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MAPPING THE LANDSCAPE: A SYSTEMATIC LITERATURE REVIEW ON AUTOMATED VALUATION MODELS AND STRATEGIC APPLICATIONS IN REAL ESTATE

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Abstract. In the rapidly evolving real estate industry, integrating automated valuation models (AVMs) has become critical for improving property assessment accuracy and transparency. Although there is some research on the subject, no thorough qualitative systematic review has been done in this field. This paper aims to provide an up-to-date and systematic understanding of the strategic applications of AVMs across various real estate subsectors (i.e., real estate development, real estate investment, land administration, and taxation), shedding light on their broad contributions to value enhancement, decision-making, and market insights. The systematic review is based on 97 papers selected out of 652 search results with an application of the PRISMA-based method. The findings highlight the transformative role of AVMs approaches in streamlining valuation processes, enhancing market efficiency, and supporting data-driven decision-making in the real estate industry, along with developing an original conceptual framework. Key areas of future research, including data integration, ethical implications, and the development of hybrid AVMs approaches are identified to advance the field and address emerging challenges. Ultimately, stakeholders can create new avenues for real estate valuation efficiency, accuracy, and transparency by judiciously utilizing AVMs approaches, leading to more educated real estate investment decisions.

Keywords: real estate, automated valuation models, strategic applications, systematic literature review, PRISMA, conceptual framework.

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1. Introduction

The contemporary population growth requires the acquisition of land and the ensuing construction of buildings. The rising population expansion is also creating a demand for real estate, which is making it more challenging to assess its market value (Baur et al., 2023). Accurate real estate valuations are necessary for a fair and effective real estate market (Jafary et al., 2024b). Due to its application in many areas of the economy, such as taxation, mortgage transactions, expropriations, buying, and selling, the valuation process has been one of the most important factors in the economy of the country (Reite, 2023). However, accurate real estate valuation is time-consuming and requires expert knowledge (Glumac & Des Rosiers, 2020). As a result, automated solutions that enable quick and accurate real estate estimation are beneficial to real estate stakeholders (Jafary et al., 2024a). Since inaccurate valuations can have a substantial negative impact on a variety of stakeholders, including governments, policymakers, investors, real estate developers, banks, insurance agencies, and consumers, it is imperative that the valuers accurately estimate the market value (Swietek, 2024). Further, since most clients want to pay less for valuation services, the valuation should rapidly embrace automation to offer affordable services (Trojanek et al., 2024). Key aspects of real estate valuation, like durability, immovability, and a strong reliance on location and property attributes, inherently make valuations more difficult (C. L. Lee et al., 2024). Furthermore, economic characteristics, heterogeneity, and stakeholder behaviors are among the other significant aspects that might impact real estate values (Despotovic et al., 2023). Thus, while working with a large number of properties with various features, valuation professionals are unable to handle

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such volumes of data and considerations accurately and efficiently (H. Lee et al., 2024). Hence, to address such issues, smart, trustworthy, and efficient automated valuation models (AVMs) should be used (Krämer et al., 2023; Matysiak, 2023).

AVMs have generated a buzz in real estate because they can be used for several purposes. It is found that AVMs have higher precision than traditional appraisal methods, particularly for commercial real estate (Renigier-Biłozor et al., 2019). Glumac and Des Rosiers (2020) exemplified a range of applications deemed most critical for AVMs, including iBuyer platforms, mortgage financing, and mortgage-backed securities as well as property tax assessment. Other applications may include land readjustment, portfolio risk assessment, real estate investment, insurance risk assessment, lending risk evaluation, and negotiation margin (Renigier-Biłozor et al., 2022). Marketing real estate, in addition, the intricate process of valuing real estate requires the consideration of numerous value-related criteria that vary by type, origin degree of impact, and unit measurement (Su et al., 2021). In this context, AVMs presume that the value of a property is predicted by various independent factors and estimate the value as an outcome variable in parametric or non-parametric regression models over different dimensions of value (Renigier-Biłozor et al., 2022). Apart from these essential features, some researchers further leverage artificial intelligence (AI), computer vision, and deep learning to extract certain visual characteristics from image data, such as interior, external, and remote sensing images, to improve the AVMs' predictive capabilities (Baur et al., 2023; Wan & Lindenthal, 2023). Although contemporary valuation techniques have been shown to reduce uncertainty in the real estate valuation field, their actual application has lagged behind expectations, and one of the main reasons may be the inability to obtain reliable and accurate datasets (Batista & Marques, 2021). Besides, AVMs require clear, structured, precise, and classified data about different property features (Yalpir et al., 2021). In addition, unbiased, objective, systematic assessments of real estate have always been essential (Oliveira et al., 2021). The need for a fair market value appraisal is urgent now because banks need to know the value of a property before approving a loan and the government needs to know the value to calculate property taxes accordingly (Droj et al., 2024).

AVMs are currently in high demand in the real estate market because they can deliver property values faster, better, and cheaper (Matysiak, 2023). Also, the deep involvement of big data and technology in the real estate sector has boosted the development of AVMs into becoming an important tool for property complementary (Despotovic et al., 2023). A summary of earlier literature review research regarding the application of AVMs in real estate contexts can be found in Table 1. Therefore, this paper aims to review the strategic use of AVMs for real estate valuation, shed light on their shortfalls and limitations in practice, and explore their potential impact and advantages they present to the industry stakeholders based on the following research questions (RQs):

RQ1. In what ways have AVMs influenced strategic practices in the real estate sector?

This research question investigates how AVMs have a revolutionary impact on strategic decision-making in the real estate industry.

RQ2. What are the main AVMs opportunities and challenges in the real estate sector?

Given the strategic role of AVMs identified in RQ1, this research question addresses the opportunities and challenges that AVMs bring, which are crucial in comprehending the practical adoption and success of AVMs in the real estate industry.

To this end, a systematic review of the literature was carried out with an emphasis on the strategic applications for real estate valuation to contribute to research on the development of modern AVMs. The structure of the remaining paper is described herein. Section 2 describes the

Table 1. Main literature review studies on automated valuation models and real estate

Author(s)	Keywords	Number of articles	Focus
Tekouabou et al. (2024)	Artificial intelligence; machine learning; systematic survey; urban real estate; prediction	70	A systematic review of machine learning-based artificial intelligence in urban real estate prediction
Wei et al. (2022)	Real estate appraisal; big data; hedonic price model; valuation method	124	Reviews literature on hedonic price model-based real estate appraisal in the era of big data
Bilge and Yaman (2021)	Integrated project delivery; building information modeling; project management; information management; project lifecycle; real estate development lifecycle	45	Review of literature on information management roles in real estate development lifecycle
D. Wang and Li (2019)	Mass appraisal; artificial intelligence; real-estate; geo-information systems; mixed models	104	Review of literature on mass appraisal models of real estate
Our study	Systematic literature review; automated valuation models; real estate	97	A systematic review of the strategic applications of automated valuation models in the real estate

methodology adopted for the systematic literature review, explaining the research questions, scope, database, and criteria for the search and selection of the final pool of papers. Next, Section 3 delves deeper into the content analysis outcomes, presenting the significant findings from influential scholarly articles. Building upon this, Section 4 encompasses an extensive discussion along with future research perspectives, and the main conclusions of the review are presented in Section 5.

2. Methodology

The study methodology used to investigate the literature on AVMs and real estate, as well as the interactions between both of these topics, was a systematic literature review (SLR). An SLR is a significant research procedure that goes beyond a simple review of prior studies and employs a pre-planned research strategy. The purpose of this kind of review is to address particular research questions, expand upon prior research, choose and assess contributions, analyze and synthesize data, and present evidence in a way that enables the researcher to make their own decisions regarding what is known and unknown (Denyer & Tranfield, 2009; Malek & Desai, 2020). Compiling the findings from various studies on a particular subject leads to a deeper level of conceptual or theoretical growth and a better grasp of the subject than would be possible with a single investigation (Thomé et al., 2016).

The present study reported the information of quality and relevance for the chosen publication by using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. To move away from the subjective processes that produce biased research, the PRISMA group developed these standards in 2009 to report methodically and statistically to ensure complete transparency (Liberati et al., 2009). Finding a relevant journal article about AVMs in the real estate industry is the first step, which prompts a topic-based search for SLR in two licensed databases (Scopus + WoS). According to several researchers, these are the most extensive relevant databases for our research issue (Kipper et al., 2020; Vieira & Gomes, 2009).

Using the query string in the advanced search, the databases have revealed over 652 available articles. During the penetrating keywords phase, the keywords and queries string information method was employed to locate related material. The query string search for the Scopus database consists of TITLE-ABS-KEY ("automated valuation models" OR "automated property appraisal") AND "real estate" OR "property" OR "dwelling" OR "house" OR "housing"). Meanwhile, the WoS query string search is TITLE-ABS-KEY "automated valuation models" OR "automated property appraisal" AND "real estate" OR "property" OR "dwelling" OR "house" OR "housing"). The second step involves going through the listed literature and selecting the appropriate articles related to the study's topic.

The third step consists of the eligibility and exclusion process. The authors have determined a number of eligibility and exclusion criteria (All peer-reviewed journal articles published in the English language between January 2000 and July 2024 are among the inclusion criteria that are applied. Similarly, only articles that directly addressed the strategic use of AVMs in the real estate industry were taken into account. Under the exclusion criteria, editorials, PhD and master's theses, book chapters, conference papers, and proceedings were excluded. Moreover, publications that were accessible before the year 2000 were disregarded to allow space for the analysis of more current research on the selected topic. Lastly, publications that the authors were unable to access were also excluded). Subsequently, the publications were examined comprehensively to verify their alignment with the research goal. Following this last evaluation, 97 papers were remained. The fourth phase of data analysis and synthesis involved classifying the selected articles according to their title, author, year of publication, kind of publishing, type of research, and theme of approach. The results were categorized to provide a clearer picture of the previous research works in this field. An overview of the strategic applications of AVMs in real estate was provided in the fifth phase through discussions regarding the content analysis and the research's results.

Following the search process, 97 peer-reviewed scientific articles were found to be the primary sources discussing or concentrating on the strategic applications of AVMs in the real estate industry.

- **Year-wise publications:** The publication window was unrestricted and extended until July 2024 with a total of 9 articles. Between 2020 and 2023, there was a notable increase in the number of publications (total 36 articles). Researchers' interest in the contemporary and highly significant construct of automated valuation, its consequent innovations, and their strategic implications is evident from the increasing trend in the number of publications.
- **Journal-wise publications:** The research is broadly dispersed throughout numerous journals. Academic papers have covered AVMs and real estate in great detail. There is decentralization across thematic areas – engineering, urban studies, technological and social change, operations management, and strategy. Concerning the numbers, leading journals included the Journal of Property Investment and Finance, Journal of Property Research, Journal of Real Estate Finance and Economics (n = 5 each), and Journal of Property Tax Assessment and Administration, and Sustainability (n = 4 each), followed by Property Management (n = 3).
- **Contributions by Country:** This section covers the contribution of different countries to the literature on real estate and AVMs. Aside from China, developed countries in America, Europe, and Asia account for the majority of publications. The analysis indicates the topmost productive countries. With 13 publications – 13.4% of the pool of articles–China is the

most productive country. Poland, the USA, Australia, and Italy produced 8.2%, 7.2%, 6.2%, and 6.1% of the total literature, respectively. The main factor contributing to higher productivity in countries like China is the easily accessible and well-documented data. The availability and dependability of property transaction data are major issues in the majority of developing countries, which limits the scope of AVMs research.

- **Research method:** We examined the trend of different research methods used to investigate the strategic applications of AVMs for the real estate sector, taking into account the importance of the research methodologies utilized in the articles. It is evident from our findings that mixed studies (n = 25) make up the majority of the literature, followed by empirical/case studies (n = 19), survey (n = 17), modeling (n = 15), literature reviews including conceptual papers (n = 12) and experimentations (n = 6) and simulation articles (n = 3). The results indicate that both qualitative and quantitative academic views have drawn attention to the current study issue. The case studies included an overall validation of the theoretical principles coupled with practical applications, while the conceptual and review papers explained how AVMs may affect various real estate markets. Prototypes, simulation techniques, and testing are nevertheless necessary to evaluate design issues and suggest feasible solutions.

3. Data analysis and findings

Following a comprehensive review of 97 carefully selected papers, we conducted a content-based analysis of the literature. To make informed decisions, content analysis aims to organize and evaluate the information acquired (Gaur & Kumar, 2018). The topics and keywords found in each pertinent article were identified using a content analysis of the articles. To aid in the discussion that follows, the primary real estate sub-sectors, AVM approaches, and strategic applications of AVMs in the real estate industry are defined in the following subsections.

3.1. AVMs approaches

In terms of AVM approaches, the majority of articles have taken a broad perspective. More than one approach was discussed in some papers, which resulted in 136 approach references from 97 papers. During the analysis, we found that not all AVM approaches have received the same amount of attention in the literature. The most singly addressed AVM approaches were hedonic pricing models (HPMs), machine learning (ML) models, artificial neural networks (ANN), and hybrid models (HM). Some of the approaches are at more advanced stages of maturity (e.g., HPM, ML, and ANN) in research and real estate property applications, while others such as genetic algorithm (GA) (Cardone et al., 2024) are still in the early stages of development. Remarkably, although regression analysis (RA) applications are only starting to be implemented in real estate property (Foryś, 2022), RA itself has already attracted considerable academic attention.

Automated valuation models may produce a report in a matter of seconds and utilize a variety of data sources, including location, property age, and condition (Krämer et al., 2023). AVMs are practical for real estate buyers, as they reduce the need for prospective buyers to personally check every property on the market (Jafary et al., 2024a). The primary AVMs approaches that are intended to give an accurate picture of AVM performance are covered in the following subsections.

3.1.1. Hedonic pricing models

The unique features of the housing market have led to the widespread application of hedonic pricing in real estate assessment research. This approach evaluates real estate pricing by considering the core attributes of the asset (Zaki et al., 2022). The hedonic approach would assert the wisdom of real estate as an asset that can be considerably conformed by many in terms of location, number of rooms, or living area (Potrawa & Tetereva, 2022). Property attributes in this sense are often grouped according to their hedonic characteristics. Gröbel and Thomschke (2018) characterized the three fundamental groups: locational group referring to real estate attributes like view type, distance to central business district (CBD), structural attributes delineating the housing space, such as number of bedrooms, or building age; and neighborhood features as characterizing a real estate.

Until recently, the hedonic pricing model (HPM) has been widely used to estimate the market value of real estate utilizing multiple regression analysis (Rey-Blanco et al., 2024; Zaki et al., 2022). The model presupposes that real estate is a differentiated commodity with various characteristics defining utility (Potrawa & Tetereva, 2022). In other words, the buyer of a property is buying not this or that characteristic of the property, but rather a set of them that can be realized in specific value to utilities. Multi-family residences are different in that parking issues will drive up the price of the actual property (Valdez Gómez de la Torre & Chen, 2024). This can be attributed to a generic instance of the model, criticized in some literature for oversimplifying the nonlinearity or complexity of the real world (Rey-Blanco et al., 2024; R. Wang & Rasouli, 2022). Following Schirripa Spagnolo et al. (2024), the functional form of the standard HPM is informed by robust priors on housing and household preferences. The model assumes that every attribute is continuous and discrete which means perfect competition, market equilibrium, discrete preference, and a union of the market.

3.1.2. Machine learning models

Machine learning (ML) is changing the real estate valuation sector. ML is a state-of-the-art artificial intelligence technique that learns from the provided input data being used to give the right predictions (Potrawa & Tetereva, 2022). Moreover, ML can be more disruptive in terms of

changing existing valuation methodologies (Zaki et al., 2022). More and more are leveraging these technical advancements in their work, which is clear, especially with the increase of papers around the topic: The body of literature on utilizing Machine Learning models for real estate valuation is rapidly expanding. Several studies show that ML-based AVMs outperform human pattern recognition-based models (Steurer et al., 2021; Su et al., 2021). In addition, in real estate forecasting, ML techniques such as decision trees, random forests, and gradient boosting are becoming more popular (Doumpos et al., 2021; Sing et al., 2022). It also constructs an advanced model that allows accessing large complex data sets, and inferring patterns to forecast more accurately (Potrawa & Tetereva, 2022). However, these methods can capture non-linear patterns but require extensive data preprocessing and parameter tuning to avoid overfitting (Baur et al., 2023).

3.1.3. Artificial neural networks

The artificial neural network (ANN) is one of the stream methods commonly employed for appraisal purposes (Kamara et al., 2020). The ANN computational model can accept much more variation than HPM can, given the fact that it does not rely on linear bonds (Foryś, 2022). After this, the ANNs, using a complex system of artificial neurons, can predict house prices since they know how each real estate-related input variable relates to its corresponding output (Horvath et al., 2021). There are several studies to test the superiority of HPM and ANN which have been done in real estate appraisal. In general, ANN has reportedly delivered MAE of 5–10% for property valuation methods, however, the average HPM is higher and typically ranges from 10 to 15% (Abidoye & Chan, 2017, 2018). However, there are no specific numbers on how many samples to use when valuing real estate with ANNs can be effective and if this is a universal principle (Hoxha, 2023). The primary advantage of using ANNs is that they can care for uncertainty input into the prediction model, provide gain in terms of accuracy, and are time-saving (Foryś, 2022). ANNs operate as black box apparatuses meaning, the process of how the output values were generated is not explicated (Yasnitsky et al., 2021). Because of this lack of transparency, ANNs are difficult to utilize in certain scenarios, such as expropriation and property taxation, where the assessments may be contested and require a legal defense (Rampini & Re Cecconi, 2021).

3.1.4. Hybrid models

The goal of the hybrid model is to reduce counterarguments. This paradigm is described as a system that combines elements of both new and old components built in an agile manner, creating a synergistic whole (Kamara et al., 2020). In this particular domain, hybrid refers to the interchangeable use of Combining human intervention (e.g., field inspection and situations where physical inspection is required to obtain initial property features, the analysis of results, and final decisions) with computer use (e.g., calculation processes); manual (e.g., for coding variables and quality control programs); automated solutions (e.g., for assessing the significance of features, comparable properties selection); and classical learning (e.g., regression, classification, association, clustering, generalizations) with deep learning and neural nets within ML approaches (e.g., recurrent neural networks, convolutional neural networks, generative adversarial networks) (Nor & Raheem, 2024; Özöğür Akyüz et al., 2023). These hybrid techniques can improve the accuracy and dependability of valuation decisions by incorporating domain experience and expert knowledge into ML-driven valuation models, especially in specialized or complicated real estate markets (El Jaouhari et al., 2023; X. Zhang et al., 2024).

3.1.5. Geospatial models

The geographical components of real estate prediction are examined using geospatial analysis models (Aydinoglu & Sisman, 2024). Spatial statistics and geographic information systems (GIS) are useful tools for modeling real estate trends based on proximity and location (Mete & Yomralioglu, 2023). Although they might need unique data, these techniques are crucial for studying location-specific characteristics (Xia et al., 2022). The standard hedonic price regression model is not able to effectively address these spatial issues given the substantial spatial autocorrelation and spatial variability of housing price data (Schirripa Spagnolo et al., 2024). Thus, two spatial modeling paradigms have been developed as a result of researchers' improvement of the model through the consideration of spatiality. First, several researchers have combined traditional hedonic price regression with spatial econometrics models (Oust et al., 2020; R. Wang & Rasouli, 2022). For instance, Y. Wang et al. (2017) found that the spatial lag and spatial error model produced better accuracy than the ordinary least squares (OLS) regression model when examining Beijing, China, home prices. Others have mostly focused on how spatial variability affects housing costs. For example, Cao et al. (2019) examined the cost of public housing in Singapore using big data from smart cards and discovered that the geographically weighted regression (GWR) model performed significantly better than classic linear regression. Second, some studies estimate housing prices using spatial interpolation in addition to spatial econometric models (Dambon et al., 2021; Zhou et al., 2020). The primary benefit of this approach is its ability to retrieve the price surface of the entire region using a small number of sampling points (Aydinoglu & Sisman, 2024). Further, geospatial modeling has significantly increased accuracy when compared to numerous linear regression models (Saldana-Perez et al., 2024).

3.1.6. Regression analysis

Through the use of regression analysis, a set of data can be examined to estimate a potential functional relationship between an independent and dependent variable (Foryś, 2022). Besides, "Multiple" regression methods are characterized by the dependent variable being a function

of multiple factors in general (Liu, 2022). Precisely such systems need to be used for the study of intricate economic systems such as the real estate market (N. Chen, 2022). Much like in regression analysis, the appraiser defines the independent factors that impact the value in regression analysis and then chooses the conditional attribute in the same manner (Carbonara et al., 2021). In the last stage, the appraiser examines the connections between conditional and decisional features (Liu, 2022). Furthermore, since they are comprehensible and capable of handling numerous predictor variables, both linear and non-linear regression models are often employed in real estate forecasting (Pai & Wang, 2020). However, if not properly adjusted, they may overfit and fail to adequately represent non-linear connections (Steurer et al., 2021).

3.1.7. Income and cost approach

The income approach states that the capitalized value of the income that a piece of income-producing real estate generates both now and in the future, matches the piece's market value (Glumac & Des Rosiers, 2020). The appraiser assesses the amount, quality, direction, and duration of this income before converting it into an expression of present value, or market value, using an acceptable capitalization rate (Su et al., 2021). Either the Discounted Cash Flow (DCF) method or the direct capitalization method is used to estimate the value of the property under investigation, depending on its kind and complexity (Frodsham, 2024). The DCF method makes sense theoretically and is especially suitable for assets with many income streams that are not often traded (like hotels and shopping malls) (Čirjevskis, 2021). Furthermore, the cost approach is used to determine a property's value by adding the land value and the depreciated reconstruction cost (DRC) (Arcuri et al., 2020). According to the cost approach, a real estate asset's market value is equal to the land purchase price plus building costs, minus depreciation (Leskinen et al., 2020). Further, the cost approach is mostly applied to single-use, non-income-producing real estate properties (such as schools and churches) and certain industrial buildings that are rarely sold on the market for property insurance purposes (Su et al., 2021).

3.1.8. Market approach

The market approach consists of determining the property's value by contrasting the property under assessment with similar properties for which transaction prices or sales are available (Tajani et al., 2019). Its accuracy and application are largely dependent on the level of development and local circumstances of the real estate market, with the valuers' main duty being application and interpretation (Ghosn et al., 2024). However, there is a wealth of literature regarding challenges associated with valuation, especially when applying the market approach. Information asymmetry (Li et al., 2019), valuation variances (Arcuri et al., 2020), uncertainty in valuation (Despotovic et al., 2023), and accuracy of valuation (H. Lee et al., 2024) are only a few of the challenges covered by these studies. As a result, in reality, practitioners alter this fundamental model based on the kind of property being valued, variations in the amount of available market data, technological developments, raised client awareness, requests for greater accuracy in the assessed values, and generally altered real estate market dynamics (Ghosn et al., 2024; Tajani et al., 2019).

3.2. Integrating AVMs in real estate: Strategic applications (RQ1)

The number of published articles in this research area led to the identification of eight separate real estate subsectors. With 24% of the articles, real estate development was identified as the primary real estate sub-sector. The real estate investment subsector contained 19% of the documents, followed by land administration (16%). Leasing and renting, Property transactions, and real estate business only contributed 9%, 7%, and 5% of the papers, respectively. Lastly, real estate administration and real estate maintenance received less attention.

Two more "segments" were found in light of the existence of several publications about the global real estate market and the investigation of mixed intended uses in the same study. It should be noted that the studies that concurrently examined the effects of AVMs on two or more real estate subsectors were included in the "mixed uses" group. Instead of focusing on a particular intended purpose, the "global real estate market" segment is meant to gather research that examines the dynamics and trends of global real estate indices to identify the broader impact of AVMs.

3.2.1. Real estate development

The goal of real estate development is to use investments to raise the value of a single property or an area within a property (Baur et al., 2023). A plot of land within a real estate, a building or its components within a plot, or a land or water region that forms raw land for real estate can all be the object of real estate development (Jafary et al., 2024b). Development of real estate can either concentrate on the portion of land that is still undergoing planning or on already existing real estate and its components (Reite, 2023). Furthermore, AVMs–particularly those that use HPM–evaluate property values by considering both locational and intrinsic qualities, offering a thorough breakdown of value drivers (Abidoye & Chan, 2018). Similarly, ML models, especially neural networks, are excellent at analyzing big data sets to identify intricate patterns and make remarkably accurate predictions about real estate prices while dynamically responding to shifting market conditions (Pai & Wang, 2020). Furthermore, regression analysis is still fundamental since it uses statistical modeling to quantify the correlations between values and property attributes (Liu, 2022).

3.2.2. Real estate investment

Investing capital in real estate or its components to generate profit or other advantages is referred to as real estate investment (Swietek, 2024). According to Saldana-Perez

et al. (2024), the most recent ML models offer precise cost estimation through data exchange formats, assess risk, growth, and depreciation rates in real estate investments, and give the owner clear, graphical, and economically significant information. Since ML models are parametric and smart, Fazeli et al. (2020) proposed a semi-automated BIM-based cost estimation approach that enables practitioners to estimate the cost of projects. Further, real estate depreciation was calculated using HPM by R. Wang and Rasouli (2022), providing developers and real estate managers with an effective tool for decision assistance. Further, Lisi (2019) integrated a market approach, multiple regression analysis, and the implicit prices of housing to evaluate environmental impacts during the early stages of design and provide building envelope alternatives for decision-making throughout the building lifecycle.

3.2.3. Land administration

Information regarding the ownership, value, and usage of land and its related resources are recorded and disseminated through the process of land administration (C. L. Lee et al., 2024). Several research concentrating on land administration and taxation highlight the new opportunities for real estate valuation making use of the advantages of machine learning models, particularly by applying and/or expanding the land administration domain model (LADM), which is an international standard for land administration (Atazadeh et al., 2021; Indrajit et al., 2020). According to Rey-Blanco et al. (2024), HPMs offer a comprehensive examination of property values through the dissection of intrinsic features and locational qualities, facilitating fair land assessment and efficient property taxation. Similarly, hybrid models combine sophisticated algorithms and conventional valuation methodologies to provide comprehensive land valuation frameworks by fusing the predictive power of contemporary technologies with the interpretability of proven methods (Kamara et al., 2020). Likewise, regression analysis measures the connections between values and land attributes, offering factual information for determining land values and formulating policies (N. Chen, 2022).

3.2.4. Leasing and renting

The transfer of the right to use real estate or any portion of it in exchange for money is known as leasing (Y. Zhang et al., 2020). This includes land leasing, apartment leasing, and lease-purchase. In a similar vein, renting involves paying for the privilege of using real estate (Tanrıvermiş, 2020). The fourth-largest literature category was devoted to studies on leasing and renting, which mostly contained solutions intended to alleviate existing leasing problems, like intermediary dependencies, inefficiencies, and trust issues (J. Chen et al., 2022; Rosenthal et al., 2022). Further, the leasing process is frequently manual, labor-intensive, and paper-based (Y. Zhang et al., 2020), which adds to the industry's non-transparency, high costs, information asymmetry, and fraud.

Through the dissection of intrinsic qualities and locational elements, AVMs-enabled HPMs could assess the worth of properties and help landlords and renters negotiate for reasonable rental rates that are in line with market dynamics and property details (Potrawa & Tetereva, 2022). Furthermore, geospatial models improve market segmentation and strategic property positioning for rental investments by utilizing spatial data to evaluate rental values based on neighborhood dynamics and proximity to facilities (Aydinoglu & Sisman, 2024). Further, landlords can set competitive rents and maximize property management techniques with the help of regression analysis, which quantifies the links between rental property qualities and market rates (Carbonara et al., 2021).

3.2.5. Property transactions

The purchase and transfer of proprietary rights to real estate or its components is known as a property transaction (Evangelista et al., 2020). Actions about the purchase and sale of real estate, such as real estate exchanges, purchases, sales, and valuations, are included in the category of property transactions (Jiao & Xu, 2022). AVMs could primarily assist in resolving the problem of intermediary-dependent, manual, paper-based, expensive, and time-consuming property transaction processes (Glumac & Des Rosiers, 2020). Furthermore, by breaking down property values into intrinsic qualities and locational aspects, HPMs may offer a thorough analysis that supports reasonable pricing and negotiation tactics (Zaki et al., 2022). Similarly, ANNs use massive datasets to forecast real estate values based on past performance and present market dynamics, providing critical information for pricing competitiveness and investment choices (Horvath et al., 2021). Further, the cost approach assesses property value based on replacement or reproduction costs, directing decisions on property renovations and asset assessment (Glumac & Des Rosiers, 2020), whereas the income approach assesses property worth based on income-generating possibilities, which is crucial for evaluating investments in commercial real estate (Su et al., 2021).

3.2.6. Real estate business

The activities with financial goals connected to the ownership, use, and production of real estate or the provision of services to customers within it are collectively referred to as real estate business (Matysiak, 2023). Establishing services that create value addition for real estate users, and consequently, owners and investors, throughout the real estate lifecycle, is the fundamental concept of the real estate business (Krämer et al., 2023). AVMs combining several approaches – like cost, income, and market approach – provide complete valuations in the real estate business helping guide strategic business decisions (Tajani et al., 2019). These approaches facilitate pricing strategies, risk management, competitive positioning, and market analysis, which promotes operational excellence and business success (Glumac & Des Rosiers, 2020). Further, Kamara et al. (2020) proposed a novel hybrid neural network model to generate property values instantaneously.

3.2.7. Real estate administration

Real estate administration includes the management of real estate-related finances, operations, human resources, and information services, as well as the administration of real estate-related legal matters (Renigier-Biłozor et al., 2022). More specifically, real estate administration can be defined as the management of the complete real estate company and building management (Wan & Lindenthal, 2023). As per Rey-Blanco et al. (2024), HPMs break down property attributes to determine how each one contributes to market value, taking into account the complex preferences of both buyers and sellers. Meanwhile, ML models, which are distinguished by their capacity for adaptive learning, enhance valuation accuracy by combining large datasets and spotting complex patterns those conventional methods might miss (Foryś, 2022). Further, Saldana-Perez et al. (2024) argued that geospatial models might use spatial data to contextualize valuations in space and capture localized market dynamics.

3.2.8. Real estate maintenance

The service of keeping real estate in the intended state and with the desired condition, value, and attributes is known as real estate maintenance (Batista & Marques, 2021). Energy management, facility services, technical services, cleaning services, trash management, and management of outdoor areas are all included in real estate maintenance (Yalpir et al., 2021). Rey-Blanco et al. (2024) assessed market prices and examined the features of the properties using HPM, which helped with portfolio management and property tax assessments. Moreover, Ogunfowora and Najjaran (2023) developed an ML system to improve maintenance scheduling by estimating the life of equipment and allocating resources as efficiently as possible using past data. In addition, Aungkulanon et al. (2024) employed a hybrid approach to estimate maintenance requirements and lower operating expenses by fusing real-time sensor data with predictive analytics. Similarly, Cheng et al. (2020) developed a framework based on BIM and IoT technologies for property maintenance management to compare the costs of property maintenance to those of comparable assets, helping to guide decisions about maintenance and redevelopment expenditures.

Furthermore, we summarize the strategic applications of AVM approaches in different real estate subsectors from the perspective of three fundamental pillars, such as technology, social, and environment, in Table 2, which includes knowledge from our extensive descriptive and content analysis of academic publications.

Table 2. Strategic applications of AVM approaches in different real estate subsector

AVM approach / Real estate subsector	Real estate development	Real estate investment	Land administration	Leasing & renting	Property transactions	Real estate business	Real estate administration	Real estate maintenance
Hedonic pricing models	Property and Land valuation based on amenities, location, and market conditions	Comparative pricing analysis of property features for investment purposes	Land valuation for taxation and public policy determination	Rental pricing is based on property features	Estimating transaction prices via feature-based comparisons	Pricing tactics are determined by market dynamics and consumer preferences	Regulation compliance and real estate tax assessments	Forecasting maintenance costs by feature-based comparisons
Machine learning models	Predictive models for risk assessment and development profitability	Market trend analysis and portfolio optimization	Automated assessment for urban planning and zoning	Forecasting changes in rental prices using past data	Precise and dynamic estimation of property values in rapidly evolving marketplaces	Predictive modeling and scenario analysis for business intelligence	Predictive analytics for optimized property management and increased operational effectiveness	Predictive maintenance plans are built on insights from machine learning and historical data
Artificial neural networks	Assessing complex non-linear market factors to identify development prospects	Risk reduction through the examination of market emotions and investing trends	Automated border appraisal and land parcel identification	Nonlinear pricing forecasting for intricate leasing situations	Forecasting transaction prices in different market scenarios	Demand forecasting and sophisticated market segmentation for real estate companies	Automated property management using forecasts of several variables for trends	AI-based property degradation and maintenance requirement predictions
Hybrid models	Combining several AVM approaches for development planning and accurate valuation	Combining market and economic data to enable sound investment decision-making	Thorough valuation for infrastructure development and land registration	Dynamic pricing models combining machine learning, ANN, and hedonic methods	Strong transaction pricing using a variety of assessment techniques	Integrated valuation models for improved decision-making	Coordinated administrative decision-making and property valuation systems	Hybrid model-based maintenance cost forecasting and optimization

End of Table 2

AVM approach / Real estate subsector	Real estate development	Real estate investment	Land administration	Leasing & renting	Property transactions	Real estate business	Real estate administration	Real estate maintenance
Geospatial models	Land use-optimized valuation based on geographic and locational considerations	Investment tactics focusing on geography-based asset valuation	Geographic information systems (GIS) for planning and land registration	Spatial analysis of pricing dynamics and rental demand	Estimating transaction prices with the use of geographic data	Location-based strategic planning and business intelligence	Effective property management and land use planning using GIS	Geographical forecasting for environmental factor-based maintenance planning
Regression analysis	Linear regression for expenses and revenue estimation in development projects	Forecasting investment performance and analyzing market trends	Determination of property value for tax assessment and land-use policy	Regression models to forecast rental prices based on property attributes	Transaction pricing forecasts derived from regression analysis of past data	Regression analysis for financial forecasting and valuation	Regression model-based administrative assessments and reporting	Modeling maintenance costs using historical attributes and trends
Market approach	Pricing new developments through comparative market analysis	Benchmarking real estate investments against market comparables	Market value evaluation for property parcels in public and private transactions	Rental property comparison within the same market	Assessment derived from analogous real estate transactions	Market-driven pricing tactics for corporate activities	Reviewing and evaluating market-based valuations through administrative processes	Evaluating maintenance expenses via market comparisons
Income & cost approach	Project viability analysis based on development expenses and anticipated revenue	Analyzing capitalization rates and revenue through real estate investment appraisal	Assessment of land use considering development expenses and prospective profits in the future	Valuation of rental income for rental properties	Transaction pricing determination based on income-generating potential	Strategies for income-based real estate operations valuation	Evaluations of administrative expenses and strategies for generating income	Analyzing maintenance costs in light of the cost structure and prospective revenue of the property

3.3. Opportunities and challenges (RQ2)

Navigating the real estate industry's vast AVM landscape reveals an array of opportunities and challenges. There is enormous complexity in the number and types of data sources that have to be integrated – ranging from market reports to real estate listings. Moreover, an advanced infrastructure is required to manage the heavy data load in time and quality (Glumac & Des Rosiers, 2020). The real estate markets also indicate the difficulty of validating accuracy and so require agile systems that can handle change faster (C. L. Lee et al., 2024).

Opportunities: The real estate industry can benefit a lot from AVMs, mainly in terms of enhancing decision-making skills, improving accuracy and efficiency (D. Wang & Li, 2019). AVMs can simplify the procedures of property valuations and consume fewer labor costs and timeframes than conventional methods to evaluate properties (Bilge & Yaman, 2021). In addition, AVMs allow dynamic decisions in the field of real estate investment and portfolio management through on-the-fly valuation adjustments because of market fluctuations (Wei et al., 2022). AVMs have powerful advanced analytics such as ML and ANNs to improve prediction accuracy – allowing investors to anticipate market movements, and hedge their risk (Abidoye & Chan, 2018). By utilizing geospatial data to contextualize valuations within local market dynamics, these models enhance the precision of property assessment and strategic planning (Ghosh & Mukherjee, 2018). Additionally, AVMs also allow for the optimization of resources and reduction of transactional risks while taking advantage of market opportunities by automating complex valuation processes (Tekouabou et al., 2024). This in turn ensures a more firm and effective real estate industry (Droj et al., 2024).

Challenges: While there are benefits to using AVMs, there are also many challenges. One of the primary challenges of AVMs is that because most of them are heavily data-dependent – drawing information from various databases and sources like property attributes, transaction histories, or market conditions – achieving high-quality and accessible data becomes an issue to grapple with (Oliveira et al., 2021). Inconsistent or outdated data may then cause inaccurate values, which in turn could compromise the effectiveness of the model (Yalpir et al., 2021). Model Transparency and Complexity: In the last background, model transparency is also necessary to bear in mind, and due to their complexity, advanced techniques such as ANNs and

Table 3. Summary of opportunities and challenges from the selected papers

Groups	Opportunities	Challenges
Technological	Improved prediction accuracy using neural networks and machine learning	Issues with data availability and quality
	Agile decision-making is facilitated by real-time value updates	Advanced models' complexity and lack of transparency
	Combining several data sources (such as transactional and geospatial) for a thorough analysis	Inability to adjust to quickly evolving data environments and technological advancements
	Time and labor costs are decreased through the automation of valuation operations.	Data privacy issues and cybersecurity threats
	Using advanced analytics to spot investment opportunities and market trends	Reliance on substantial datasets that aren't always available
	Capacity to effectively manage vast amounts of data	Models must be updated and maintained constantly to guarantee relevancy
Environmental	Environmental risk assessment supporting proactive maintenance and management of real estate	Difficulties in accurately incorporating and updating environmental data
	Enhancing evaluation of the effects of environmental changes (such as climate change and natural disasters) on property values	Variability in the local environment influencing the model's output consistency
	Promoting sustainable growth by making well-informed decisions	Complicated interactions between environmental factors
	Enhanced distribution of resources for environmental sustainability	Potential for bias in sources of environmental data
	Increased accuracy in property value taking into account the dynamics of the local environment	Predictive accuracy is impacted by market volatility and other variables (such as changes in the economy or regulations)
Social	Enhanced stakeholder trust through greater transparency in property appraisal	Human monitoring is required to handle subjective influences in value
	Democratization of real estate appraisal using easily available AVM instruments	The potential of algorithmic bias affecting valuations' equity and fairness
	Process simplification improving stakeholder engagement and customer satisfaction	Industry experts' resistance to the changes in standard processes
	Improved ability to predict and reduce market risks	Ethical issues in using data and making decisions using algorithms
	Assistance in formulating policies with data-driven perspectives on housing markets Encouraging more informed investment decisions from the public and private sectors	Automating real estate transactions while maintaining a requirement for individualized services

ML are difficult to interpret, which complicates the understanding of how a decision was made (Foryś, 2022). Externally, they have to face market volatility, and the influences that come from outside, such as changes in the economy or regulations, cause the model to fail in predicting the future creating uncertainty in valuation results (Batista & Marques, 2021). In addition, human judgment still plays an important role in the transactions of real estate, as valuations take into account subjective factors while property inspections have to be done in person, causing problems for AVMs when they only rely solely on data (Batista & Marques, 2021). Consequently, taking into account that progress in the field of models and methods used in AVMs will occur dynamically due to new data sources, improved model approaches, and changing regulatory framework, the readiness of these models to be applied should always be qualified (Renigier-Biłozor et al., 2022).

Based on the content analysis of the 97 articles, we have grouped challenges and opportunities into the following segments: (1) Environmental, (2) Social, and (3) Technological (see Table 3).

4. Discussion

Global real estate markets are developing quickly both as an asset class for investors and as a means of facilitating human interaction. As a result, the accuracy of their value is becoming a more important indicator of their performance and appeal to businesses, governments, and communities (Swietek, 2024). Policymakers are facing mounting pressure to devise tactics and implement novel regulatory structures that enhance the efficiency of the real estate market, thereby enabling the sector to rival other asset classes, in response to the changing demands of investors, enterprises, and consumers (Jafary et al., 2024a; Reite, 2023).

To this end, the discussion considers possible areas for future research and development and considers the strategic implications of including AVMs in real estate valuation processes. The use of AVMs methods in the evaluation of real estate carries promise for faster, and more accurate property valuation (Despotovic et., 2023). AVM-driven valuation techniques may be automated and facilitated by effective ML models and HPMs for accurate, faster property valuations (Evangelista et al., 2020; Potrawa & Tetereva, 2022). These models can capture complex market dynamics and provide stakeholders with valuable information through the use of large datasets and state-of-the-art computational methods. In addition to this, the integration of ANNs with real estate appraisal allows stakeholders to anticipate market behaviors and trends, identify risks, and be able to make sound investment choices (Abidoye & Chan, 2017). So AVMs-enabled regression analysis can also analyze historical data and market indicators from the past to help give a better estimate of property values/value trends and potential (N. Chen, 2022). To ensure trust together with regulatory compliance when using AVM-based valuation processes methods should be accounted for (Doumpos et al., 2021). Similarly, the development of acceptance and use of AVMs in real estate needs to consider bias, data privacy, and interpretability of AVM methodologies (Jafary et al., 2024b).

In the realm of strategic applications, it is evident that an AVM plays a vital role in revolutionizing the real estate industry such as decision-making, and enhancing efficiency and accuracy of valuation. Such AVMs provide geospatial data derived, real-time property valuations, as a function of machine learning and advanced analytics rendering decision-making to the stakeholders in managing their portfolios (Steurer et al., 2021). These models have simplified the evaluation process reducing human errors, as well as time and cost associated with conventional approaches (Zaki et al., 2022). "AVMs also allow you to quickly assess market trends and estimate risk, which is a key driver of proactive property asset management" (Potrawa & Tetereva, 2022). In addition, AVMs are a comprehensive and agile method to assess property by combining diverse data resources through advanced algorithms (Baur et al., 2023). This results in data-driven and strategic practices in the real estate sector. Efforts should focus on the development of user-interpretable interfaces that are specifically tailored to real estate valuation, to improve interpretability and accuracy of AVM-driven evaluation models. Alternatively, as demonstrated by Baur et al. (2023), those approaches, that delve into the construction of hybrid AVM systems which combine human expertise with ML skills, offer a way forward for improved valuation insights and decision support. New insight and possibilities for both accuracy, efficiency, and transparency of property assessments are provided by the integration of ML-based AVMs in real estate valuation procedures (Potrawa & Tetereva, 2022). Considering the high demand to access and interpret vast datasets, real estate stakeholders can harness the transformational capability of AVMs to navigate through contemporary property mechanisms and formulate an ethical, regulatory, and technical solution that can redefine industry practice in a resilient sustainable future.

4.1. Future research directions

There is a potential in the future to be extremely important for the real estate sector due to its direct interest, among other things, in AVMs and real estate value. AVM approaches continue to evolve rapidly and so there are many research and development opportunities to make the valuation process better. There is a need for more research on AVMs-driven valuation approaches developed and implemented. These approaches use more advanced ML models like deep learning, computer vision, and natural processing language to automatize and enhance the procedure of valuation (Potrawa & Tetereva, 2022). Using massive datasets and advanced computational algorithms, these models would be able to generate more accurate and insightful property valuations. In addition to this, another advantage of using AVMs is that it might expand the predictive strength of real estate valuation. In addition, the AVM methods can detect patterns and relations which are more accurately done by analyzing past data and market trends to forecast with accuracy which property value drivers move the market. So, the use of predictive analytics can help stakeholders mitigate risks and select investments with more depth (Hoxha, 2023). Future research can also explore approaches to include data from diverse sources in AVMs-centric appraisal models. Some of the data is structured, some are unstructured, such as emotions in social media and satellite images, and property attributes, transaction histories, etc. An AVM-centric valuation methodology also has the added benefit of providing richer, more comprehensive evaluations of real property value by capitalizing on these diverse data sources as well (Foryś, 2022).

The focus of further study works in this field would be centered on issues relating to ethics and regulation in real estate valuation and AVMs (Nor & Raheem 2024; Özöğür Akyüz et al., 2023). The concerns of data privacy, bias, equity, and regulatory compliance need to be addressed with the increased adoption of AVMs in the valuation process. Future research work could develop models and recommendations to ensure that AVM-assisted policies are consistent with ethical norms as well as legal regulations. We further find that exploring hybrid AVM systems, fusing human knowledge with ML models, is an interesting way for future research. By refining and combining real estate value knowledge and expert domain experience into AVMs-driven valuation processes, these hybrid systems can increase the reliability and accuracy of valuation outcomes, particularly in more complex or niche property markets. As more real estate valuation index data become accessible, future research could replicate the current findings. Furthermore, supplementary qualitative case studies at the national and international level, for instance, provide additional specific data about transferred property, such as

owners and their addresses, purchase prices, land valuations, land use laws, and future modifications to land use laws. More in-depth information about the circumstances and structure of successful AVM investments, taking into account institutional configurations, political environments, regional contexts, and capability levels, would aid in the analysis and validation of the paper's findings.

More interdisciplinary research on the potential applications of AVMs in the real estate industry is needed. This research should bridge the gap between the technological perspective and other relevant perspectives, such as those related to politics, government, economics, the environment, organizations, law, education, and behavior. Since the industry is inherently resistant to change, promoting advancement will probably need an interdisciplinary strategy. In this case, some real estate market participants may benefit from the use of design science research tools and related techniques. Finally, considering the substantial ecological impact of the real estate industry, new ideas and approaches to climate change and sustainability need to be developed immediately.

Based on this study's findings, we have proposed some open research questions for future researchers as follows:

- What are the factors and influences that delineate how these innovative technologies can shape performance (driving accuracy), and efficiency in (scoring) AVMs for real estate transactions?
- What is the relationship between the accuracy of AVM property valuations and the quality, availability, and integration of data from various sources?
- How will the broader adoption of AVMs in the real estate industry affect market patterns such as property value trends, market stability, and stakeholder behavior in the future?
- What does it look like to confirm and have deep-seated biases in AVM approaches, be scrutinized, evaluated, and develop mitigation strategies, ensuring unbiased and fair property assessments?
- What are the key drivers of consumer and real estate professional acceptance and use of AVMs, and how can user-friendly AVM models be constructed to overcome the adoption barriers?
- How are different hurdles related to regulating and policymaking for AVMs, specifically about data privacy, enforcement, and standardization in the real estate industry?
- What roles do the number and quality of data inputs (transactional, economic, geospatial) play in determining how well AVMs predict property prices?
- To what extent do AVMs affect the long-term trust of stakeholders, and in this case particularly how do these models impact the cycle of a real estate market, as well as investors' strategies?
- What are the main bottlenecks in terms of AVM adoption and how can they be dealt with given low user confidence and acceptance?
- In what ways are AVMs most accurate and the least transparent in the eyes of consumers and real estate professionals, and how could they be improved to ensure better a more reliable product?
- What are the ethical considerations that stem from employing AVMs, specifically in terms of ensuring transparency, fairness, and privacy within property valuations?
- What are the competitive implications for real estate markets of AVM integration with emerging technologies, and what are the strategies by which businesses might respond to remain competitive?
- What implications can the adoption of AVMs have on property investment behaviors and market speculation (especially for volatile or developing markets) in real estate over the long run?

4.2. Limitations

As with any research project, there are significant limitations to our study. First, the reading and selection of the publications may have been biased subjectively. It's possible that important articles for analysis were left out of the exclusion criteria used in the literature review technique as they were determined based on the goals of the papers. From this perspective, we might have missed some literature because we chose articles from just two databases (Scopus and WoS), even though they are both well-populated. Moreover, the knowledge gained from the content analysis depends on how we understand the arguments made in the literature review, which could change in other research projects of a similar kind. Secondly, only articles and reviews were included in this review, which ultimately resulted in a smaller total number of publications under assessment. Therefore, researchers may choose to consider more diverse papers in the future. Third, mapping all the strategic applications of AVMs in the real estate industry requires more than one qualitative study.

5. Conclusions

The adoption of AVMs in valuation procedures has tremendous promise for influencing the future trajectory of the real estate industry, which continues to play a crucial role in promoting economic growth and development. Therefore, this study aimed to ascertain the state-of-the-art AVMs being used in the real estate sector as well as the strategic applications of AVMs promoting data-driven decision-making in the sector. The results of the systematic literature review showed that there has been a rise in publications recently. A total of 97 pertinent academic papers that discussed or used AVM techniques for real estate valuation were identified and analyzed. The literature identified eight primary sub-sectors related to real estate: land administration, leasing and renting, property transactions, real estate development, real estate investment, real estate administration, and real estate maintenance. The conceptual framework developed in this research will be insightful for researchers and practitioners who want to further research in this area.

Ultimately, the integration of AVMs and real estate valuation has the potential to completely transform conventional valuation procedures by providing novel approaches, resources, and understandings to successfully negotiate the complexity of the contemporary real estate market. Stakeholders may leverage the transformative power of AVMs to unlock value, reduce risks, and promote favorable outcomes for the real estate sector and the whole economy by continuing to collaborate and innovate. Researchers can identify gaps in the literature on the use of AVMs in real estate and conduct additional can-do research by using the data above. Similarly, the valuers and other real estate stakeholders – from buyers and sellers to investors and policymakers – will find great practical value in the insights gained from this study.

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