: 22 August 2023).

Office for National Statistics (2023g) *Lower Layer Super Output Areas (2021) Boundaries EW BFE*. Available at: https://geoportal.statistics.gov.uk/datasets/lower-layer-super-output-areas-2021-boundaries-ew-bfe/explore (Accessed: 22 August 2023).

Office for National Statistics (2023h) *Mean house prices by lower layer super output area: HPSSA dataset 47*. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/housing/datasets/meanpricepaidbylowerlayersuperoutputareahpssadataset47 (Accessed: 22 August 2023).

Office for National Statistics (2023i) *Number of rooms*. Available at: https://www.ons.gov.uk/datasets/TS051/editions/2021/versions/4 (Accessed: 22 August 2023).

Office for National Statistics (2023j) *Sex by single year of age (detailed)*. Available at: https://www.ons.gov.uk/datasets/RM200/editions/2021/versions/1 (Accessed: 22 August 2023).

Office for National Statistics (2023k) *Wards (May 2023) Boundaries UK BFE*. Available at: https://geoportal.statistics.gov.uk/datasets/ons::wards-may-2023-boundaries-uk-bfe/explore (Accessed: 22 August 2023).

Olivari, B. *et al.* (2023) ‘Are Italian cities already 15-minute? Presenting the Next Proximity Index: A novel and scalable way to measure it, based on open data’, *Journal of Urban Mobility*, 4, p. 100057. Available at: https://doi.org/10.1016/j.urbmob.2023.100057.

Ordnance Survey (2023) *Points of Interest | Data Products*. Available at: https://www.ordnancesurvey.co.uk/products/points-of-interest (Accessed: 23 August 2023).

Planning Implementation, Department of Transport and Planning (2023) *Plan Melbourne 2017–2050: 20-minute neighbourhoods*, *Planning*. Planning. Available at: https://www.planning.vic.gov.au/guides-and-resources/strategies-and-initiatives/20-minute-neighbourhoods (Accessed: 23 August 2023).

Pozoukidou, G. and Chatziyiannaki, Z. (2021) ‘15-Minute City: Decomposing the New Urban Planning Eutopia’, *Sustainability*, 13(2), p. 928. Available at: https://doi.org/10.3390/su13020928.

Rosen, S. (1974) ‘Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition’, *Journal of Political Economy*, 82(1), pp. 34–55. Available at: https://doi.org/10.1086/260169.

Royal Town Planning Institute (no date) *15 Minute Cities/20 Minute Neighbourhoods*. Available at: https://www.rtpi.org.uk/find-your-rtpi/rtpi-english-regions/rtpi-london/latest-updates/15-minute-cities20-minute-neighbourhoods/ (Accessed: 23 August 2023).

Sadiq, K. and Caroline, R. (2020) *Fifteen-minute neighbourhoods as part of London's recovery | London City Hall*. Available at: https://www.london.gov.uk/who-we-are/what-london-assembly-does/questions-mayor/find-an-answer/fifteen-minute-neighbourhoods-part-londons-recovery (Accessed: 23 August 2023).

Shanghai Urban Planning and Land Resources Administration Bureau (2016) *Planning Guidance of 15-Minute Community-Life Circle*. Available at: http://up.caup.net/file/life-circle.pdf (Accessed: 23 August 2023).

Stevens, F.R. *et al.* (2015) 'Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data', *PLOS ONE*. Edited by L.A.N. Amaral, 10(2), p. e0107042. Available at: https://doi.org/10.1371/journal.pone.0107042.

Talk London (2020) *15 minute cities – the city on your doorstep | TalkLondon*. Available at: https://www.london.gov.uk/talk-london/communities-regeneration/15-minute-cities-%E2%80%93-city-your-doorstep (Accessed: 23 August 2023).

Tim, E. and Julia, T. (2021) *20-Minute Neighbourhoods – Creating Healthier, Active, Prosperous Communities | An Introduction for Council Planners in England*. Available at: https://www.tcpa.org.uk/wp-content/uploads/2021/11/final_20mnguide-compressed.pdf (Accessed: 23 August 2023).

Town and Country Planning Association (2023) *Town and Country Planning Journal: Special Issue on 20-Minute Neighbourhoods*. Available at: https://www.tcpa.org.uk/wp-content/uploads/2023/06/TCP_May-Jun23_R.pdf (Accessed: 23 August 2023).

Transport for London (2023) *Planning for Walking Toolkit*. Available at: https://haveyoursay.tfl.gov.uk/access-our-older-consultations/widgets/34106/documents (Accessed: 22 August 2023).

Vich, G., Gómez-Varo, I. and Marquet, O. (2023) 'Chapter 3 - Measuring the 15-Minute City in Barcelona. A geospatial three-method comparison', in Z. Allam et al. (eds) *Resilient and Sustainable Cities*. Elsevier, pp. 39–60. Available at: https://doi.org/10.1016/B978-0-323-91718-6.00004-9.

Weng, M. *et al.* (2019) 'The 15-minute walkable neighborhoods: Measurement, social inequalities and implications for building healthy communities in urban China', *Journal of Transport & Health*, 13, pp. 259–273. Available at: https://doi.org/10.1016/j.jth.2019.05.005.

Wiewel, W. and Kafoury, D. (2012) 'The Portland Plan'.

Willsher, K. (2020) 'Paris mayor unveils "15-minute city" plan in re-election campaign', *The Guardian*, 7 February. Available at: https://www.theguardian.com/world/2020/feb/07/paris-mayor-unveils-15-minute-city-plan-in-re-election-campaign (Accessed: 23 August 2023).

Yang, Y. and Diez-Roux, A.V. (2012) 'Walking Distance by Trip Purpose and Population Subgroups', *American Journal of Preventive Medicine*, 43(1), pp. 11–19. Available at: https://doi.org/10.1016/j.amepre.2012.03.015.

Yin, X. (2023) 'XianlaiYin/Convenience-of-Property-Location'. Available at: https://github.com/XianlaiYin/Convenience-of-Property-Location (Accessed: 25 August 2023).

Zhang, S. *et al.* (2023) 'Towards a 15-minute city: A network-based evaluation framework', *Environment and Planning B: Urban Analytics and City Science*, 50(2), pp. 500–514. Available at: https://doi.org/10.1177/23998083221118570.

# Appendix

***Table**. Meeting Details with Prof. Andrew Hudson-Smith*

| DATE | TIME | CONTENT |
|---|---|---|
| ***17/04/2023*** | 15:00-15:30 | The initial meeting, defined the overall direction of the research and organised the timing and progress of dissertation work. |
| ***12/05/2023*** | 15:00-15:30 | Based on the reading and research of the literature referenced, proposal and specific methods that will be used in the research are discussed. |
| ***19/07/2023*** | 11:00-11:30 | Based on the settled research framework, the Introduction, Data Collection, and a draft of the Methodology of the dissertation were discussed, follow-up workplan was scheduled. |
| ***16/08/2023*** | 16:00-16:30 | The research methodology and some of the results of the study are discussed, the issue of merging the results from the supply and demand perspectives is addressed. |
| ***24/08/2023*** | 14:00-14:30 | The complete draft was discussed, the Introduction and Discussion sections were optimised, and the dissertation was wrapped up. |