



SOUZAEAD[®]

Revista Acadêmica Digital

ISSN 2595-5934



PERIODICIDADE
MENSAL

OUT
2026

EDIÇÃO
Nº102

IDIOMAS
PORTUGUÊS E INGLÊS

QUALIS B3



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REAL ESTATE 4.0: THE DIGITAL TRANSFORMATION OF THE REAL ESTATE MARKET IN THE DATA AGE

REAL ESTATE 4.0: A TRANSFORMAÇÃO DIGITAL DO MERCADO IMOBILIÁRIO NA ERA DOS DADOS

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ABSTRACT

This article examines Real Estate 4.0, the integration of artificial intelligence, Big Data and blockchain into the valuation, financing and management of property. The objective is to analyze how these technologies change information asymmetry, pricing accuracy and asset liquidity, and which risks and institutional barriers limit their adoption in Brazil. It combines a narrative literature review, documentary analysis and illustrative cases. Machine learning models reduce valuation error compared with regressions, including in a Brazilian study, but have not been compared with appraisal reports. Tokenization widens access to real estate investment, but its effect on liquidity has not been measured against direct ownership, and registry authorities in Rio Grande do Sul and São Paulo have restricted links between tokens and property records. Evidence that connectivity adds to location value comes from a single study. The article concludes that Real Estate 4.0 reduces market opacity without eliminating information asymmetry and argues that an algorithmic asymmetry emerges between those who control data and those evaluated by them. Its benefits depend on human oversight, data governance compatible with Brazil's General Data Protection Law (LGPD) and coordinated regulation.

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Keywords: Real Estate 4.0. PropTech. Artificial intelligence. Tokenization. Information asymmetry.

RESUMO

Este artigo examina o Real Estate 4.0, a integração da inteligência artificial, do Big Data e do blockchain à avaliação, ao financiamento e à gestão de imóveis. O objetivo é analisar como essas tecnologias alteram a assimetria de informação, a precisão da precificação e a liquidez dos ativos, e quais riscos e barreiras institucionais limitam sua adoção no Brasil. O estudo combina revisão narrativa da literatura, análise documental e casos ilustrativos. Os modelos de aprendizado de máquina reduzem o erro de avaliação em relação às regressões, inclusive em um estudo brasileiro, mas ainda não foram comparados com laudos de avaliação. A tokenização amplia o acesso ao investimento imobiliário, mas seu efeito sobre a liquidez não foi medido em comparação com a propriedade direta, e as corregedorias do Rio Grande do Sul e de São Paulo restringiram o vínculo entre tokens e matrículas. A evidência de que a conectividade agrega valor à localização vem de um único estudo. O artigo conclui que o Real Estate 4.0 reduz a opacidade do mercado sem eliminar a assimetria de informação e argumenta que surge uma assimetria algorítmica entre quem controla os dados e quem é avaliado por eles. Seus benefícios dependem de supervisão humana, de governança de dados compatível com a Lei Geral de Proteção de Dados (LGPD) e de regulação coordenada.

Palavras-chave: Real Estate 4.0. PropTech. Inteligência artificial. Tokenização. Assimetria de informação.

1. INTRODUCTION

The digitalization of real estate has not happened as a single rupture. Baum (2017) describes PropTech as a succession of waves, from the first property databases of the 1980s to listing portals and, more recently, start-ups that use data, platforms and distributed ledgers to change how property is traded and financed. Harth, Maqbool and Gledson (2026) call this stage Real Estate 4.0, in which digital technologies stop supporting isolated tasks and begin to reshape value creation and business models across the sector.

The scientific problem behind this transition is information asymmetry. Akerlof (1970) showed that when sellers know more about the quality of a good than buyer, prices fall, good products leave the market and transactions shrink. Real estate fits this description: each property is unique; transactions are infrequent and much of the

relevant information is local. Garmaise and Moskowitz (2004) found that, in United States commercial property, information asymmetries shape which properties are traded and how much buyers rely on brokers. The question that guides this article is: how do artificial intelligence (AI), Big Data and blockchain change information asymmetry and illiquidity in the real estate market, and what risks and institutional barriers emerge from their adoption?

The objective is to analyze the effects of Real Estate 4.0 on pricing accuracy, information and liquidity in the light of international evidence and the Brazilian institutional context. Three propositions guide the discussion. The first (P1) states that machine learning valuation models reduce pricing error compared with hedonic and comparative methods. The second (P2), that tokenization lowers the minimum investment and increases the liquidity of property interests. Third (P3), that digital connectivity is becoming a component of location value. The contribution of this article is to confront the international evidence, already mapped by recent reviews (BAUM, 2020; EL JAOUHARI et al., 2024; 2025), with the Brazilian legal framework that changed between 2022 and 2026.

2. THEORETICAL FRAMEWORK

2.1 INFORMATION, PREDICTION AND VALUE

Two problems should be kept apart in this debate. The first is information asymmetry in Akerlof's (1970) sense: one party holds private information about the specific good, such as hidden defects of a house. The second is market opacity: prices and transaction data are scattered, costly to collect and hard to compare. Digital technologies act mainly on the second problem. Hedonic price theory links both, since it treats the price of a property as the sum of implicit prices paid for its attributes, such as size, location and finishing (ROSEN, 1974). This article also uses the term algorithmic asymmetry for a third gap, which concerns not the property itself, but the data and pricing rules used by those who value it.

Agrawal, Gans and Goldfarb (2018) describe AI as a fall in the cost of prediction, which raises the value of complementary inputs such as data and judgment. In real estate, this suggests that advantage moves from privileged local information toward the control of data and models.

2.2 CITIES, DATA AND HOUSING

The real estate market is also part of the financialization of housing, in which homes are increasingly treated as financial assets rather than as goods for use and as a social right (AALBERS, 2016; ROLNIK, 2015). Fields (2022) shows that digital platforms for rent collection and maintenance allowed large investors in the United States to manage dispersed portfolios and channel rental income to capital markets, a figure she calls the "automated landlord".

3. METHODOLOGY

This study adopts a qualitative, exploratory and descriptive approach, based on a narrative literature review with explicit selection criteria, complemented by documentary analysis and illustrative cases. Searches were carried out in October 2026 in Crossref, RePEc/IDEAS and the platforms of the main publishers in the field (Elsevier, Emerald, SAGE, Springer and Vilnius Tech), complemented by Brazilian journal portals and official sources of legislation and regulation, with descriptors such as "PropTech", "Real Estate 4.0", "automated valuation model", "tokenization" and "iBuyer" and their Portuguese equivalents. Peer-reviewed articles, academic books and working papers were included, with priority for publications from 2020 onward, together with classic works on information economics and hedonic pricing; news articles were excluded, except as the only public source of a market figure. The documentary corpus comprised corporate and agency reports, Brazilian legislation, regulations of the Securities and Exchange Commission of Brazil (CVM) and decisions on property registration. Literature and documents total 42 sources.

The sources were organized by proposition and analyzed through thematic synthesis. Each proposition was classified as supported, when at least two empirical studies point in the same direction and the corpus contains no contrary evidence; partially supported, when the evidence confirms only part of the proposition or there is contrary evidence; or not established, when the evidence is only indirect or comes from a single empirical study. Two business models were selected as illustrative cases: algorithmic home buying (iBuying) in the United States, examined through the evidence on Opendoor and Zillow Offers, and QuintoAndar, a rental platform in Brazil. The transfer to Brazil of results obtained abroad is treated as a question, not as a given.

4. THE TECHNOLOGICAL PILLARS OF REAL ESTATE 4.0

4.1 ARTIFICIAL INTELLIGENCE AND AUTOMATED VALUATION

In Brazil, property appraisal follows the ABNT NBR 14653-2 standard, in which the direct market comparison method relies on samples of similar properties treated by an appraiser (ABNT, 2011). Automated Valuation Models (AVMs) apply machine learning to large transaction databases.

Hong, Choi and Kim (2020) compared a Random Forest model with a hedonic regression using apartment transactions in Gangnam, South Korea, between 2006 and 2017. The average deviation from market prices was about 5.5% for the algorithm and nearly 20% for the regression. In Brazil, Zilli and Bastos (2024) modeled 1,572 apartments in Florianópolis and found a mean absolute percentage error of 12.25% for Gradient Boosting, against 18.98% for multiple linear regression. Poursaeed, Matera and Belongie (2018) added to listing data, including Zillow's own estimate, a luxury score extracted from photographs by convolutional neural networks, and reached a median error of 5.8%, against 7.9% for the Zestimate. None of these studies compare the algorithm with the report of an appraiser.

This limit matters in Brazil. AVMs depend on large bases of formal transactions, and a significant part of Brazilian housing is irregular. According to the 2022 Census, 16.4 million people, or 8.1% of the population, live in favelas and urban communities,

a share that reaches 18.8% in Pará (IBGE, 2024). Law No. 13,465/2017 created the Urban Land Regularization (Reurb) to address this situation (BRASIL, 2017). Where registered transactions are few, training data are scarce and model error tends to increase. Land regularization and the digitalization of records are therefore preconditions for automated valuation.

4.2 BIG DATA, CONNECTIVITY AND DIGITAL TWINS

Big Data broadens the set of variables that explain prices. Glaeser, Kim and Luca (2018) used Yelp data to show that gentrifying neighborhoods in the United States record growth in cafés, groceries, restaurants and bars, and that local business activity works as a leading indicator of housing price changes. The same signals that help an investor anticipate appreciation may also indicate pressure on lower-income residents, a dimension the study does not measure. As for digital infrastructure, Ahlfeldt, Koutroumpis and Valletti (2017) found that faster broadband is capitalized into house prices in England, with diminishing returns at higher speeds. Connectivity may thus join distance and access to services as an attribute of location, but this evidence comes from a single country, and its relative weight remains unknown.

Continuous data also supports digital twins, virtual replicas of buildings or cities that Deng, Zhang and Shen (2021) describe as a new pattern of urban governance, useful for energy management in a sector that accounts for about 32% of global energy consumption and 34% of carbon dioxide emissions (UNEP, 2025).

4.3 BLOCKCHAIN, TOKENIZATION AND LIQUIDITY

Real estate is the world's largest store of wealth, estimated at US\$393.3 trillion in 2025 (SAVILLS, 2025 apud IREI, 2025), and one of the least liquids. Here, liquidity means the ability to sell an asset quickly and at low cost without a large discount. Tokenization represents rights linked to a property, or to the vehicle that owns it, as digital units recorded on a blockchain.

Empirical studies are more cautious. Swinkels (2023) analyzed 58 tokenized rental homes in the United States and found an average of 254 owners per property, which shows that fractionalization widens access. Ownership of each property's tokens

changed about once a year, in a sample concentrated in Detroit, and token prices followed the regional house price index. No study in the corpus compares this turnover with that of the underlying homes. Kreppmeier et al. (2023) found that token investors do not yet hold well-diversified portfolios and that trading responds both to property fundamentals and to the crypto-asset market. Both studies analyze tokenized rentals in the United States, which limits generalization. Baum (2020), analyzing mainly the British case, adds that tokenization does not remove high transfer taxes and usually requires an intermediate legal vehicle, and Garcia-Teruel (2020) argues that blockchain improves registration only if integrated into existing property law. Table 1 summarizes these differences.

Table 1 – Traditional transaction and tokenized model: main differences

Dimension	Traditional transaction	Tokenized model	Evidence and limits
Minimum investment	Whole unit or shares in a fund	Fractions of a property or of the vehicle that owns it	Wider access: average of 254 owners per property (SWINKELS, 2023)
Transfer of rights	Public deed and registration at the Real Estate Registry	Transfer of tokens between digital wallets	In Brazil, real rights arise only from registration (BRASIL, 2002), now operated electronically through the SERP (BRASIL, 2022a)
Transfer taxes	ITBI due on the transfer of the property	Depends on the legal structure (property or shares of a vehicle)	Tokenization does not remove high transfer taxes, as in the British case (BAUM, 2020)
Secondary liquidity	Sale of the whole property	Trading of fractions on digital platforms	Token ownership changes about once a year, mostly in Detroit; no comparison with the underlying homes (SWINKELS, 2023)
Legal structure	Direct ownership	Usually requires an intermediate vehicle	Additional cost and regulation, including CVM rules (BAUM, 2020; CVM, 2022a)

Source: prepared by the author based on Baum (2020), Garcia-Teruel (2020), Swinkels (2023), Brasil (2002; 2022a) and CVM (2022a).

Smart contracts can automate rent payments and guarantees, but in Brazil the recovery of a leased property depends on a judicial eviction action under Law No. 8,245/1991 (BRASIL, 1991), which code cannot replace.

5. PROPTECHS IN PRACTICE: ALGORITHMIC BUYING AND RENTAL PLATFORMS

The iBuying model is the most direct test of algorithmic pricing. Companies such as Opendoor and Zillow Offers bought homes through automated offers and resold them. Buchak et al. (2025) show that iBuyers paid about 3.1% less than comparable listed homes, sold at a premium of about 1.5% and charged service fees of around 6%. The same study shows its limits: iBuyers concentrated on new, mid-priced and easily valued homes and avoided those hard to price or to sell, because sellers retain information that the algorithm cannot observe. Private information, in Akerlof's sense, did not disappear and continued to expose the algorithmic buyer to adverse selection.

The decision to close Zillow Offers, announced in November 2021, illustrates model risk. The company stated that it had been "unable to accurately forecast future home prices at different times in both directions" (ZILLOW GROUP, 2021, n.p.) and that scaling the operation would create excessive volatility.

In Brazil, the clearest case is in the rental market. Batista (2025) describes QuintoAndar as the largest rental platform in the country: it replaced the traditional guarantor (fiador) with rental insurance, automated contracts and reached about 175,000 contracts in 2022. Batista (2025) interprets this growth as the centralization of rights over rental income, a reading close to Fields' (2022) "automated landlord": digitalization reduces frictions but concentrates data and income in the platform.

6. RISKS AND BARRIERS TO ADOPTION

6.1 MODEL RISK AND ALGORITHMIC COORDINATION

When many agents use similar models, their decisions can converge. Calder-Wang and Kim (2026) studied algorithmic pricing software in the United States multifamily rental market between 2005 and 2019. Adopters reduced rents faster during downturns, but, in markets with greater penetration of the software, rents were

higher and occupancy lower during recoveries, with estimates consistent with coordination that raised markups by about US\$25 per unit per month.

6.2 PRIVACY AND ALGORITHMIC DISCRIMINATION

Smart buildings collect behavioral data that, in what Zuboff (2019) calls "surveillance capitalism", can be turned into predictions sold to third parties. Insurers, lenders or landlords may use such data to discriminate, and anonymization does not prevent a model from penalizing entire neighborhoods. The General Data Protection Law (LGPD) offers two relevant instruments: the principle of non-discrimination (art. 6, IX) and the right to request review of decisions taken solely by automated processing (art. 20), although, since Law No. 13,853/2019, this review no longer has to be carried out by a person (BRASIL, 2018; 2019).

6.3 REGULATORY BARRIERS IN BRAZIL

Tokenization in Brazil faces two regulatory fronts. The first is property registration. Under the Civil Code, real rights over real estate arise only from registration at the Real Estate Registry (BRASIL, 2002, arts. 1,227 and 1,245), and Law No. 14,382/2022 established the Electronic System of Public Records (SERP) as the official channel for digitalizing these records (BRASIL, 2022a). In Rio Grande do Sul, Provision No. 38/2021 of the Office of the Inspector General of Justice allowed deeds exchanging property for tokens, but in October 2025 the same office suspended it until the National Council of Justice (CNJ) decides a pending national proceeding, ordered registrars in the state to refuse titles that link properties to tokens and prohibited the recording of private ownership controls outside the SERP (RIO GRANDE DO SUL, 2025). In January 2026, São Paulo followed the same path: Provision No. 54/2025 of its Office of the Inspector General of Justice prohibited any annotation that links a property registration to a digital token until federal law or the CNJ regulates the matter (SÃO PAULO, 2026). These decisions signal that any hybrid registry will have to operate within the public system.

The second front is the capital market. According to Guidance Opinion No. 40/2022 of the CVM, crypto-assets that grant participation in the results of an enterprise may be classified as securities (CVM, 2022a). Offerings to small investors can use crowdfunding platforms under CVM Resolution No. 88/2022 (CVM, 2022b), and Law No. 14,478/2022 regulates virtual asset service providers (BRASIL, 2022b). Tokenization in Brazil therefore depends on the convergence of registry law and capital market regulation, a point that the international studies reviewed here do not address.

7. DISCUSSION AND FINAL CONSIDERATIONS

Table 2 summarizes the evidence for each proposition, according to the scale defined in Section 3.

Table 2 – Research propositions and evidence

Proposition	Main evidence	Assessment
P1. Machine learning valuation models reduce pricing errors compared with hedonic and comparative methods	Hong, Choi and Kim (2020); Zilli and Bastos (2024); Poursaeed, Matera and Belongie (2018); El Jaouhari et al. (2024)	Partially supported: lower error than regressions, including in Brazil; no comparison with appraisal reports; limits in hard-to-price homes (BUCHAK et al., 2025)
P2. Tokenization lowers the minimum investment and increases the liquidity of property interests	Swinkels (2023); Kreppmeier et al. (2023); Baum (2020)	Partially supported: wider access confirmed by two studies; effect on liquidity not measured against direct ownership
P3. Digital connectivity is becoming a component of location value	Ahlfeldt, Koutroumpis and Valletti (2017)	Not established: a single empirical study (England); no Brazilian evidence

Source: prepared by the author, applying the scale defined in Section 3.

This evidence suggests that Real Estate 4.0 reduces market opacity but does not eliminate information asymmetry. Prediction has become cheaper and new data anticipates price changes, which reduces the advantage of the local broker or developer who relied on privileged information. At the same time, sellers still hold private information that algorithms cannot observe, which exposed iBuyers to adverse selection (BUCHAK et al., 2025). The article also argues that an algorithmic asymmetry

emerges between those who control data and pricing rules, such as platforms and software providers, and those who are evaluated by them, such as tenants and small owners. The studies on algorithmic rent pricing and on platform landlords point in this direction, but measure concentration and market power rather than information itself (CALDER-WANG; KIM, 2026; FIELDS, 2022), so this interpretation remains to be tested. Liquidity remains limited by taxes, registration and securities rules.

For practitioners, AVMs can support, but not replace, the appraisal report prepared under NBR 14653-2. As Starr, Saginor and Worzala (2021) argue, these technologies change the skills required of professionals, who move from holders of information to interpreters of data. For regulators, they point to the need to coordinate the CNJ, the registries and the CVM before tokenized products reach small investors. The main limitations are the absence of primary data and the predominance of foreign evidence. Future research could compare AVMs with appraisal reports using Brazilian data and measure the liquidity of tokenized products against direct ownership.

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