REMV REAL ESTATE MANAGEMENT AND VALUATION

Journal homepage: www.remv-journal.com

METHODOLOGY FOR HOMOGENOUS MARKET AREA DETERMINATION HAD2 - MISSION ACCOMPLISHED

Marek Walacik[1]*

[1] *Department of Real Estate and Urban Studies, University of Warmia and Mazury in Olsztyn, Prawochenskiego 15, 10-724 Olsztyn, Poland; e-mail: marek.walacik@uwm.edu.pl, ORCID: 0000-0003-1904-476X*

* *Corrected author*

ARTICLE INFO

Keywords:

property market tessellation, real estate valuation, homogeneity, similarity

JEL Classification:

A10, C38, R00

ABSTRACT

Property market delineation or determination of areas signifying property market consistency has been a subject of scientific investigation by a variety of researchers from different perspectives. Some explored it for the purposes of decision-making support systems, others for, for example, zoning or housing policy. The theory of property valuation also did not remain indifferent for spatial extraction of homogenous market areas. The following paper constitutes a several-year study within that area. Following the trace of thought formulated by John Maxwell that “every step back is a chance to look at your goals from a different perspective”, the study being based on, amongst others, the method of historic research and critical analysis, ultimately organizes and complements the author’s contribution to the scientific discussion, and in that scope is one of the substantial issues included in the concept of spatial management. It contributes to the current state of the art discussion by introducing the definition of property market tessellation, utilizing it for the purposes of original HAD^2 methodology implementation.

Citation: Walacik, M. (2025). Methodology for homogenous market area determination HAD2 - Mission accomplished. *Real Estate Management and Valuation*, *33*(1), 113-124. https://doi.org/10.2478/remav-2025-0010

1. Introduction

Property valuation is a process predicated on multiple assumptions, among which determination of similarity is fundamental (Meszek, 2013; Pagourtzi et al., 2003). In comparison-based approaches, this similarity may manifest in the selection of real estate transactions used for valuation, or in identifying the markets from which these transactions originate (Wyatt, 2022). Conventionally, this process occurs intuitively, based on the expertise of a property appraiser. Thus, there is a pursuit for solutions and tools that can support this stage of the valuation process and provide standardized procedural patterns. The consistency in defining similarity aligns with international practice, which, although it clarifies the concept of "comparable property," does not specify how to measure this similarity (Bogin & Shui, 2020; Cienciała et al., 2023). In practice, property appraisers often cannot convincingly justify their assumptions regarding why certain properties were considered over others in their valuations. Another issue is the lack of data. For valuation purposes, databases are created based on information from official property transaction registers, notarial deeds, land registries and open-source platforms such as Open Street Map or google.pl/maps. However, it is often challenging to find appropriate transactions from the same area (building, street, district) as the property being appraised, with a date close to the date of valuation. Consequently, it becomes necessary to extend the search area to so-called similar markets, which again complicates the determination of the degree of similarity.

2. Theoretical framework and research hypothesis formulation

The process of property market delineation is a multifaceted challenge, particularly due to the diverse approaches and variables influencing real estate transactions (Kindström et al., 2023; McCluskey & Borst, 2017; Usman & Lizam, 2023). Traditional methods of market analysis often rely heavily, similarly to comparable sales selection, on subjective expert judgment, which can lead to inconsistencies in property valuations (Varol & Catma, 2024; Bogin &

Shui, 2020; Glennon et al., 2018). The lack of standardized methodologies for identifying comparable market areas complicates the valuation process, especially in markets characterized by spatial and economic heterogeneity (IAAO, 2017; RICS, 2021; TEGOVA, 2020). The literature on the "new regional science" (Hamelink et al., 2000) emphasizes the growing importance of regions in shaping economic outcomes. As Healey observes, "in a world where integrated place-bounded relationships are pulled out of their localities, "disembodied" and refashioned by multiple forces which mold them in different directions, the qualities of place seem to become more, not less, significant" (Healey, 1998).

No matter what kind of aim is taken into account, the indication of the homogeneous markets constitutes one of the key problems that have a significant impact on the accuracy of the achieved appraisal results (Chen et al., 2023; Cellmer et al., 2011; Manganelli et al., 2014; Morano & Manganelli, 2014; Rae, 2015; Renigier-Bilozor et al., 2019; Wu et al., 2012; Wu et al., 2020). Incorrect delineation of elementary zones can have significant implications. If too few zones are established, resulting in overly large areas, real properties with distinctly different market appeal and other characteristics may be grouped together. This can lead to substantial errors in appraisal outcomes. Conversely, creating an excessive number of elementary zones, meaning zones of relatively small size, may not compromise accuracy but could unnecessarily extend the appraisal process and increase costs (Su et al., 2024; Gnat, 2019). Existing research, responding to the ongoing discussion on methodological communication between individual disciplinary matrices (functional paradigm vs interpretative paradigm) of social sciences (Mazurek-Łopacińska & Sobocińska, 2018; Nadolna, 2012), emphasizes the importance of integrating advanced spatial analysis methods with real estate valuation to address these challenges. For that reason, application of quantitative spatial analysis, ought to aim at capturing the composition and configuration of property market activities and on this basis, support evidence-based comparisons between different areas and possible correlations with non-spatial dynamics.

Many researchers concentrate on the potential of hedonic modeling in market analysis, highlighting the critical role of identifying similarities among analyzed entities, whether individual properties or entire markets. Understanding the random and dynamically evolving nature of relationships within the real estate market is crucial. Technological advancements offer promising opportunities for tackling complex challenges, encouraging researchers to seek alternative approaches. For example, Gnat introduces modified entropy measures for assessing area homogeneity based on specific property characteristics and employs the XGBoost algorithm for mass valuation (Gnat, 2019). Similarly, (Heckman et al., 2008) investigates non-linear causality using multivariable fractional polynomials (MFPs) to identify homogeneous markets. Chen proposed spatial clustering conducted using global spatial autocorrelation analysis alongside the local spatial correlation analysis tool, i.e., the Local Indicator of Spatial Association (LISA), to gain a better understanding of the spatial homogeneity of average annual housing prices - AAHP (Chen et al., 2020). Cellmer and Kuryj utilized spatial interpolation through kriging methods to prepare land value maps and estimate the values of individual undeveloped properties (Cellmer et al., 2011). They applied cluster analysis, incorporating location criteria, to define the boundaries of zoning ranges. (Giudice et al., 2017) explored the relationship between rental prices and geographic location using genetic algorithms (GA). (Eremeev et al., 2017) examined the spatial relationships of objects on the map using two algorithms: the simplex search algorithm and the hole search algorithm, aiming to identify homogeneous land areas. Additionally, (Manganelli et al., 2014) and (Massimo et al., 2019) applied geographically weighted regression (GWR) in housing market analyses to identify homogeneous zones and quantify the marginal impact of specific locations (defined by these areas) on property market values.

In real estate, homogeneity refers to areas or sub-markets characterized by consistent unit features. This uniformity is essential for performing objective and precise property analyses. The concept is inherently tied to the goals of property market analysis for valuation, as a homogeneous area ensures that external factors affecting property values remain uniform across units. This uniformity mitigates potential inaccuracies that might arise when analyzing properties in diverse areas. Consequently, various methodological approaches are employed to achieve this, including integrated clustering regression (Alenany et al., 2021), equilibrium models (Watkins, 2001), hedonic models (Watkins, 1999), and principal component analysis combined with cluster analysis

(Keskin & Watkins, 2017). Renigier-Biłozor et al. introduced the concept of indistinguishable objects in the real estate market, forming the basis for an HO-MAR algorithm that integrates geoprocessing and geo-analysis to classify object homogeneity (Renigier-Biłozor et al., 2022). The development for the presented algorithm and an attempt to minimize distortion from spatial interactions and urban environmental factors was the methodology for homogenous area determination (HAD). This modified algorithm focuses on identifying uniform geo-market areas (Walacik & Janowski, 2024).

Although the above presented literature review is not intended to be an exhaustive account of all contributions, it nonetheless offers an overview of the solutions either proposed or utilized in state of the art in real estate market classification/delineation, and even though the proposed HAD methodology has already been applied in a variety of research, it still, in the author's opinion, requires particular amendment to bring the evidence-based verification of the methodology derived results to an acceptable level. For that reason the following hypothesis was formulated:

HYPOTHESIS 1: Utilizing morphological tessellation in property market reality via the HAD methodology, improve the identification of homogenous market areas and enhance market derived evidence-based verification.

Verification of the hypothesis enables providing an answer for the central research question guiding this study: whether the application of the advanced spatial techniques will result in a more objective, transparent, and verifiable process for determining property market areas, thereby improving the accuracy of property valuations in diverse and evolving market conditions. The remaining part of the paper has been structured as follows:

– Chapter 3 describes the concept of morphological tessellation and its possibility of application on the real estate market;
– chapter 4 proceeds with the utilization of the method in the case study area;
– chapter 5 presents and discusses the findings of the analysis, some advantages and limitations of the proposed solution and final conclusions.

3. Morphological tessellation - concept that could be tailored for property valuation

Morphological tessellation refers to the process of dividing a space into non-overlapping, adjacent regions, or "cells," that cover the entire domain, based on certain criteria such as proximity, density, or other spatial characteristics. This concept, which has its roots in spatial partitioning methods, including the well-known Voronoi tessellation, is a critical tool in numerous fields such as geography, biology, urban planning, and physics. Morphological tessellation enables the analysis of spatial structures and patterns, providing insights into the interactions and relationships between elements within a given space (Okabe et al., 2000).

At its core, morphological tessellation extends the basic principles of Voronoi diagrams, which partition space into regions where each point within a region is closest to a designated "seed" point or generator. These diagrams have been widely used in various disciplines to model proximity-based phenomena. The concept of morphological tessellation enhances this by considering not only proximity but also other spatial attributes such as shape, density, and distribution. This makes it particularly useful for complex environments where spatial interactions cannot be adequately captured by simple Euclidean distance-based tessellation (Sugihara & Inagaki, 1995).

In applications where morphological attributes are critical, the tessellation process considers the morphology of the objects themselves.

In geography and urban planning, morphological tessellation is used to study spatial organization, such as the distribution of urban infrastructure or the arrangement of natural features. A key advantage of morphological tessellation in this context is its ability to account for the organic growth and development of cities, where administrative boundaries often fail to reflect actual spatial interactions. By using tessellation based on morphological features, planners can delineate areas that are functionally or spatially cohesive, helping to optimize resource allocation, transportation networks, and urban services (Fleischmann et al., 2020).

While morphological tessellation has shown great potential in urban studies and geographic analysis, its specific application to property valuation remains underexplored. That justifies an attempt of verifying its usability via HAD methodology implementation called HAD^2 (HAD2).

Morphological tessellation refines traditional urban planning (Pelorosso, 2020; Pozoukidou & Chatziyiannaki, 2021) and property valuation by using spatial homogeneity to delineate market areas, challenging subjective methods reliant on arbitrary boundaries (Wisniewski and Brzezicka, 2021). This approach aligns with spatial pattern theories, promoting a data-driven, objective comparison of properties based on proximity, density, and configuration (Bruna, 2024; Cellmer et al., 2024). The implications suggest a shift towards evidence-based practices in real estate, enhancing valuation accuracy.

3.1 Morphological perception of property markets by their participants

Whenever noting real estates, regardless of the perspective (eye view/satellite view/streetview), the eye of real estate market participants extracts the existence of fundamental relationships between properties: the plot pattern (reflected by e.g. fences), spatial configuration of buildings (Grzelka et al., 2023; Ying et al., 2022; Zhen et al., 2020) or land use geometry likewise in decomposing urban fabric (Araldi & Fusco, 2017). For that reason, as underlined by Fleischmann et al., this "intuitive relationship makes Voronoi tessellation-based approaches sensible in spatial analysis" (Fleischmann et al., 2020); unfortunately, this is not the case when property valuation - legal based consideration are concerned.

It seems indisputable that the line separating a homogeneous market area that intersects a similar property that is one of the elements of the analysis (Fig. 1a) or the building in which the residential flats are located (Fig. 1b) may leave many doubts as to whether the results of the analysis are correct and properly imitate the behavior of market participants.

a) b)

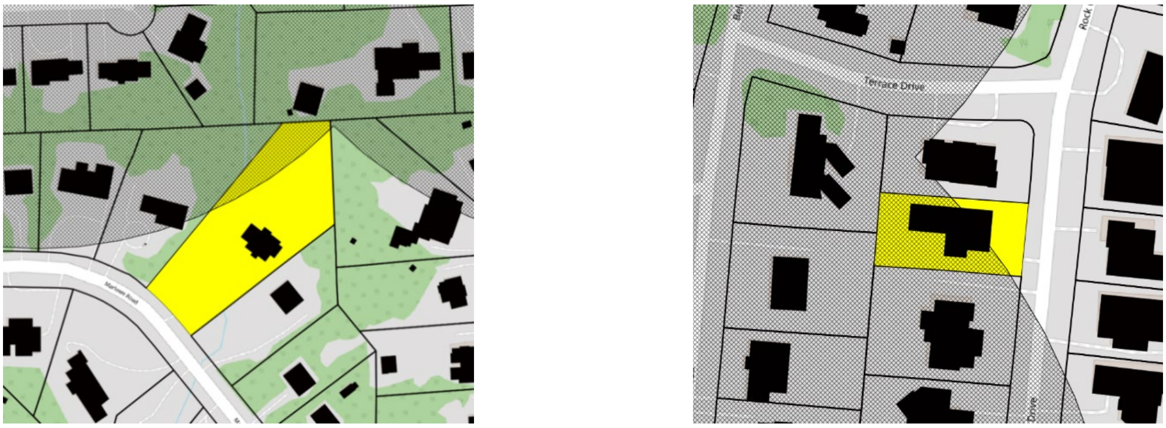

Fig 1. Examples of methodological pitfalls questioning proper imitation of market participants morphological perception: lack of plot area consistency (a), lack of building feature uniformity (b). *Source*: own study.

From that standpoint and conclusions drawn from the author's previous studies within the scientific problem of real estate market delineation, the research indicated the need of defining a structured pattern or procedure tailored for the purpose of property valuation. The aforementioned consideration justifies the attempt of verifying modified morphometric tessellation for the purposes of property valuation. From this perspective, the established solution, was called property market tessellation (PMT) for the purposes of semantic clarification and defined as an *objectively and universally applicable method that derives a spatial unit named property marketmetric-cell (PMMC) from widely available data on the property footprint and tests its informational value in capturing property-scale spatial patterns of the property market.*

The procedural conceptualization for the purpose of PMT utilization within the original HAD^2 methodology implementation was presented in Fig 2. The following chapters describe utilization of HAD^2 methodology.

4. HAD^2 methodology utilization

The initial stage of HAD^2 methodology utilization included the selection of input data within a HAD methodology extracted spatially consistent unit for the purposes of property footprint derivation.

4.1 Property footprint derivation

The property footprint derivation required case study area selection.

4.1.1 Case study area

The initial stage of PMT required property footprint derivation within a locationally consistent area determined with HAD methodology. For that reason, the administrative boundaries of a particular municipality were selected - the Raleigh City, North Carolina, USA - Fig. 3.

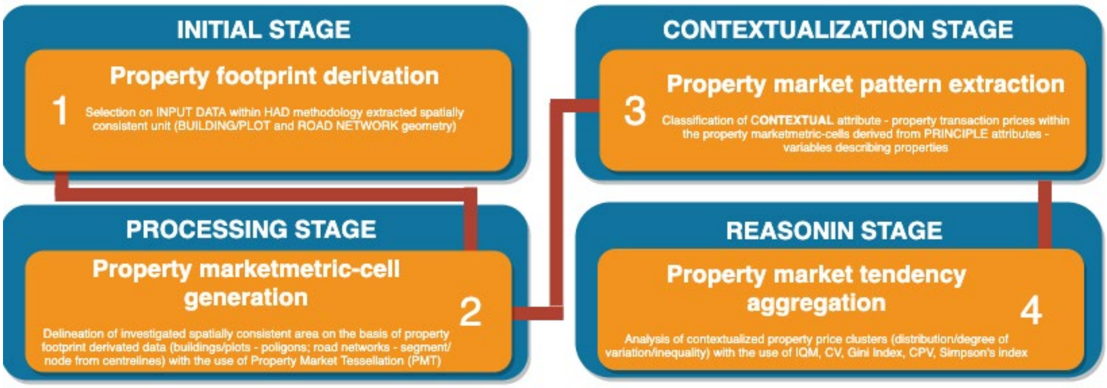

Fig. 2. Procedural conceptualization of HAD^2 methodology implementation. *Source*: own study.

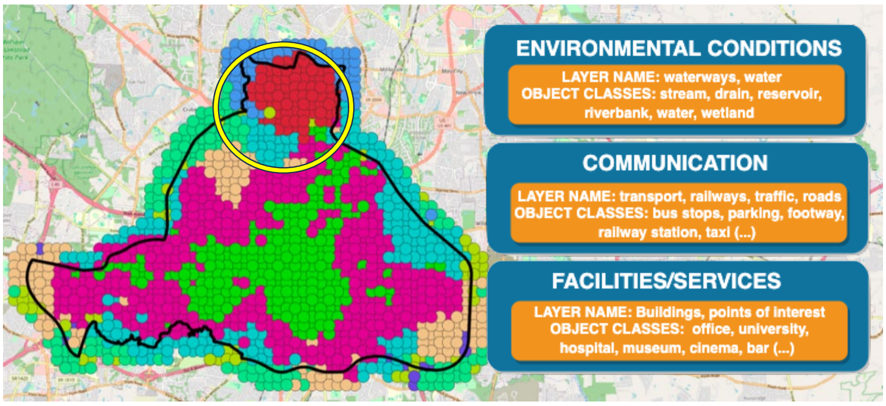

Fig. 3. Selected locationally consistent area (Raleigh City, North Carolina, USA) and the OSM derived factors that were used to extract spatial consistency. *Source*: own study.

The justification for the selection of Raleigh City resulted both from its' particular attributes (e.g. geographical diversity, population dynamics, economic viability, representative urban fabric) and the unique opportunity provided by the author's academic affiliation and participation in an internship at the University of North Carolina. This affiliation granted the author access to vital local data, administrative support, and substantial collaborative opportunities, greatly enriching the research. Raleigh was chosen not merely for its geographic and economic attributes but also due to the logistical practicality and the local government's cooperative stance, particularly evident in interactions with the Wake County Government Tax Office, facilitating a thorough examination of the proposed methodology. The level of spatial consistency was measured with the variables presented in Fig. 4 and was decreased by 73% in the selected area, in reference to the whole area of Raleigh City.

4.1.2 Data acquisition and database creation

The delineation of a spatially consistent case study area indicated the scope of data originated from public registers for real estate transactions which, according to the database structural assumptions, was based on the (qualitative/quantitative) encoding of variables. Having reached locational consistency and property transactions, georeferencing exclusion of variables describing location (e.g. street type) had to be adopted. The lack of differentiation in the "heating" attribute and gaps in data provision in the floor finish/interior finish attribute also resulted in variable exclusion. In the study, the principles of a naive variable inclusion approach were adopted, where all variables were treated quantitatively without considering their qualitative context or real-world implications.

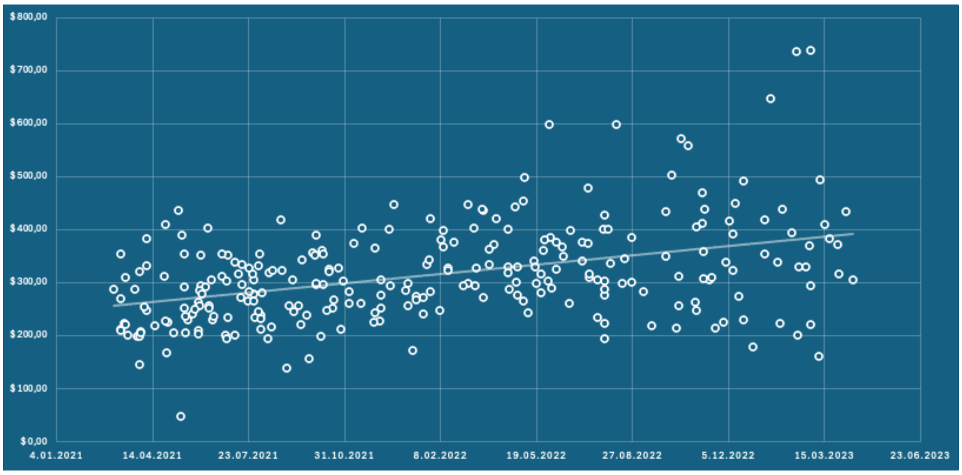

Fig. 4. Analysis of time adjustment index within the analyzed area and timeframe. *Source*: own study.

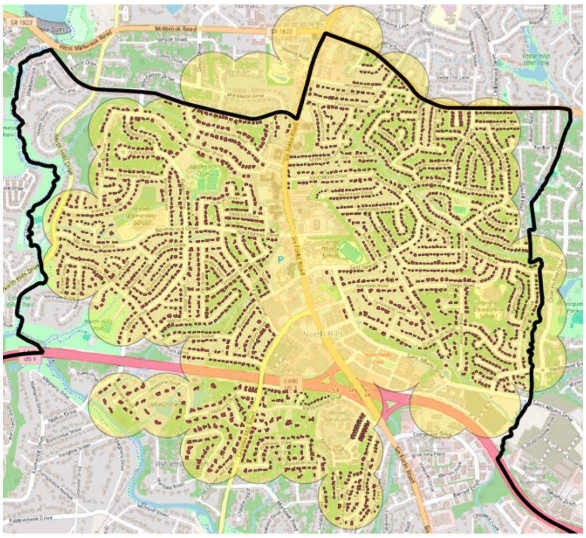

Fig. 5. Property footprint indication INPUT DATA - OSM derived building shape (brown polygons). *Source*: own study.

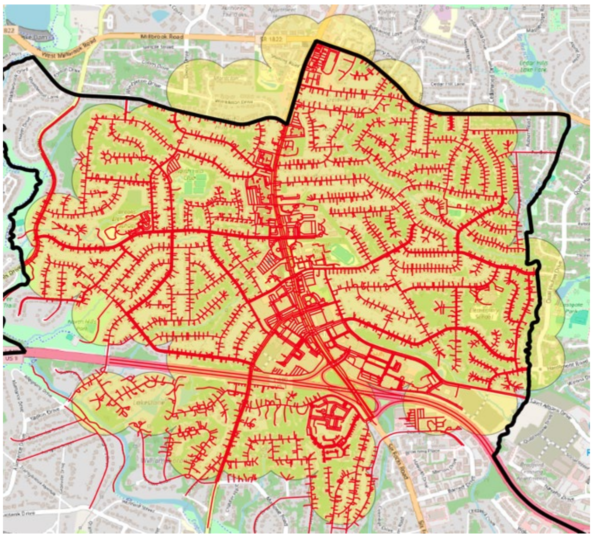

Fig. 6. Property footprint indication INPUT DATA - OSM derived road network (red lines). *Source*: own study.

This approach was chosen to maintain consistency across the dataset and ensure that the analysis remained purely data-driven, without introducing subjective adjustments. Additionally, in order to obtain temporal consistency, the transaction prices were updated with the use of time adjustment index determined with linear regression analysis. According to the analysis, the property prices within the analyzed timeframe (5.2021-12.2022) were rising 22.3% per year[1].

Having acquired both locational and temporal consistency, a particular spatial element had to be selected for the purpose of property marketmetric-cell generation. Even though public registers in the case study area include data describing a property plot, which are most preferable elements from the perspective of evidence-based results comparison, the author decided to use residential building shape (Fig. 5). The methodological universal applicability was the reason for that. Regardless of the scope of data given in diverse property registers in different countries, the building shape can always be acquired from open street map sources. The second indispensable spatial element necessary for

[1] The empirical value of the t-Student statistic (empirical) is 7.498, which is greater than the theoretical value of the t-Student statistic (theoretical, alpha, n-2) at 1.444. The probability of accepting the occurrence of a false trend resulting from a random arrangement of data is approximately 0% and is lower than the assumed significance level of 0.15. This means that at the assumed significance level of 0.15, the statistical significance of a trend can be affirmed. The relative dimension of the trend (%)/year is approximately 22.3% and can be described as slightly increasing. The confidence interval for the calculated trend, at the assumed significance level of 0.15, is approximately ±4.3%. This means that, with a probability of 0.85, the actual value of the trend ranges from 18%/year to 26.6%/year

marketmetric-cell generation – a road network - was acquired from OSM (Fig.6).

4.2. Property marketmetric-cell generation

Derivation of spatial units named PMMC from widely available data on a property footprint was executed with the use of following open-source Pythos toolkits: momepy (Fleischmann, 2019), PySAL (Rey & Anselin, 2010), Geopandas (Jordahl et al., 2019) and, amongst others, QGIS software. The unitization was executed according to the following five steps, described in detail by Fleischman (Fleischmann et al., 2020) :

1. Inward offset from property footprint,
2. Discretization of polygon's boundaries into points,
3. Generation of Voronoi cells,
4. Dissolution of Voronoi cells,
5. Clip of preliminary tessellation.

The generated marketmetric-cells were presented in Fig. 7.

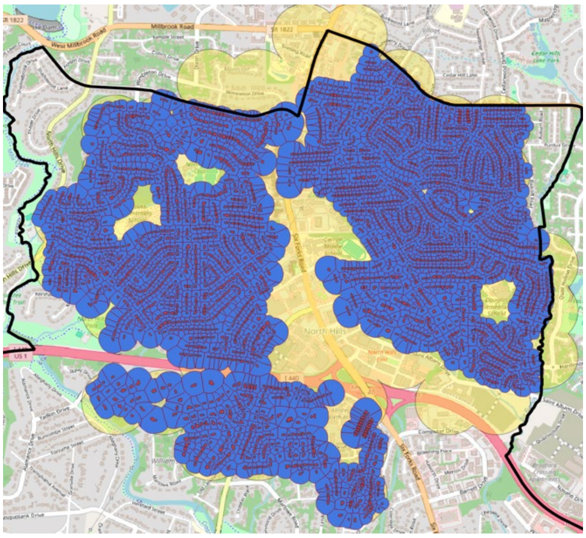

Fig. 7. Property marketmetric-cells generated in the case study area.` *Source*: own study.

Fig. 8. Property Examples of methodological adequacy of market participants' morphological perception imitation. *Source*: own study.

What the author wanted to highlight in reference to the imitation of market participants morphological perception, and methodological pitfalls of HAD methodology within that scope (Fig. 1), is that property marketmetric-cells perform much higher comparability to particular properties (Fig. 8) with complete elimination of lack of building features uniformity. The indicated adequacy is crucial from the perspective of evidence-based verification of methodology results, so important in case of transparency and equity principle. Generation of property marketmetric-cells enabled property market pattern extraction.

4.3. Property market pattern extraction

Property market pattern extraction was based on property describing contextual (dependent) variable – comparable property transaction prices, that is determined by principle (independent) property characters, with spatial reference to generated property marketmetric-cells. Property transaction prices are a fundamental metric in real estate market analysis, providing a direct reflection of market dynamics and valuations. They represent the actual amounts agreed upon by buyers and sellers, encapsulating a variety of economic factors including supply and demand dynamics, consumer confidence, and purchasing power. Therefore, using transaction prices as a basis for extracting market patterns ensures that the analysis is grounded in real-world financial exchanges, rather than hypothetical or estimated values.

Market-based patterns of primary property characteristics were presented in Fig. 9, while property contextual ones in Fig. 10. Following rules by (Sokal, 1963) to minimize potential collinearity and limit redundancy of information, while retaining the universality of the method, contextualization of the property market pattern was performed with the Jenks natural breaks classification, which is a data clustering method used in statistical analysis to determine the best arrangement of values into different classes. This method seeks to minimize the variance within classes and maximize the variance between classes. Based on the number of property transactions, the assumed number of clusters equaled 3. Property market pattern extraction enables property market pattern aggregation – the last stage of the proposed HAD methodology improvement.

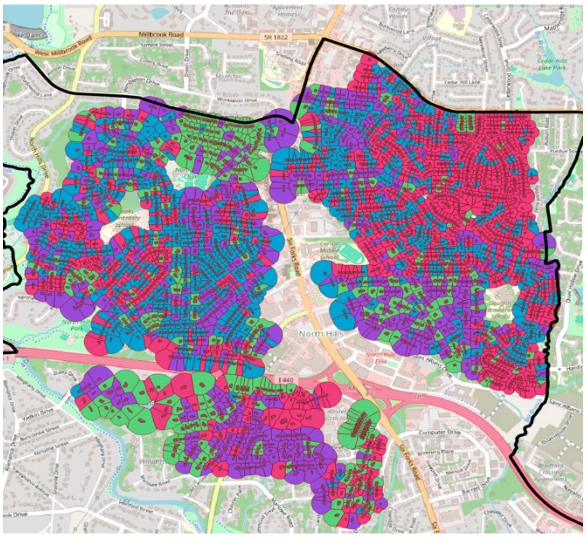

Fig. 9. Property primary characteristics market-based pattern (4 groups). *Source*: own study.

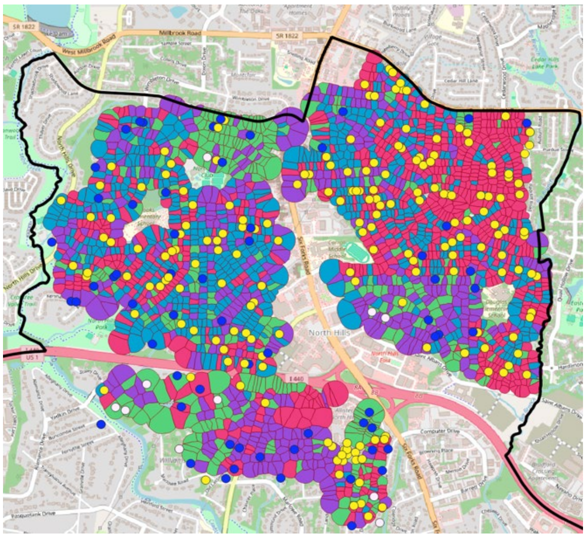

Fig.10. Property contextual characteristics market-based pattern (3 groups in each 4 property primary characteristics market-based patterns). *Source*: own study.

4.4 Property market tendency aggregation

Property market tendency aggregation based on a set of selected statistical measures was applied to evaluate individual property price clusters, enabling a comprehensive analysis of price distribution, their degree of variation, and inequality. The measures used – Interquartile Mean (IQM), Coefficient of Variation (CV), Gini Index, CPV (Coefficient of Price Variation), and Simpson's Index – were chosen due to their ability to identify key features of the transaction price distribution, allowing for a deeper understanding of the data structure within each cluster.

The Interquartile Mean (IQM) was employed as a measure of central tendency, due to its resistance to outliers, which are often present in property price datasets. Unlike the arithmetic mean, which is sensitive to extreme values, IQM considers only the middle 50% of observations, defined by the range between the first quartile (Q1) and the third quartile (Q3). This approach provides a more representative picture of the average price level within a given cluster, particularly when there is significant price variability.

$$\mathrm{IQM} = \frac{\sum_i^n x_i \text{ for } x_i \in [Q1,Q3]}{n_{[Q1,Q3]}} \qquad (1)$$

where Q1 and Q3 are the first and third quartiles, respectively; $n_{[Q1,Q3]}$ - number of observations between Q1 and Q3.

The Coefficient of Variation (CV) and its variant CPV (specific to property price analysis) allow for assessing the level of price variability relative to the mean. Expressed as a percentage, CV enables the comparison of data dispersion between clusters, regardless of the absolute price level. A high CV or CPV value indicates significant price dispersion.

$$\mathrm{CV} = \left(\frac{\sigma}{\bar{x}}\right) \cdot 100\% \qquad (2)$$

where σ is the standard deviation and $\bar{x}$ is the arithmetic mean of prices in the cluster.

The Simpson's Index (SDI) was introduced to assess the diversity of the price distribution, enabling the estimation of the probability that two randomly selected properties will belong to different price intervals.

$$\mathrm{SDI} = 1 - \frac{\sum_{i=1}^{R} n_i(n_i - 1)}{N(N-1)} \qquad (3)$$

where R - number of price ranges; number of properties in the i-th interval; N - total number of properties. Implementation of all the HAD[2] procedural steps provided the following results being the subject of further discussion.

4.5 Property market tendency verification

The determination of all the aforementioned measures allowed a multidimensional evaluation of price structures within individual clusters. The results were presented in the Table 1. The Interquartile Mean (IQM) provided insight into the central tendency of prices while eliminating the influence of outliers. The Coefficient of Variation (CV) enabled the assessment of price variation relative to the mean, while Simpson's Index evaluated price diversity. Their complementary use allowed for a more comprehensive understanding of the dynamics and structure of property prices in the examined clusters, which is of significant importance in real estate market analyses.

Market-based pattern O: The highest probability of occurrence is presented by Price Cluster 2, which includes as many as 30 observations, representing the dominant majority of the available data. A high SDI and low CV indicate its stability and homogeneity relative to the other clusters. Price Cluster 1 represents the segment of properties with lower price values. A high CV indicates significant price variability within this group. Price Cluster 3 represents luxury properties with the highest average values. Its lower SDI and moderate variability suggest that this segment is less cohesive and occurs less frequently in the analyzed area.

Table 1

Property market aggregation measures

	Market-based pattern O	Market-based pattern 1	Market-based pattern 2	Market-based pattern 3
Price Cluster 1				
IQM	930 667	616 067	502 880	478 176
CV	21.00%	23.28%	16.26%	20.55%
SDI	0.917	0.966	0.965	0.953
Price Cluster 2				
IQM	1 518 179	1 096 000	754 778	718 800
CV	12.88%	23.60%	13.18%	12.62%
SDI	0.962	0.889	0.960	0.966
Price Cluster 3				
IQM	2 848 750	/*	1 525 667	1 375 000
CV	15.34%	18.39%	11.71%	9.59%
SDI	0.875	0.500	0.800	0.667

/* Interquartile Mean (IQM): No data (due to an insufficient number of values in the interquartile range)

Source: own study.

Market-based pattern 1: Price Cluster 1 is characterized by the highest probability of occurrence in the analyzed area and the lowest average prices. The high coefficient of variation suggests greater price variability. Price Cluster 2, despite its moderate price level, shows a lower probability of occurrence and the greatest price variability. This may indicate limited availability of properties with mid-range price values in the given area. Price Cluster 3 represents a segment of properties characterized by the lowest probability of occurrence and relatively stable prices. The high value of properties in this group and their low frequency suggests a limited market.

Market-based pattern 2: Price Cluster 1 has the highest probability of occurrence in this area because it includes the largest number of properties, characterized by relatively low-price variability and high cohesiveness. Price Cluster 2 is also a significant price cluster, featuring moderate prices and fairly stable values. Price Cluster 3, although encompassing higher property prices, has a smaller concentration of data, which may suggest a lower probability of occurrence for properties in this cluster within the analyzed area.

Market-based pattern 3: The real estate market in the studied area is characterized by the predominance of lower-value properties (Cluster 1), which may be related to local demand and the availability of affordable properties. The stability and homogeneity of clusters increase with price (Cluster 3). High prices may indicate premium properties with a uniform standard. Price variability is the highest in Cluster 1 and decreases as prices increase, suggesting that higher price segments are more predictable.

The analysis indicates that lower and mid-price segments are more susceptible to price fluctuations, which may create both risks and opportunities for investors. In contrast, the high stability and predictability of luxury property prices suggest that this segment may be preferred by investors seeking safe and stable assets. The price structure of real estate in the analyzed area shows a hierarchy of stability and cohesiveness, which increases with property values. The results of the analysis provide a basis for further research into the factors influencing differences in real estate price structures and their variability in the context of local market and socio-economic conditions.

5. Conclusions

The following research composes a study crowning several years of scientific work, initiated in 2018 with a study originally devoted to the considerable procedural problems of property forced sale value determination, which pointed out a substantial gap in property valuation theory connected with "the methodology for determining comparable real estate markets and an accurate selection of sales" (Renigier-Biłozor et al., 2018). The study, setting the objective and direction for further research, additionally indicated the need of in-depth investigation of relationships between uncommon phenomena occurence on real estate market and the corresponding transaction prices. For that reason, subsequent studies progressively explored various dimensions of real estate market analysis, employing advanced methodologies aiming at subjectivity and uncertainty decrease. The research conducted in 2019 introduced an original methodology of utilizing geoscientific methods integrated with fuzzy logic to address the subjective elements of property market analysis. This approach aimed to create a more objective and precise valuation model by incorporating spatial decision factors and geoprocessing activities, thus facilitating better decision-making processes in real estate investments (Renigier-Bilozor et al., 2019). Building on this foundation, a 2020 study emphasized the importance of sustainability and highest and best use (HBU) analysis in determining property value, especially under varying market conditions. This study underlined the critical role of aligning property valuation practices with sustainable development goals, thereby addressing both the economic and environmental aspects of property use (Walacik et al., 2020). Further research in 2022 and 2024 addressed modern challenges in the real estate market, particularly focusing on the human aspect of valuation and the evolving expectations of property market participants and real estate market asymmetry. The studies highlighted the dynamic nature of real estate markets and the need for adaptive valuation methods that consider not only traditional economic factors but also socio-behavioral aspects (Renigier-Biłozor et al., 2022), with "reference to the methodological transparency and possibility of the results substantial verification" (Walacik, 2024). The culmination of these studies is the present research, which synthesize these diverse approaches and provide a comprehensive framework for property valuation substantive and methodological support that accounts for the complexities and nuances of modern real estate markets. The study integrates geoscientific methods, sustainability considerations, and socio-behavioral factors into a consistent methodology for property market analysis, addressing the multidimensional challenges identified throughout the six-year research journey, and aims to answer the question of whether the aim of homogenous area methodology provision has been achieved by providing a fully operational and replicable solution.

To increase the theoretical foundation of morphological tessellation in further studies, it is valuable to integrate perspectives from urban sociology, economics, and environmental studies. Urban sociology can interpret the mutual influences between social structures and spatial configurations, enriching the comprehension of how tessellation mirrors community organization and social dynamics. From an economic standpoint, theories pertaining to land use and property valuation can shed light on the financial consequences of spatial patterns, thus providing a framework for appraising economic efficiency and market behaviors in tessellated areas. Environmental studies contribute insights into various consequences of urban planning, stressing the importance of sustainable development and conservation measures. Collectively, these interdisciplinary perspectives significantly fortify the theoretical framework, thereby enhancing the extent and practical relevance of morphological tessellation in diverse urban contexts. Considering the above future research could also explore morphological tessellation in contexts characterized by rapid urban expansion, gentrification, or significant socio-economic disparities. These settings present unique challenges where tessellation could offer novel insights into spatial equity, economic viability, and environmental sustainability.

Despite rigorous methodologies and the innovative use of spatial analysis tools, the study is not without potential sources of error or bias. One source of bias may stem from the initial selection and classification of spatially consistent areas, which inherently involves judgments about what constitutes homogeneity in locational characteristics. The reliance on the spatial utilization of a Voronoi tessellation - based solution introduces another layer of complexity and potential bias. These models depend heavily on the underlying assumptions about spatial relationships and data distribution, which may not accurately reflect the non-spatial dynamics of the real estate market. Furthermore, the data collection process, primarily reliant on public registers and open-source platforms, could suffer from incompleteness or inaccuracies in reported transactions. Such limitations in data quality and availability could skew the analysis, leading to under or overestimation of property values in certain areas. Acknowledging these potential biases is crucial for interpreting the results. For this reason, it is crucial that the substantive verification of the obtained results (both partial and final) is carried out by real estate market specialists - property valuers who have specialist market knowledge, or in the case of using the methodology in automatic valuation, it is carried out in accordance with the principle of AVM Assistance.

Funding Sources

The publication was written as a result of the author's internship in the School of Government at the University of North Carolina, USA, co-financed by the European Union under the European Social Fund (Operational Program Knowledge Education Development), carried out in the project Development Program at the University of Warmia and Mazury in Olsztyn (POWR.03.05. 00-00-Z310/17). This work was also supported by the IAAO Research Grant.

References

Alenany, E., Lekham, L. A., & Lu, S. (2021). Integrated clustering regression for real estate valuation. Real Estate Finance. Aspen Publishers Inc.

Araldi, A., & Fusco, G. (2017). Decomposing and recomposing urban fabric: The city from the pedestrian point of view. In Computational Science and Its Applications–ICCSA 2017: 17th International Conference, Trieste, Italy, July 3-6, 2017 [Springer International Publishing]. *Proceedings, 17*(Part IV), 365–376.

Bogin, A. N., & Shui, J. (2020). Appraisal accuracy and automated valuation models in rural areas. *The Journal of Real Estate Finance and Economics, 60*(1-2), 40–52. https://doi.org/10.1007/s11146-019-09712-0.

Boots, B., Okabe, A., & Sugihara, K. (1999). Spatial tessellations. *Geographical information systems, 1*, 503-526.

Bruna, F. (2024). Market potential, spatial theories and spatial trends. *Spatial Economic Analysis, 19(4)*, 1527–548. https://doi.org/10.1080/17421772.2024.2325517, https://doi.org/10.1080/17421772.2024.2339022

Cellmer, R., & Kuryj, J. (2011). Określanie stref o podobnej cenności gruntów z wykorzystaniem metod geostatystycznych. *Studia i Materiały Towarzystwa Naukowego Nieruchomości, 19*(3), 7–19.

Cellmer, R., Bełej, M., & Trojanek, R. (2024). Housing prices and points of interest in three Polish cities. *Journal of Housing and the Built Environment, 39*, 1509–1540. https://doi.org/10.1007/s10901-024-10124-7

Chen, M., Chun, Y., & Griffith, D. A. (2023). Delineating housing submarkets using space–time house sales data: Spatially constrained data-driven approaches. *Journal of Risk and Financial Management, 16*(6), 291. https://doi.org/10.3390/jrfm16060291

Chen, S., Sleipness, O., Xu, Y., Park, K., & Christensen, K. (2020). A systematic review of alternative protocols for evaluating non-spatial dimensions of urban parks. *Urban Forestry & Urban Greening, 53*, 126718. https://doi.org/10.1016/j.ufug.2020.126718

Cienciała, A., Sajnóg, N., & Sobolewska-Mikulska, K. (2023). Unreliability of cadastral data on parcel area and its effect on sustainable real estate valuation. *Reports on Geodesy and Geoinformatics, 116*(1), 39–46. https://doi.org/10.2478/rgg-2023-0009

Del Giudice, V., De Paola, P., & Forte, F. (2017). Using genetic algorithms for real estate appraisals. *Buildings, 7*(2), 31. https://doi.org/10.3390/buildings7020031

Eremeev, S. V., Kuptsov, K. V., & Seltsova, E. A. (2017). Algorithm for selecting homogeneous regions from a set of spatial objects. In 2017 *XX IEEE International Conference on Soft Computing and Measurements (SCM)* (pp. 109-112). IEEE https://doi.org/10.1109/SCM.2017.7970511

Fleischmann, M. (2019). Momepy: Urban morphology measuring toolkit. *Journal of Open Source Software, 4*(43), 1807. https://doi.org/10.21105/joss.01807

Fleischmann, M., Feliciotti, A., Romice, O., & Porta, S. (2020). Morphological tessellation as a way of partitioning space: Improving consistency in urban morphology at the plot scale. *Computers, Environment and Urban Systems, 80*, 101441. https://doi.org/10.1016/j.compenvurbsys.2019.101441

Glennon, D., Kiefer, H., & Mayock, T. (2018). Measurement error in residential property valuation: An application of forecast combination. *Journal of Housing Economics, 41*, 1–29. https://doi.org/10.1016/j.jhe.2018.02.002

Gnat, S. (2019). Measurement of entropy in the assessment of homogeneity of areas valued with the Szczecin Algorithm of Real Estate Mass Appraisal. *Journal of Economics and Management, 38*(4), 89–106. https://doi.org/10.22367/jem.2019.38.05

Grzelka, K., Bieda, A., Bydłosz, J., & Kondak, A. (2023). Visual perception of property rights in 3D. *ISPRS International Journal of Geo-Information, 12*(4), 164. https://doi.org/10.3390/ijgi12040164

Hamelink, F., Hoesli, M., Lizieri, C., & MacGregor, B. D. (2000). Homogeneous commercial property market groupings and portfolio construction in the United Kingdom. *Environment & Planning A, 32*(2), 323–344. https://doi.org/10.1068/a31146

Healey, P. (1998). Building institutional capacity through collaborative approaches to urban planning. *Environment & Planning A, 30*(9), 1531–1546. https://doi.org/10.1068/a301531

Heckman, J. J. (2008). Econometric causality. *International Statistical Review, 76*(1), 1–27. https://doi.org/10.1111/j.1751-5823.2007.00024.x

IAAO. (2017). *Standard of Mass Appraisal of Real Property*. International Association of Assessing Officers.

Jordahl, K., Van den Bossche, J., Wasserman, J., McBride, J., Gerard, J., Tratner, J., . . . Farmer, C. (2021). *Geopandas/Geopandas: v0. 5.0*. Zenodo.

Keskin, B., & Watkins, C. (2017). Defining spatial housing submarkets: Exploring the case for expert delineated boundaries. *Urban Studies (Edinburgh, Scotland), 54*(6), 1446–1462. https://doi.org/10.1177/0042098015620351

Kindström, D., Makkonen, H., & Kaartemo, V. (2023). Delineating the fuzzy front end of market shaping. *Industrial Marketing Management, 112*, 51–59. https://doi.org/10.1016/j.indmarman.2023.05.004

Manganelli, B., Pontrandolfi, P., Azzato, A., & Murgante, B. (2014). Using geographically weighted regression for housing market segmentation. *International Journal of Business Intelligence and Data Mining, 9*(2), 161-177. https://doi.org/10.1504/IJBIDM.2014.065100

Massimo, D.E., Del Giudice, V., De Paola, P., Forte, F., Musolino, M., Malerba, A. (2019). Geographically weighted regression for the post carbon city and real estate market analysis: A case study. In: Calabrò, F., Della Spina, L., Bevilacqua, C. (eds) New Metropolitan Perspectives. ISHT 2018. *Smart Innovation, Systems and Technologies, vol 100*. Springer, Cham. https://doi.org/10.1007/978-3-319-92099-3_17

Mazurek-Łopacińska, K., & Sobocińska, M. (2018). *Triangulacja w badaniach jakościowych*. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, (525). https://doi.org/10.15611/pn.2018.525.01

McCluskey, W. J., & Borst, R. A. (2017). The Theory and practice of comparable selection in real estate valuation. Studies in systems. *Decision and Control, 86*, 307–330.

Meszek, W. (2013). Property valuation under uncertainty. Simulation vs strategic model. *International Journal of Strategic Property Management, 17*(1), 79–92. https://doi.org/10.3846/1648715X.2013.782165

Morano, P., & Manganelli, B. (2014). Estimating the market value of the building sites for homogeneous areas. *Advanced Materials Research, 869*, 14–19.

Nadolna, B. (2012). Paradygmaty badawcze nauk społecznych a triangulacja metod badawczych w rachunkowości zarządczej. *Zeszyty Teoretyczne Rachunkowości, 66*, 153–164.

Pagourtzi, E., Assimakopoulos, V., Hatzichristos, T., & French, N. (2003). Real estate appraisal: A review of valuation methods. *Journal of Property Investment & Finance, 21*(4), 383–401. https://doi.org/10.1108/14635780310483656

Pelorosso, R. (2020). Modeling and urban planning: A systematic review of performance-based approaches. *Sustainable Cities and Society, 52*, 101867. https://doi.org/10.1016/j.scs.2019.101867

Pozoukidou, G., & Chatziyiannaki, Z. (2021). 15-Minute City: Decomposing the new urban planning eutopia. *Sustainability (Basel), 13*(2), 928. https://doi.org/10.3390/su13020928

Rae, A. (2015). Online housing search and the geography of submarkets. *Housing Studies, 30*(3), 453–472. https://doi.org/10.1080/02673037.2014.974142

Renigier-Bilozor, M., Janowski, A., & Walacik, M. (2019). Geoscience methods in real estate market analyses subjectivity decrease. *Geosciences, 9*(3), 130. https://doi.org/10.3390/geosciences9030130

Renigier-Biłozor, M., Janowski, A., Walacik, M., & Chmielewska, A. (2022). Modern challenges of property market analysis-homogeneous areas determination. *Land Use Policy, 119*, 106209. https://doi.org/10.1016/j.landusepol.2022.106209

Renigier-Biłozor, M., Walacik, M., Źróbek, S., & d'Amato, M. (2018). Forced sale discount on property market–How to assess it? *Land Use Policy, 78*, 104–115. https://doi.org/10.1016/j.landusepol.2018.06.026

Rey, S. J., & Anselin, L. (2009). PySAL: A Python library of spatial analytical methods. In *Handbook of applied spatial analysis: Software tools, methods and applications* (pp. 175-193). Berlin, Heidelberg: Springer Berlin Heidelberg. 11

RICS. (2021). *Valuation - Global Standards*. RICS. https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/valuation-standards/red-book/red-book-global

Sokal, R. R. (1963). The principles and practice of numerical taxonomy. *Taxon, 12*, 190–199. https://doi.org/10.2307/1217562

Su, T., Dharmasena, S., Leatham, D., & Gilliland, C. (2024). Texas rural land market integration: A causal analysis using machine learning applications. *Machine Learning with Applications, 18*, 100604. https://doi.org/10.1016/j.mlwa.2024.100604

Sugihara, K., & Inagaki, H. (1995). Why is the 3D Delaunay triangulation difficult to construct? *Information Processing Letters, 54*(5), 275–280. https://doi.org/10.1016/0020-0190(95)00028-B

TEGOVA. (2020). *European Valuation Standards*. TEGOVA. https://tegova.org/static/72fa037473e198cbd428e465158bcfdb/a6048c931cdc93_TEGOVA_EVS_2020_digital.pdf

Usman, H., & Lizam, M. (2023). Exploring some spatially constrained delineation methods in segmenting the Malaysian commercial property market. *International Journal of Strategic Property Management, 27*(6), 379–390. https://doi.org/10.3846/ijspm.2023.20498

Varol, S., & Catma, S. (2024). Unlocking insights in real estate markets: Integrating geo-spatial data for comprehensive property valuation and urban planning. *Data in Brief, 57*, 111141. https://doi.org/10.1016/j.dib.2024.111141 PMID:39687372

Walacik, M. (2024). Property appraisal via lens of property registration abundance–real estate market asymmetry assessment. *International Journal of Strategic Property Management, 28*(6), 393–410. https://doi.org/10.3846/ijspm.2024.22686

Walacik, M., & Janowski, A. (2024). *The original methodology for homogenous area determination (HAD) for the purpose of property taxation procedures' fairness and equity increase* [Unpublished presentation form GIS/Valuation Technologies Conference 2024]

Walacik, M., Renigier-Biłozor, M., Chmielewska, A., & Janowski, A. (2020). Property sustainable value versus highest and best use analyzes. *Sustainable Development (Bradford), 28*(6), 1755–1772. https://doi.org/10.1002/sd.2122

Watkins, C. (1999). Property valuation and the structure of urban housing markets. *Journal of Property Investment & Finance, 17*(2), 157–175. https://doi.org/10.1108/14635789910258543

Watkins, C. A. (1998). *The definition and identification of housing submarkets in Glasgow*. (Doctoral dissertation, University of Paisley).

Wisniewski, R., & Brzezicka, J. (2021). Glocal real estate market: Evidence from European Countries. *Journal of European Real Estate Research, 14*(1), 120–149. https://doi.org/10.1108/JERER-09-2019-0031

Wu, C., & Sharma, R. (2012). Housing submarket classification: The role of spatial contiguity. *Applied Geography (Sevenoaks, England), 32*(2), 746–756. https://doi.org/10.1016/j.apgeog.2011.08.011

Wu, Y., Wei, Y. D., & Li, H. (2020). Analyzing spatial heterogeneity of housing prices using large datasets. *Applied Spatial Analysis and Policy, 13*(1), 223–256. https://doi.org/10.1007/s12061-019-09301-x

Wyatt, P. (2022). *Property valuation*. John Wiley & Sons.

Ying, Y., Koeva, M., Kuffer, M., Asiama, K. O., Li, X., & Zevenbergen, J. (2022). The perception of the vertical dimension (3D) through the lens of different stakeholders in the property market of China. *Land (Basel), 11*(2), 312. https://doi.org/10.3390/land11020312

Zhen, W., Yang, L., Kwan, M. P., Zuo, Z., Wan, B., Zhou, S., Li, S., Ye, Y., Qian, H., & Pan, X. ... (2020). Capturing what human eyes perceive: A visual hierarchy generation approach to emulating saliency-based visual attention for grid-like urban street networks. *Computers, Environment and Urban Systems, 80*, 101454. https://doi.org/10.1016/j.compenvurbsys.2019.101454