A Comprehensive Overview Regarding the Impact of GIS on Property Valuation

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Abstract: In the face of pressing global challenges such as climate change, socioeconomic inequalities, and rapid urbanization, ensuring sustainable development in the regions has become essential. The COVID-19 pandemic has highlighted how vulnerable cities are to unforeseen crises and underscored the urgent need for proactive urban planning strategies capable of navigating dynamic and unpredictable futures. In this context, the use of geographic information systems (GIS) offers researchers and decision makers a distinct advantage in the study of spatial data and enables the comprehensive study of spatial and temporal patterns in various disciplines, including real estate valuation. Central to the integration of modern technology into real estate valuation is the need to mitigate the inherent subjectivity of traditional valuation methods while increasing efficiency through the use of mass appraisal techniques. This study draws on extensive academic literature comprising 103 research articles published between 1993 and January 2024 to shed light on the multifaceted application of GISs in real estate valuation. In particular, three main areas are addressed: (1) hedonic models, (2) artificial intelligence (AI), and mathematical appraisal models. This synthesis emphasizes the interdependence of numerous societal challenges and highlights the need for interdisciplinary collaboration to address them effectively. In addition, this study provides a repertoire of methodologies that underscores the potential of advanced technologies, including artificial intelligence, GISs, and satellite imagery, to improve the subjectivity of traditional valuation approaches and thereby promote greater accuracy and productivity in real estate valuation. By integrating GISs into real estate valuation methodologies, stakeholders can navigate the complexity of urban landscapes with greater precision and promote equitable valuation practices that are conducive to sustainable urban development.

Keywords: geoinformation/GI; GIS; real estate valuation; mass appraisal

1. Introduction

Climate change, socioeconomic problems, uncontrolled urbanization, and population growth or decline can have catastrophic effects on the sustainable development of regions. The COVID-19 pandemic highlighted the vulnerability of cities to unforeseen events, as cities around the world were completely unprepared for the magnitude and economic and social impacts of the pandemic and sounded the warning that urban areas must be prepared for a dynamic and unpredictable future. We live in a time of global threats and disruptions that require concerted action that can only be achieved in a spirit of solidarity and cooperation. Therefore, the world must be better prepared to effectively predict, prevent, detect, assess, and respond to threats in a highly coordinated manner. In this context, key societal challenges such as climate change, demographic fluctuation, social inclusion, good quality of life, clean energy, green buildings, and technological change are interrelated and have significant implications for all aspects of real estate, including land prices and property values.
The main objective of property value forecasting is very different for each type of beneficiary:

- For municipalities, property taxes are the primary source of revenue, financing not only urban development projects but also social policies;
- A developer strives to make the best business decision and maximize profit by investing in undervalued land or property and constructing a profitable building [1,2];
- Banks and lenders seek to minimize their risk and are interested in the market efficiency of guaranteed properties [3];
- Homebuyers have priorities such as lifestyle, suitability, and location [1];
- For urban planners, the housing market is an efficient tool with which to measure the effect of urban policies and identify the areas that require priority intervention [4].

The biggest challenge for all these potential beneficiaries is to establish an objective value. However, valuing real estate through manual methods based on empirical analysis and human judgment is usually subjective and can lead to disagreements between appraisers. Traditional property valuation methods rely on the appraiser’s expertise and judgment. Despite a rigorous valuation approach, an appraiser’s opinion of a property’s value is not completely objective, as it is influenced by personal preferences, differing opinions about the property itself, or market developments.

A comprehensive strategy and interdisciplinary collaboration are essential to effectively and objectively address the challenges of real estate valuation. In order to achieve a standardized analysis, the use of digital technologies is vital. These technologies and information systems play a crucial role in streamlining real estate valuation processes and shortening time-to-value. After the subprime crisis, the revaluation of mortgage collateral became a major issue for global banking systems. Consequently, mass real estate valuation became a critical issue, leading to the development of numerous studies using various mathematical models such as regression, neural networks, and fuzzy logic to determine real estate values. A major drawback of these automated valuation models (AVMs) or computer-aided mass appraisal (CAMA) systems has been the lack of location analysis, a shortcoming that can be remedied through the use of geographic information systems (GISs). GIS platforms provide spatial analysis capabilities that enable a deeper understanding of the relationships between various factors such as land use patterns, demographic data, environmental conditions, and infrastructure. One of the first studies in this area was conducted by Longley et al. [5]. They analyzed the optimization of valuation methods for taxable buildings and land by incorporating GIS in the valuation process and tried to develop some perspectives on the use of GIS to increase local revenues.

Numerous studies have examined the relationships between GIS and real estate valuation from a variety of perspectives. For example, some researchers have investigated various methods to automate the valuation process by combining geospatial methods with mathematical methods based on fuzzy logic [6–9], interpolation [10,11], or statistical methods. Other researchers have studied the combination of GIS with artificial intelligence, neural networks [12–14], or machine learning [15]. Another automatic evaluation method studied is the combination of the hedonic model with spatial analysis based on GIS [16,17].

However, not only are valuation methods the subject of research, but also the impact of environmental elements on real estate value. In this sense, the effects of an existing risk on the value of real estate have been studied, such as earthquake risk [18], floods [19,20], and the way the value changes after a disaster [21]. On the other hand, some researchers have studied the positive effects of a sustainable environment on market value [22,23]. The socioeconomic impact of GIS on property valuation has also been studied. Some examined how sustainable infrastructure and amenities affect property values by contributing to a higher quality of life and attractiveness of a location [24]. Others explored whether GIS can also assess the potential impact of renewable energy projects on the environment and neighboring communities, and on the value of properties affected by renewable energy projects [15]. The effects of accessibility and mobility on property value have also been studied [25,26]. In countries with no public records of average house prices,
many researchers have created property valuation maps [27–30]. Many studies have used the power of GIS to examine the relationships between urban morphology and economic growth. Geographic information systems as a decision support tool can be used in formulating housing policies not only to increase the comfort and safety of residential areas, but to also integrate the valuation of mass real estate, providing additional sources of revenue for local households through specific mechanisms, thus contributing to the sustainable development of the area [31].

This article undertakes a systematic review of the scientific literature in order to shed light on the existing state of knowledge on automated real estate valuation methods. The focus is not only on methods based on geographical information systems (GIS), but also on spatial- and location-related aspects that have a significant influence on land prices and property values or are subject to market dynamics. In addition, this article is structured according to the technical methods used to improve automatic real estate valuation.

The main research objective of this paper is to answer the following assumptions:

1. Major societal challenges such as climate change, demographic fluctuations, social inclusion, good quality of life, green energy, green building, and technological change are influencing real estate market value;
2. Various social challenges are interconnected and there is a need for holistic approaches and collaboration between different sectors to effectively address them;
3. Sustainable urban planning, renewable energy transition, energy efficient buildings, social justice, climate resilience and adaptation, sustainable transport, green finance and investment, smart cities, and digital innovation can have a significant impact on land prices and property values;
4. Digital technologies and information systems are crucial in optimizing real estate appraisal and shortening the time to assess property values.

The authors hope that the research presented here can form the basis for further studies on the applicability of GIS in real estate valuation and how spatial analysis based on GIS technology and real estate prices can be used for sustainable urban planning by both researchers and local authorities.

The main objective of this review is to highlight the interconnectedness of various societal challenges and the need for holistic approaches and collaboration between different sectors to effectively address them, and to identify how modern technologies such as artificial intelligence, GIS, and satellite imagery could be used in real estate valuation to reduce the subjectivity associated with traditional methods. The current review also highlights the benefits and challenges associated with the usage of GIS in real estate valuation and identifies where the key applications for GIS in real estate valuation lie.

2. Materials and Methods

In this study, we conducted a systematic literature review to understand the complex relationships between real estate value and the major challenges facing today’s society (climate change, demographic change, social inclusion, good quality of life, etc.), and how GISs can help solve problems and challenges.

The analysis included empirical research on several broad topics drawn from all published research on the applicability of geographic information systems in real estate valuation methods: (1) hedonic models, (2) artificial intelligence (AI), and mathematical appraisal models.

2.1. Data Collection

In conducting the proposed study, we followed established protocols for conducting a systematic review, taking steps to avoid bias in the identification, selection, and synthesis of relevant literature. Our initial literature search was conducted by rigorously screening titles, abstracts, and keywords in the comprehensive literature databases Web of Science (all years) and Scopus (all years). Considering the large number of scientific papers dealing exclusively with Geographic Information Systems (GIS) or real estate valuation, we were
confronted with an overwhelming number of articles. Despite this abundance, we have focused on the comparatively small amount of literature that deals explicitly with both GISs and real estate valuation. Strikingly, the connection between GISs and real estate appraisal remains a niche area in this broad field, with only a fraction of articles acknowledging this convergence. This rarity emphasizes the importance and novelty of our study in the broader context of academic discourse.

The selection was initially based on a keyword search using the following terms: “GIS” and “real estate appraisal”. The search using Scopus found 38 responses and that using Web of Science found 64. We repeated the search for the terms “GIS” and “real estate appraisal”, with that using Scopus returning 69 responses and that using Web of Science returning 80. Therefore, synonyms (e.g., property, real estate) and full and abbreviated terms were included in the search string. The final search term combination was as follows: (“property valuation” OR “real estate valuation” OR “real estate appraisal” OR “real estate valuation” OR “real estate prices” OR “property prices”) AND (“GIS” or “Geographic Information System”).

The first search was conducted in March 2023 and yielded 363 articles, including 144 results from Web of Science and 219 from Scopus. Of these, we found 112 duplicates, articles that were indexed in both catalogues. After this first phase of screening, we obtained a list of 251 entries. In the second screening phase, the abstracts of the scientific papers were analyzed in detail and the list was narrowed down by topic. In this step, additional papers were rejected because they were not in the public domain (71), did not constitute a scientific paper (13), or were reviews (4).

Another 74 articles were eliminated since they were not relevant to this study due to the following reasons:

- GIS is not used effectively in the assessment process (11);
- The assessment was not applied to real estate, e.g., water or groundwater quality, soil, vegetation, etc. (32);
- They were not relevant to the current state of assessment research (31);
- They were not considered relevant to automated assessment or mass appraisal because they focus on biological or chemical analysis (7);
- They were duplicated (3).

After the second step, 89 academic articles and book chapters remained. Based on this, 14 articles and studies were included in this review. Following the final screening, 103 studies were included in this study.

Figure 1 below shows the schematic flow of the review methodology.

2.2. Overview of the Selected Papers

A brief analysis of the 103 selected papers showed that the number of relevant papers has increased significantly over time, correlating with the development of informatics and the growing use of information systems in general and GIS in all aspects of decision support,
including real estate valuation. This indicates an increased research interest since 2015. Figure 2 illustrates the distribution of reviewed literature over time. As can be seen in this graph, interest in the applicability of GIS in real estate valuation has increased significantly after the subprime crisis, with most academic articles being published after 2016.

![Figure 2](image_url)

**Figure 2.** The distribution of the literature over time.

Some of the reviewed articles addressed the broad usage of GIS in real estate appraisal and explored its diverse applications in various fields, while others examined the complicated legal framework for GIS implementation or the progress made in specific geographic regions or countries, offering a picture of the integration of GIS technology into real estate practice. Figure 3 below provides a comprehensive visual representation of the geographic distribution of countries where the effectiveness of GIS in real estate appraisal has been studied in depth and illustrates the global interest and diversity of research efforts in this area.

![Figure 3](image_url)

**Figure 3.** Number of papers according to the location of case study (created by the authors using ArcGIS online).
The global distribution of the literature shows that most studies on the applicability of GISs in the assessment process were conducted in the United Kingdom (13) and Italy (12), closely followed by Poland (10) and China (10). When analyzing the distribution of articles in Europe, it became clear that many studies were also conducted in Cyprus (7), Greece (3), Spain (3), and Ireland (3). The countries where mass valuation based on GIS was studied overlap with the countries which were most affected by the economic and financial crisis triggered by the subprime crisis because mortgages had to be revalued or because more objective valuation models were required. It should be noted that not all of the articles examined are case studies; some deal with the valuation methodology or the applicable algorithms.

3. Results

The main purpose of using modern technologies in real estate appraisal is to reduce the subjectivity of the appraiser and increase productivity through mass appraisal. For this reason, this study addressed three main topics related to the application of GISs in mass appraisal: (1) hedonic models, (2) artificial intelligence (AI), and (3) mathematical appraisal models. The following diagram, Figure 4, shows the distribution of these main topics in the literature review.

![Figure 4. Distribution of studies according to the methodology used (in percent) (created by the authors).](image-url)

The automated valuation model (AVM) and computer assisted mass appraisal (CAMA) are both automated approaches used in real estate valuation. However, while AVMs are typically used to estimate the value of individual properties, CAMA systems are designed for the mass appraisal of properties within a specific geographic area, such as a municipality or county, where the values of multiple properties are determined simultaneously using standardized valuation models. However, a notable shortcoming of most AVM and CAMA systems is the lack of property location analysis, even though spatial components play a central role in determining the market value of a property. A review of the literature on the integration of geographic information systems (GIS) into real estate valuation methodology has shown that very few valuation systems used spatial data until 2008. However, after the turmoil of the subprime crisis and the subsequent need to revalue bank guarantees, the integration of GIS into CAMA became critical for banking institutions and other creditors. After 2008, both AVM and CAMA experienced rapid development and also more research was conducted regarding the integration of GIS [32,33]. Although AVMs initially had fewer regulatory requirements than CAMA systems, which must meet specific property valuation standards and guidelines in accordance with local laws and ordinances, AVMs today seek to meet CAMA requirements as well. As a result, geographic information systems have helped to improve the accuracy of both AVMs and CAMAs by merging mathematically based models with spatial property location data and eliminating this critical limitation.
3.1. Hedonic Model

Hedonic modeling is a widely used technique for determining property value. By breaking down a property into distinguishable attributes, each valued independently, hedonic models provide a comprehensive approach to valuation. These attributes include various characteristics such as the number of bedrooms, floors, plot size, and other relevant factors. The final valuation is then determined by aggregating the estimated prices for each individual attribute. This method provides a nuanced and holistic understanding of property value as it takes into account the numerous factors that are influencing the overall value.

Hedonic models have been applied throughout the world in urban areas, including Naples, Venice [17], Geneva, Dublin [18, 20], Quebec [34], Berlin [35], Philadelphia, Baltimore, Washington DC, Oradea [32], or Seoul and in rural areas in Cyprus [16], Nigeria [36], and Malaysia [37].

The studies show that AVMs based only on the hedonic model should have similar values for two similar properties in different neighborhoods. This drawback can be overcome by incorporating specific spatial information, which is why the introduction of GIS technology into statistical property valuation models has proven extremely efficient.

Different applications of AVMs based on hedonic models improved with spatial features have been studied by Demetriou [16] to improve the process of mass property valuation in Cyprus by using a spatially based linear hedonic pricing model. This study was realized in order to improve the inefficient existing valuation model employed in Cyprus for agricultural land.

In another study [17], a model for valuing the benefits of environmental and urban improvement investments is presented using a mixed hedonic–multiactive method to model a value function of urban real estate values. The valuation model was integrated with a GIS to represent residential value and to reflect its change due to urban investments. The proposed model showed plausible and robust results.

The paper [34] combines GIS technology and geo-statistics with hedonic models to evaluate housing prices. Location attributes related to transaction prices, neighborhood quality, accessibility, and socioeconomic censuses were used to improve hedonic models of single-family home value appreciation in Quebec, Canada. The study also includes a principal component analysis of the hedonic model deployed in the housing market.

In the article [38], an automated valuation model is proposed to determine the value of commercial real estate using a hedonic model based on GIS location analysis of cadastral data and other socioeconomic information. In another study [39], spatial analysis of cadastral data was combined with the hedonic model to estimate housing prices in the city center of Madrid using spatial data from official government and private company websites. Given the enormous volume of data and the large number of parameters and coefficients resulting from the cadastral work, the aim of the work was to establish the minimum number of parameters that determine the housing price and that, translated into automatic valuation methods, provide similar predictions to the official methods.

Wang and others proposed a mass appraisal method that is a combination of GIS technology and a multi-criteria decision method—VIKOR. By combining the advantages of GIS and VIKOR, a new mass appraisal model for real estate and its application were developed, tested in Ganzhou, and its accuracy was demonstrated [40]. Given the rapid development and growth of China’s real estate sector, the financial risks associated with this industry have a significant impact on both banking institutions and the real estate mortgage valuation system in the market. Based on the GIS framework, the article [41] collected data from relevant websites and combined residential real estate pricing methods to create a “Hedonic Commodity Housing Price Influence Factor Model”. Similarly, a study conducted in Kenya [42] advocates the integration of hedonic models with GIS technology to reassess the valuation of mortgage loans.

The approach proposed in [43] emphasizes a logical and rational aggregation based on a set of property attributes with location attributes and other valuation factors determined
by spatial analysis using GIS and a multi-criteria valuation system. To expand the detailed characteristics of real estate, researchers are exploring the integration of three-dimensional (3D) information into valuation practice, which could significantly improve the estimation and explanation of individual property values [44–47]. Alternatively, some researchers argue for the integration of advanced technologies such as 3D cadaster and Building Information Modeling (BIM) into property valuation. They show how the fusion of geographic information systems (GIS) and BIM improves the analytical capabilities of real estate valuation processes, particularly through implementing automated methods [48,49]. Others are investigating how LIDAR data [50] or even data from social media can be integrated into real estate valuation models [51].

Environmental benefits include natural features and resources that enhance a location’s attractiveness and quality of life. These elements are included in various hedonic evaluation algorithms that consider factors such as proximity to parks, lakes, beaches, and clean air. Geographic information systems (GIS) facilitate the visualization and overlay of environmental features with real estate transaction data and help with pattern recognition and correlation analysis. Numerous studies have examined the impact of such features on attractiveness and value, with some arguing that they should be considered as price indicators. Metrics such as the landscape forest size–distance index and accessibility to green space are used to refine hedonic price models [23,34,35,52,53].

Some studies have also tested cultural heritage-based indicators in hedonic pricing methods. In this sense, the study [54] examines the impact of cultural heritage—in particular, protected buildings and cultural–historical sites (or historical landmarks)—on property values in the city of Zaanstad in the Netherlands. The authors analyzed this from three angles: (1) how the fact that a building is part of the cultural heritage influences its market price, (2) the influence that a protected building is projecting on neighboring properties, and (3) how the location in cultural–historical sites influences the price of properties in the area. The authors found that buyers are willing to pay 26.9% more to purchase a listed building, while surrounding homes have an additional value of 0.28% for each additional listed building within 50 m.

GIS technology improves the algorithms based on hedonic models by not only evaluating the positive characteristics of locations, but also taking into account negative factors. For example, one study [55] examines the impact of power lines on real estate prices, considering both direct devaluation and the indirect perception of damage at different distances. Variables derived from GIS data such as proximity to power lines, the presence of infrastructure, and the attractiveness of natural and architectural landmarks serve as important predictors in the utility functions of households. The results of this study have also been incorporated into the evaluation of license fees and compensation in Italy.

In another study [56] from the UK, researchers attempted to quantify the monetary value of negative impacts of road construction, such as noise and visual disturbance. Using GISs and large-scale digital data, the study quickly derived all the necessary variables, modeled datasets, and produced price estimates for road noise and visual disturbance. The benefits of GISs in such studies were highlighted, while the limitations of wider application were discussed.

Similarly, a study conducted in Ukraine [57] attempted to identify and quantify environmental factors affecting property value by combining GIS tools with traditional empirical methods. This method, which takes into account the distribution of environmental factors, proved to be valuable for understanding the actual environmental impact. Another study [58] also combined GIS-based tools with mathematical hedonic valuation methods to assess the impact of urban green spaces on real estate prices.

In addition, GIS play a crucial role in assessing the negative impact of real estate in vulnerable areas, such as flood plains or earthquake zones. By integrating hazard maps, topographic data, and historical information, GIS enable comprehensive risk assessments that help assessors and decision makers to formulate appropriate strategies for properties in such areas.
Several studies have examined the impact of flood risk on the value of residential property. For example, in Ireland [18], consumer behavior under uncertain flood risk was examined using hedonic property price functions to estimate the impact of flood risk. Studies in Dublin [20] and England [21] analyzed the impact of flood risk on housing costs using detailed datasets and GIS and showed short-term price declines following flood events. In [58], the vulnerability to flooding of commercial properties in the UK was assessed, and [59] investigated how to value the ecosystem services of flood protection in suburban watersheds. Some studies have attempted to assess willingness to pay for flood insurance using methods such as the contingency valuation method (CVM) [19].

GIS can also facilitate the assessment of damage caused by natural disasters. As shown in studies such as the analysis of the impact of Hurricane Iniki on Hawaii [60] and earthquake-related fires [61], GIS-based models are used to estimate property damage and the extent of damage. These studies demonstrate the utility of GIS in assessing various negative factors affecting property values, from environmental hazards to infrastructural developments. In addition, GIS could serve as a fundamental tool for the development of risk modeling, mapping, and communication tools aimed at reducing vulnerability to natural hazards [62].

Based on the results of the articles reviewed, Figure 5 presents the key indicators used in property valuation through hedonic modeling. These indicators cover a comprehensive spectrum, including property characteristics, physical attributes, geographical location, neighborhood quality, infrastructure accessibility, environmental aspects, socioeconomic dynamics, legal aspects, and negative factors affecting value.

**Figure 5.** Schematic diagram of the indicators for property valuation based on hedonic modeling created by the authors based on [23,38].

### 3.2. Artificial Intelligence

The proliferation of the internet has enabled the acquisition and dissemination of large data sets, representing a significant impact of the information age on real estate valuation. This expansion of big data technology increases the amount and scope of data accessible for valuation purposes and requires the transition from manual valuation methods to automated methods based on artificial intelligence (AI). The use of AI in property valuation integrates big data, remote sensing data, and geographic information systems (GISs) to recognize patterns, leverage aerial imagery, and aggregate spatial data.
into comprehensive maps that enable informed property valuation. Figure 6 illustrates the main types of big data resources used in automated, artificial intelligence-based real estate valuation processes.

![Diagram of data sources for real estate valuation adaptation](image)

**Figure 6.** Schematic diagram of data sources for real estate valuation adaptation, created by the authors based on [23,63].

Some researchers are investigating the usage of spatial data mining techniques on public geportals to improve and automate assessment [64–66]. Another study [67] investigated the effective use of GIS in combination with reliable remote sensing data and forecasting tools that provide a robust and realistic solution for predicting real estate trends. Even social sensing data and street imagery were used to extract information using deep learning algorithms to automatically assess the physical characteristics of properties for real estate price evaluation [68,69]. Dimopoulos et al. investigated how CAMA, GIS, and remote sensing can be integrated to create a tool that enables effective and efficient data collection to determine property value to support real estate taxation in Greece and Cyprus [70].

In the field of real estate valuation, artificial intelligence applications involving artificial neural networks (ANNs) and machine learning have been developed to achieve better price estimation and prediction [71]. Neural networks can map complex nonlinear relationships between data and process multidimensional big data, and the self-learning process can reduce user intervention. Figure 7 shows a flowchart for real estate valuation using big data and artificial intelligence models. The process itself includes data collection, pre-processing, selection of relevant features, development of predictive models, training and evaluation of the models, their use in production, and estimation of value for decision making purposes.

Various machine learning algorithms are used to evaluate housing, but they are often very computationally intensive and do not take spatial attributes into account. With the increase of public and open-source geospatial data GISs, machine learning methods can be improved. Mete and Yomralioglu [15] used open data sources from the European Environment Agency, OpenStreetMap, and Ordnance Survey to perform a mass assessment of residential properties in England and Wales using a hybrid approach combining GISs and machine learning regression algorithms. In this study, the results of different regression methods were compared and the random forest algorithm was found to have higher accuracy than other algorithms. Crosby at all [1] investigated the accuracy of improved Gaussian regression with spatial data. Their tests show improved accuracy compared to random forest.

Graczyk and others [72] conducted several tests investigating expert mixture (ME) to support mass appraisal, where expert mixture is a neural network architecture for supervised learning. Learning datasets were obtained by combining cadastral data from GISs with sales/purchase transactions from 1999–2005. Based on these datasets, 12 experiments were conducted using a mixture of expert models: 6 with a GLM (general linear
model) and 6 with MLP (multilayer perceptron). The best results were obtained with the GLM architecture.

In another study [14], a mass assessment model using artificial neural networks (ANNs) was proposed and compared with another model using multiple regression analysis (MRA). Both methods were overlaid with spatial analysis in geographic information systems (GISs) and performed on 300 residential properties in Konya/Turkey. GIS-based value maps, integrated with ArcGIS, were created to produce an ANN-based algorithm and also MRA. The statistical comparison between the results of ANNs and MRA showed that ANNs are more suitable for mass appraisal and that both methods in combination with GISs provide more accurate data than without it.

Wu and colleagues [73] proposed an automatic evaluation framework by combining GIS and neural network technologies. They selected a set of spatial factors that affect land price and created a neural network training dataset to identify the complex relationships among all types of factors. The effectiveness of the proposed methodology was compared with land prices in Wuhan.

The use of an artificial neural network (ANN) in real estate valuation, complemented by the use of a geographic information system (GIS) to enrich the model with spatial analysis, was also tested in Athens [26]. The sample data used contains information about 3150 properties with different characteristics and from various parts of the city, enriched with information from GISs. The multilayer perceptual network (MPN) method was used to perform the mass evaluation and the results were compared with the traditional approach. The comparison showed that the ANN (MPN) approach provides more consistent predictions.

A similar study combining ANN and GIS was conducted in Spain. Garcia and others [13] tested three methods from ANN: the multilayer perceptron (MLP) and radial basis function (RBF) networks, and self-organizing feature maps (SOFM), all in combination with GIS. When comparing the performance of the methods, the best results were obtained with MLP.

Demetriou [24] proposes a combination of GIS with three models based on linear and nonlinear models, and artificial neural networks (ANNs). The models were tested in Cyprus, and the evaluation showed that AVMs are very efficient compared to the conventional approach.
Another study [12], also conducted and tested in Cyprus, has shown that automated valuation models based on ANN combined with GIS significantly improve traditional mass valuation models.

The increasing demand for user mobility has led to the development of web-based and mobile GIS technologies that facilitate the exchange and usage of local data while offering geographic analysis tools online. At the same time, location-based services (LBSs) leverage spatial data and GPS technologies in mobile applications and platforms that use real-time location data and provide real estate stakeholders with instant access to property information, market trends, and neighborhood insights, which has led to significant research efforts in this area.

In [74], the development of the Smart Real Estate mobile application illustrates the representation of urban real estate attributes across thematic categories through data analytics. In addition, Jamaican researchers pioneered the development of a self-contained real estate information and valuation system [75] that promotes universally accessible data while empowering the private sector to establish transparent, user-friendly websites for free data dissemination. A novel approach [76], which recognizes the central role of decision making in real estate valuation, presents a data-driven process that can be decomposed into executable applications. The project aims to use web technologies to create a computing environment that supports analysts in scenario planning. Furthermore, an application of the data processing environment is described that utilizes geospatial services, user knowledge, and statistical insights.

Other studies have investigated the potential of extracting image data from remote sensing and augmenting it with information from street-level imagery such as Google Street View by using machine vision techniques together with convolutional neural network (CNN) classifiers to extract features for estimating property values in London, UK [77]. Some researchers have not only efficiently combined data from different sources, but also processed methods that integrate deep learning technologies in the acquisition and pre-processing stages to incorporate them into complex hedonic models for objective valuation [69,78,79]. In the study [80], for example, visual features of real estate are extracted from street views using deep learning methods that influence real estate prices and combined with spatial statistical approaches for the valuation process.

### 3.3. Mathematical Appraisal Models

Mathematical methods combined with spatial analyses based on GIS represent another category of automatic assessment models. Various mathematical methods can be found in the literature, such as regression analysis [1,81], other statistical methods [10,25,82], or interpolation methods [82], but algorithms based on fuzzy logic [6,83] are most commonly used to reduce subjectivity in the evaluation process.

Renigier-Bilozor and others [8] argue for the integration of fuzzy logic with spatial methods to reduce subjectivity and uncertainty in decision support systems for real estate investment analysis. Their results underline the importance of spatial decision factors in influencing real estate value. Another study by Pagourtzi et al. [6] presents a model for a decision support system that seamlessly integrates fuzzy theory and spatial analysis into an information system architecture.

In an article by Weinzierl and Heider [7], an approach based on GIS was used to analyze data on soil types and climate models. These models were combined using fuzzy logic algorithms to evaluate and predict the future state of agriculture and, indirectly, the value of land simulating future scenarios.

A study [9] combining GIS systems with the fuzzy method proposes the use of the evolutionary Takagi–Sugeno algorithm (eTS) to build models to support the valuation of real estate based on cadastral data. The performance of the model was compared with evolutionary fuzzy systems and deterministic algorithms implemented in KEEL, including decision trees, statistical regression, and support vector machine, confirming the advantages of the eTS algorithm.
In the study [84], a multi-criteria decision analysis (MCDA)—the analytical hierarchy process (AHP)—was used to reproduce the coefficients that serve as the basis for real estate valuation. A region in the Selcuklu district of Konya, Turkey was used to test the model created with AHP. To analyze the performance of the model, the values collected and weighted using AHP or MRA were integrated into GIS and the value maps of the study area were created, proving that the AHP method is more accurate than MRA.

In another paper [85], a hybrid mathematical model was developed to predict property values suitable for mass appraisal by combining a Cobb–Douglas regression with a linear regression. Property value criteria were grouped and weighted in a hierarchical structure using the analytic hierarchy process (AHP), and geographic information systems (GIS) were used to organize the spatiality of the data. The weights obtained using the AHP were integrated into the coefficients for the criterion weights and densities of the Cobb–Douglas hybrid model. This study was evaluated using Pearson correlation analysis and further improved by the authors. Therefore, a hybrid mathematical model for predicting real estate valuations was developed in [83]. The Cobb–Douglas hybrid model (C-DHM) was used for value prediction based on the property attributes in each part of the model, while the local and spatial index was constructed using the fuzzy analytic hierarchy process (FAHP) method. The dataset was constructed using legal and physical attributes with market values of 457 parcels in the study area, Konya, Turkey. The results were integrated into geographic information systems (GIS).

Wang and colleagues [86] used set-pair analysis as a mathematical method to evaluate property prices. To reduce the uncertainty of the set-pair analysis, they integrated it with GIS-based spatial analysis and quantified the influencing factors using an entropy weight method. The study proved that the combination of location analysis and weighted pair analysis can improve the efficiency of real estate valuation.

Another paper [87] proposes an innovative approach to building an automated model for land valuation in the United Kingdom. By examining the land valuation methods commonly used in the UK, the effects of land use category, demographics, location, social preferences, and optimal land use on land value are highlighted, revealing a number of additional factors required for land valuation. Mathematical methods were used to validate the proposed model, which has 92% accuracy in predicting land prices.

Mass appraisal has many applications, but the number of criteria and the criteria themselves vary by application, region, and individual. The study [88] attempts to optimize these criteria to save time and money by reducing their number and determining the criteria that actually affect the value of the property. Based on a survey, the number of criteria was reduced to 14 with separation and 30 according to PCA results. The proposed buildings were analyzed against these criteria using multiple regression (MRA) and spatial analysis based on location and neighborhood.

Another commonly used mathematical method for valuing property prices is geographically weighted regression (GWR), as it has been shown to provide a high degree of accuracy in mass valuation [89–91]. GWR is a spatial regression technique that embeds a local spatial structure into a regression model to understand or predict a phenomenon or parameter. Dimopoulos and Moulas [92] analyzed the possibility of using GWR in ARCGIS and intended to provide a forecasting tool for more objective taxation. In another study by Yiorkas and Dimopoulos [93], a multi-criteria analysis using a combination of GWR and GISs was used to evaluate and predict property prices in Nicosia, Cyprus. Locurcio and colleagues [94] compared a GWR-based method with an evolutionary polynomial regression (EPR) model in the valuation of mortgages on corporate real estate in Milan and Rome.

In a Turkish study, big data with 121 criteria and around 200,000 real estate prices were processed. These data sets were optimized for location analysis using boxplot, cluster, and outlier analysis methods. The property-related criteria were further analyzed using spatially constrained multivariate cluster analysis (SCMCA). Mass appraisal performance was evaluated across the study area, with five clustered regions evaluated using multiple regression analysis (MRA). Finally, machine learning methods were used to assess the
accuracy of the model [95]. Multiple regression analysis (MRA) was used to improve the land valuation method used by the banking system in Indonesia [96].

In another study, an interoperable data model for residential land valuation is proposed as an extension of the National Spatial Data Infrastructure (NSDI) to make the mass appraisal process applicable through machine learning. Thus, the ensemble random forest algorithm (RF) was implemented in the Pendik district of Istanbul to evaluate the prediction performance using thematic datasets compatible with the data model [97].

Another study conducted in Russia [98] proposes a conceptual methodology for assessing historical–cultural value in urban areas and a scale for historical and cultural value. The methodology proposes a list of cultural evaluation factors classified by the method of hierarchical analysis, as well as a method for calculating the coefficient of historical and cultural value of the areas using the theory of fuzzy sets. The obtained results were presented using GIS MapInfo Pro 2019, creating a map of the historical and cultural value of the historical center of Orenburg (Russia).

Other authors investigated different spatial analysis techniques based on interpolation, such as IDW and Kriging, for rural land valuation and also for predicting market values for agricultural development [10].

The detection of changes in land use and land cover, based on remote sensing data [11] or cadastral data, and their spatial correlation with market values have been used to analyze the evolution of urban sprawl and its impact on land value and agricultural potential [99,100] or to optimize land resources and facilitate the estimation of urban industrial property values [101].

GIS-based real estate appraisal has become a strategic tool through the use of mass appraisal procedures (i) in the definition of urban development policies to improve real estate assets [31,102], (ii) in projects to re-functionalize the urban economy [103], (iii) in the evaluation of investment and credit risks [4], and (iv) in the evaluation of urban development solutions for the definition of territorial strategy programs.

4. Discussion

As we stated in the introduction of this study, its objective is to analyze existing knowledge through a systematic review of the academic literature, focusing not only on the automatic real estate valuation method based on GISs, but also on spatial and locational aspects that have a significant impact on land prices and real estate values or are influenced by the market. The main objective of this review is to highlight the interconnectedness of various societal challenges and the need for holistic approaches and collaboration among different sectors to effectively address them, and to identify how modern technologies such as artificial intelligence, GIS, and satellite imagery could be used in real estate valuation to reduce the subjectivity associated with traditional methods.

In addition, several statements were considered when creating the structure of the report. In response and in order to check these statements, the current study used 103 articles and studies to highlight the current trends in the field. This literature review provides a comprehensive overview of the application of GIS to mass appraisals, highlights the potential benefits and challenges associated with this integration, and identifies several areas for future research. As seen above, through the use of GIS technology, mass appraisals can be conducted more efficiently and accurately, resulting in improved real estate appraisal practices.

In the following lines, we will present, one-by-one, our considerations regarding each statement:

1. Major societal challenges such as climate change, demographic fluctuations, social inclusion, good quality of life, green energy, green building, and technological change are influencing real estate market value.

Regarding the first statement, we consider that the inclusion of major social changes such as demographic fluctuation, quality of life, access to green energy, quality surround-
ings which are definitely influencing the real estate market can also improve the determination of the market value of a certain property;

2. Various social challenges are interconnected and, therefore, there is a need for holistic approaches and collaboration between different sectors to effectively address them.

While considering the second statement, these various social challenges are interconnected, and there is a need for holistic approaches and collaboration between different sectors to effectively address them and include them in data analysis and modeling. Also, these elements must take into consideration that homebuyers have priorities such as lifestyle, suitability, and location;

3. Sustainable urban planning, renewable energy transition, energy efficient buildings, social justice, climate resilience and adaptation, sustainable transport, green finance and investment, smart cities, and digital innovation can have a significant impact on land prices and property values.

By integrating GIS into real estate appraisal, map interpretation provides important support for qualitative analysis. Moreover, after completing the literature review, we can conclude that, once again, the usage of GIS technology can improve valuations by providing a more accurate and comprehensive risk assessment, leading to improved property valuation practices in vulnerable areas. Therefore, sustainable urban planning, renewable energy transition, energy-efficient buildings, social justice, climate resilience and adaptation, sustainable transport, green finance and investment, smart cities, and digital innovation can have a significant impact on land prices and property values;

4. Digital technologies and information systems play a crucial role in optimizing real estate appraisal and shortening the time to assess property values.

It is clear that one of the main benefits of GISs is the ability to create maps and visualizations that provide a clear understanding of the physical and social characteristics of a city, which can help various professionals, including real estate appraisers, make data-driven decisions in a more objective way. Therefore, digital technologies and information systems play a crucial role in optimizing real estate appraisal and shortening the time to assess property values.

Discussing the deployed methodology, we can observe that there is an increasing number of studies focused on combining GIS databases with mass appraisal, hedonic pricing models, artificial intelligence, or mathematic and statistical appraisal models. Sometimes, elements of different models are combined for increased accuracy. Figure 8 represents a centralized scheme that outlines the workflow depending on the chosen methodology to automate property valuation based on geographic information systems (GISs). This figure also illustrates the fact that the valuation process is similar in the case of AVMs and CAMAs, with the difference being data collection for individual properties or in batches for multiple properties simultaneously.

While considering the environmental impact on real estate prices, we consider that the inclusion of environmental elements into the algorithm is mandatory. Environmental benefits refer to a location’s natural features, resources, and characteristics that enhance its attractiveness and quality of life. These benefits include, for example, proximity to parks, lakes, beaches, forests, clean air, beautiful views, scenic landscapes, cultural amenities, and an overall sustainable environment. Geographic information systems (GISs) make it easy to visualize the distribution of environmental features and overlay them with real estate transaction data to identify patterns and correlations. Likewise, it is interesting how other environmental features, such as power lines, pollution, noise, natural hazards, and social conditions, can negatively influence the prices of properties.
This figure also illustrates the fact that the valuation process is similar in the case of AVMs and CAMAs, with the difference being data collection for individual properties or in batches for multiple properties simultaneously.

Figure 8. A centralized schematic representation of the process used in automated property valuation based on GISs (created by the authors).

Some of the biggest promoters of mass appraisal and usage of GIS in the appraisal of properties are banks which use these analyses in the mortgage sector to protect their profit margin and, in some cases, to find distressed properties that can be used as collateral. Taxation and land development are mainly used by local, regional, and national authorities. Based on the studies reviewed, mass appraisal based on GIS is not only a flexible and cost-effective tool for many aspects of local taxation, but also a valuation tool that enables public administrators to determine the potential future value of public assets after revaluation processes. By analyzing socioeconomic factors together with traditional real estate data such as property characteristics and market trends, not only can a more comprehensive and contextualized real estate valuation be achieved, but this can also be valuable in making informed decisions in real estate investment, urban planning, and policy development by providing a holistic view of the impact of social and economic factors on real estate values.

As seen above, property valuation based on GISs can be further enhanced through the use of/can be further improved by using other spatial tools such as remote sensing and aerial photography, 3D cadaster, 3D modelling and visualization, spatial data mining, open-source geospatial data, spatial decision support systems (SDSS), web-based mobile GIS, other location-based services (LBS), blockchain technology, and smart city integration.

5. Conclusions

The ability to analyze spatial data using GISs allows researchers and decision makers to examine spatial and temporal patterns with a basic methodological approach in a variety of disciplines, including real estate appraisal.

The main purpose of using modern technologies in real estate appraisal is to reduce the appraiser's subjectivity and increase productivity through mass appraisal. For this reason, this study addressed the main issues related to the application of GISs in real estate appraisal: (1) hedonic models, (2) artificial intelligence (AI), and (3) mathematical appraisal models.
The current analysis of research in this area once again confirms the fact that causal relationships are unpredictable; spatial relationships are interactive, dynamic, and complex. The nature and value of real estate is influenced by various social, environmental, and economic factors, as well as by the relationships between these factors. All of these socioeconomic spatial parameters, such as proximity to resources and markets, transportation infrastructure, housing suitability and topography, agglomeration economics, and government intervention, influence each other.

GIS-based real estate appraisal has become a strategic tool even for the government which, through the use of mass appraisal procedures, can (i) define urban development policies to improve real estate assets, (ii) re-functionalize the urban economy, (iii) evaluate investment and credit risks, and (iv) evaluate of urban development solutions for the definition of territorial strategy programs.

As observed in the studies mentioned above, mass appraisal based on GISs is not only a flexible and cost-effective tool for many aspects of mortgage analysis and local taxation, but also a valuation tool that enables owners or investors to determine the potential future value of an asset after revaluation processes.

This study proves once again that the use of GIS technology can improve valuations by providing a more accurate and comprehensive risk assessment, leading to improved property valuation practices. Also, it shows that different tools can be combined in order to obtain a much more accurate result.

The creation of real estate valuation maps is a highly debated topic as well, with several pieces of research concentrating on creating inclusive maps that aim to quantify the market value of a property based on its qualitative characteristics, beginning with the collection and analysis of market data and property records and ending with cartographic representations created using GISs. A relatively new field of research is analyzing the usage of the data shared by the users on the internet or data collected through location-based services (LBSs).

It is essential to include environmental elements in real estate price algorithms, as features like parks, green areas, clean air, and scenic views may enhance property value, while factors like pollution and noise detract from it. GIS technology helps visualize and analyze these environmental impacts alongside real estate data. Financial institutions, mainly banks, use GIS for property appraisal to analyze and secure mortgages, while governments can use them for fair taxation and for implementing land development strategies. Also, integrating socioeconomic factors with real estate data provides comprehensive valuations, aiding, as well, in investment and urban planning.

The main limitations of this study include that the topic is extremely broad, and we had to narrow our search to provide a comprehensive overview of the research in this area.

The future research directions will focus on applying some of the above-mentioned methodologies on data collected in several European countries in order to practically test the models and propose an enhanced model for determining the value of a certain property using innovative techniques.

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