

Cascaded Fuzzy Analytics Based Model for Determining Rental Values of Residential Properties

Abstract

The world's property marketplace continues to experience enormous growth in infrastructure geared towards enhancing the quality of neighborhoods, such as physical landscaping and aesthetics, which have pushed rental values above reasonable bounds. The practice of ascertaining the market value of properties makes use of underlying key characteristics, especially in cities across the globe. Again, the rental values of property vary differently from place to place on the basis of characteristics (or factors). Studies are ongoing in determining the best factors needed to accurately arrive at appropriate market and rental values for properties. This study proposes a cutting-edge approach based on cascaded fuzzy logic controls to pair up distinct property characteristics identified by various professionals and literally works. The housing dataset was collected and used to construct the membership functions, the inference engine, and validate the proposed property rental value model. The outcomes revealed that the cascaded fuzzy analytics model was the inverse of the regression model, as the minimal MSE (0.05628) supported a good prediction of residential property values when compared to the regression model ($R = 0.7320$), whose value must be close to 1 to be a good estimate. Again, the proposed cascaded fuzzy analytics model (0.05628) was an improvement over the regression model (0.09619) in terms of MSE and standard error of estimation. These revealed the capability of the proposed model in determining residential property prices at a lower error rate than statistical inference approaches like regression estimation models.

Keywords: Rental Values, Property, Fuzzy Analytics, Accuracy, Fuzzy, Determinants.

Introduction

There is a strong focus among researchers to determine the association between sales prices and transportation infrastructure to property and land values over the past years (Kasraian et al., 2023). Global property prices are on the rise in metropolitan neighborhoods, which has caused housing affordability issues among low-income strata. Young people, new couples, and migrants continue to worry about the affordable accommodation offered by rental homes. Rental markets are strictly operated by private individuals and enterprises. Studies attempt to check housing rental prices to assist governments in providing a healthy real estate market. It became possible to identify huge variability caused by location, especially in urban areas (Hu et al., 2019).

The means of improving the decision-making process have continued to attract the attention of scholars and cognitive scientists over the years. The concept of decision-making is considered a cognitive procedure in which the beliefs and preferences of individuals are a major factor. The value of individual preferences is often vague or uncertain to establish with the increasing the popularity of Rough Set Theory (RST) (Yuan et al., 2021). The price estimates of many residential properties cannot be effectively determined without considering mirage of adjoining factors like returns on investments, location, cosmopolitan nature of the area, rate of crime, nearness to markets, age of the building, housing demands, prevailing economic circumstances, structural features, comfort, and others (Odubiyi et al., 2019). Licensing is another form of rental property market around the world where individuals and enterprises purchase or procure properties on the basis of observable quality and safety (Samuel, Schwartz, & Tan, 2019).

In the real estate subsector, rate of capitalization is a key consideration for transforming home property value into rent market value or otherwise. The hedonic model is a prominent approach to generating hedonic prices based the property characteristics. Also, the income capitalization method has been utilized to value rental properties and appraise of real estate. To this effect, market value is often used to describe economic theory because it is impossible to measure directly. One impartial estimate of market values is the sale price given fair circumstances (Lisi, 2019).

The consumption good and investment good of highest value is the housing good because the housing value is the main driver of the property marketplace. The valuation of housing property relies on economic and non-economic causes, which help market players such as professionals and consumers. The economic cause is directly related to the prevailing interest rates and income rates of the nation. Whereas the non-economic cause relates to the structural, neighborhood, and location characteristics. The usual practice of ascertaining housing prices, capital values, and rental values is mere speculative and self-regulated by the property owners. The values of rent prices for residential buildings depend on the needs of people, locations, neighborhoods, bathrooms or toilets, and the numbers of rooms. Again, availability of schools, nearness to markets and shopping malls, electricity supply, water supply, crime prevalence rate, access roads, and nearness to the city center. There are a number of techniques used in the past to achieve this, firstly, hedonic methods involving the use of values of properties to construct price indices for distinct characteristics. It depends on the regression coefficients of the price of the unit of characteristics and degree of relationships in order to determine the rental price value of property. Secondly, artificial intelligence modeling and simulation is a new paradigm for complex systems that depend on flexibility, fuzzy reasoning, and general abstraction. Thirdly, there are widespread inconsistencies in human expertise (the most primitive method) in completing the daunting tasks of rental values determination due to the expansive quantity of variables, uncertainties, and non-linearity (Kolekar et al., 2019).

Consequently, several algorithms (such as fuzzy logic, fuzzy cognitive maps, and artificial neural networks) have evolved over time to augment these processes of determining rental values of properties across the globe, which learn structures and underlying patterns in data (Agbossou, 2018). The main contributions of this paper include:

- i. To generate data from professionals and previous studies concerning rental value determination models.
- ii. To construct a cascaded fuzzy analytics-based model for determining the rental values of properties.
- iii. To evaluate the performance of the proposed model.

The remaining sections of this paper include: section two is a literature review; section three is research methodology; section four is results and discussion; and the conclusion is in section five.

2 Literature Review

2.1 Property valuation

The world's property market is a tenure encompassing private rented apartments, private owner occupation, and public sector housing. In particular, residential properties come in various types, including tenements, blocks of flats, bungalows, detached and semi-detached duplexes, maisonettes, condominiums, and terraced houses. The land values for residential expansions are a major criterion for deciding the level of economic activity of a nation (Cooper & Guntermann, 1974). Traditionally, the structural settings of cities are a great factor in estimating the quality of land; the farther the land is from city centers, the lesser the costs of development, and the lesser rental values. More so, location and accessibility, environment, tax rates, and availability of amenities are significant considerations in estimating the rental values of properties (Millington, 1982).

The main issue with real estate or property valuation and investment is uncertainty, which relies on market trends, comparable, and the attributes of a property. Though risk and uncertainty are often used in the sense of knowledge gaps, poor or inadequate information concerning inputs. In particular, risk is used to determine losses arising from decision outcomes. Whereas uncertainty relates to the disparity in a possibility distribution in the case of uncertain occurrences (or residual uncertainty). A probability distribution is a quantitative measure of uncertainty (or objective uncertainty). International Valuation Standards identified three distinct sources of valuation process uncertainty: including: market disruption, availability of availability, and method selected for valuation (IVSC, Technical Information Paper 4, Valuation Uncertainty, para 17) (IVSC, 2017).

The market disruption is associated with hash conditions of market capable of influencing real estate price movements or price volatility. The input availability occurs in case of data availability. The comparable issue happens when the appraiser faces a shortage of reliable comparable to deploy (European Valuation Standards, 2016, EVIP 2 Valuation Certainty and Market Risk, para 4.8) (D'Amato, Zrobek, Renigier, Walacik, & Mercadante, 2019; EVS, 2016).

2.2 Hedonic models

In the case of hedonic models, the factors influencing the prices of housing rentals are uneven at the macro and micro scales. At the macroscale, these factors are increasingly important, including province-or city-wide and economic indices. Numerous authors have dissociated the relevance of macroeconomic factors such as the values and prices of housing, including the cost of construction, income gaps, population growth, and other administrative considerations. There are arguments about the same macroeconomic factors and propensities for intra-urban arrangements for the various residential homes. The roles played by available environmental and social amenities bounded by adjoining communities cannot be overemphasized. The determinants of housing rental values and prices across the globe have often been investigated with the hedonic models in countries such as Poland, USA, Australia, China, and Switzerland. The assumption held by proponents of hedonic model is that house value can be determined by its neighborhood, structure, and location characteristics. Consequently, the theorem of the hedonic model enables researchers to connect numerous determinants to the rent price and value of housing properties. In effect, these

housing rent price determinants can be linked to educational opportunities, public infrastructure, polycentric urban structure, and proximity to markets and economic activities (Lirong Hu et al., 2019).

2.3 Fuzzy Analytics

Fuzzy logic control (or fuzzy logic) is considered one of the top choices of researchers and scholars in their attempts to utilize fuzzy set theory in solving everyday problems. This is most desirable for many complex analyses of systems, which renders traditional quantitative techniques incapable of dealing with them, especially in cases where the source of information is rather imprecise qualitatively and uncertainly vague. In 1965, Zadeh introduced the idea of fuzzy sets for the purpose of knowledge modeling based on the IF-THEN fuzzy rules called fuzzy logic. Fuzzy logic control is unnecessary in the precise system's model in order to enhance control effectiveness (Muhammad & Musa, 2019). Alfa, Misra, et al. (2020) pointed out that fuzzy logic controls' performances are determined by the inputs, lists of rules depicting the logical representation, and the outcomes of the inference systems and applications. In particular, the number of rule lists in the fuzzy logic rule base influences the accuracy of the corresponding outcomes of its inference system.

Fuzzy logic controllers have the inherent capability to be easily modified quickly enough to cope with the dynamic changes of diverse systems. Though the performance is highly reliant on human experts, their best is for non-linear and complex control systems (Nguyen, Nguyen, Le, & Nguyen, 2019). Also, three important configurations are identified for fuzzy logic controls, including (Nguyen et al., 2019):

1. The creation of membership functions involves alternating a collection of crisp values with fuzzy logic values.
2. Control rules are defined for processing and evaluating rule bases based on fuzzy logic.
3. The conversion of fuzzy logic values to sets of associated crisp values capable of controlling the signals within the system is known as the defuzzification procedure.

To this end, numerous methods have been adopted for optimizing fuzzy logic control parameters, including input scaling factors, fuzzy input membership functions, output scaling factors, fuzzy output membership functions, and fuzzy rule bases (Muhammad & Musa, 2019). The authors applied fuzzy logic control to photovoltaic systems after optimizing them with the particle swarm optimization algorithm, which provided improved speed and performance in numerous atmospheric situations. The fuzzy logic control optimized with the particle swarm optimization algorithm enables stable and reliable MPP search with overshoot.

The process of carrying out effective routing of wireless sensor networks through the neuro-fuzzy rule-based cluster formation and routing protocol was developed by (Thangaramya et al., 2019). This offered an improved routing algorithm for energy consumption, network lifetime, delays, and packet delivery rates on the Internet of Things.

Pau et al. (2018) introduced particle swarm optimization by altering the range of membership functions of fuzzy logic control to obtain superior outcomes for indoor localization fuzzy systems

and visible light communications. The results enable the system to determine the relative position of a receiver on the basis of the transmitters.

Singh et al. (2019) introduced an innovative braking system (known as the Eddy Current Braking System), which is contactless and frictionless against a normal braking system using particle swarm optimization with fuzzy logic control. This approach absorbs the energy required to increase the performance of optimal barrier systems by reducing overshoot and settling time.

Nguyen et al. (2019) applied a genetic algorithm and a differential evolution algorithm with fuzzy logic controls for overcoming the load frequency of linked hydroelectric power infrastructure. The control issues of load-frequency control were influenced by steady-state error, overshoots, and settling time based on the approach experimented by the authors.

Alfa et al. (2020) implemented genetic algorithm-based optimization of the fuzzy logic control inference system for reducing the redundancy in rule lists at the antecedents and consequents for obtaining better DangoteCem PLC share movements against unoptimized rule lists.

Alfa, Yusuf, Misra, & Ahuja (2020) proposed optimization of the antecedents of the fuzzy logic control's rule list to remove redundancy using genetic algorithms. The optimized fuzzy logic controls were evaluated with DangoteCem PLC share price movements, with better outcomes than traditional approaches.

Costache et al. (2021) constructed 10 flash flood forecast models based on fuzzy logic with elite machine learning algorithms. The predictive outcomes were superior for all the ensemble techniques for managing natural disasters.

Murugesan et al. (2022) adopted the neural fuzzy and fuzzy inference system to enable specialists to detect the chronic renal disease stages (that is, stage_1, stage_2, stage_3, stage_4, and stage_5) for patients. This approach reduces the risk of mortality, kidney failures, and the associated cost of early diagnosis.

Colella et al. (2022) developed a fuzzy inference system for monitoring operating room air quality to assist clinicians in maintaining safe environmental conditions during surgery. It provided the best connection between input data, parameters, and alert levels for air quality conditions. The extreme precision outcomes prevent "Bacteria Infections Post-Surgery" cases in hospital facilities.

2.4 Related works

Hu et al. (2019) introduced the concept of machine learning algorithms and a hedonic model for determining factors influencing rental property prices. The authors identified proximity to healthcare centers and sub-district job openings as highly influential determinants. While nearest accessibility takes precedence over 15-minute walking distance.

Kazimieras et al. (2019) applied the hedonic model for rental shopping valuation during one-to-one marketing. The site's sales rental value, customer satisfaction, economic indicators, attractiveness, social and psychological factors on buyers, indicators of purchasing capacity, and

emotional factors all have an influence on hedonic value. The outcomes found that potential rental shopping value is determined by the psychological and emotional states of buyers, valence, arousal, and affective attitudes.

Yanotti & Wright (2021) undertook a study of residential property prices in Australia in relation to housing supply shortfalls. The data was collected from a rich proprietary loan level of about 1.1 million mortgage requests and house price appreciation. The authors identified factors for accessing funds based on the residential nature of the investment rather than owner-occupation. There is evidence for real estate property investment in non-metropolitan locations, which explains the shortages in metropolitan location choices.

Abdulmalik & Udoekanem (2022) attempted to help real estate investors generate rental income by understanding the characteristics of the rental values of commercial complexes in Ilorin, Nigeria. A structured questionnaire and analysis of variance were deployed for data collection and analysis. The authors perceived that disparity in rental income is caused by location quality, safety, visibility of the building, and term of the lease.

Shitaye (2022) studied residential rental housing demand and supply in a township in Ethiopia. Based on descriptive and inferential statistics used, it was found that income of households, marital status, number of rooms, access to transportation facilities, and typology of house majorly influenced house rent market value affordability.

Lo et al. (2022) noted the relevance of the price-to-rent ratio for assessing the state of the housing markets by real estate owners and policymakers. The authors examined the cointegration and causal interrelationships between various macroeconomic factors and price-to-rent ratios in the housing subsector. After statistical treatment was applied to the datasets, foreign investments, large-sized housing units in prime locations, and the foreign exchange rate influence the price-to-rent dynamics of mainland China.

Rahadi et al. (2022) investigated the factors influencing housing prices in two developed markets, namely Malaysia and Indonesia. Data was harvested from survey questionnaires and analyzed with inferential statistics. The authors found that the Malaysian property market is uninfluenced by housing physical design, home design and construction, developer and real estate products, development concepts, housing location, property funding, social status, health, law provisions, and external factors. While residential property prices in Indonesia are impacted by housing location, property funding, and health.

Subaşı & Baycan (2022) studied the impact of COVID-19 on the rental housing market and its prices in Turkey. Endeksa datasets from 81 provinces were considered for the study and analyzed with descriptive statistics. The outcomes revealed that high priced movements were generally recorded through the study area. Also, the pandemic affected rental housing values significantly positively.

Kasraian et al. (2023) modeled the applicability of sustainability messages in residential property advertising in English-speaking cities. The authors noted that homebuyers allot value to certain sustainability features and claims. Consequently, the textual and visual content of 100 listed properties for sales was analyzed. The outcomes revealed that prevailing homebuyers are sparingly

served in property markets. Therefore, estate agents and developers could leverage sustainability-minded buyers to introduce commentary on property’s sustainability features on materials used for advertising.

Kasraian et al. (2023) conducted a study to identify regional and local transit and car transport accessibility in light of the rise in rental home prices in the Greater Toronto and Hamilton Area. The results from the spatial model showed that property values are linked to determinants such as proximity to transport infrastructure and low-density areas.

The summary of related works in terms of authors, scope, area of study, determinants, and weaknesses

Table 1. Summary of reviewed studies.

Authors	Scope	Area of study	Determinants	Methodology
(Hu et al., 2019)	Rental property prices.	Shenzhen	Healthcare centers, and job openings.	Machine learning algorithms and hedonic model.
(Kazimieras et al., 2019)	Rental shopping valuation	Lithuania	Site sales rental value, customer satisfaction, economic indicators, attractiveness, social and psychological factors.	Hedonic model
(Yanotti & Wright, 2021)	Residential property prices.	Australia	Mortgages requests, house price, access to fund, and location choices.	Hedonic model.
(Abdulmalik & Udoekanem, 2022)	Commercial complexes rental values	Nigeria	by location quality, safety, visibility of building, and term of lease.	Analysis of Variance.
(Shitaye, 2022)	Residential rental prices.	Ethiopia	income of households, marital status, number of rooms, access to transportation facilities, and typology of house.	Descriptive and inferential statistics.
(Lo et al., 2022)	Housing Rental-to-Prices.	Mainland China.	Foreign investments, large-sized housing units in prime locations, and foreign exchange rate.	Inferential statistics.
(Rahadi et al., 2022)	Housing prices.	Malaysia and Indonesia.	Indonesia: housing location, property funding, and healthcare. Malaysia: No significant factors identified.	Inferential statistics.
(Subaşı & Baycan, 2022)	Rental housing market prices.	Turkey	Pandemic and external factors.	Inferential statistics.
(Kasraian et al., 2023)	Residential properties advertising.	English cities	Sustainability-minded buyers and materials used for advertising.	
(Kasraian et al., 2023)	Rental home prices.	Toronto and Hamilton Area.	Proximity to transport infrastructure, and low-high density areas.	Spatial model.

From Table 1, there is a slow introduction of machine learning approaches into property rental valuations across the globe. The use of fuzzy analytics is a new form of approach worth investigating when compared to the spatial model, inferential statistics, and hedonic models, which have large inaccuracies.

3 Research Methodology

3.1 Data Collection and Preparation

This paper collected residential housing rental prices from a public repository (<https://www.kaggle.com>) for modeling purposes. The dataset file is named housing_dataset.csv composed of five column labels (price, area, bedrooms, bathroom, and stories) and 545 rows for the sampled residential property prices in Boston, Massachusetts, USA. The data was normalized into the range of [0,1] by dividing by the maximum value of each column. Thereafter, data was partitioned into ratios of 70:30 percent representing the training (first 382 rows) and testing (last 163 rows) datasets, similar to the approach in the study (Alfa et al., 2020; Alfa, Yusuf, Misra, & Ahuja, 2020). The values of the unnormalized and normalized training datasets are presented in Table 2.

Table 2: The data preparation procedure.

Column Label	Normalized Value
Price	[0.2711 – 1]
Area	[0.1176 – 1]
Bedrooms	[0.3333 – 1]
Bathroom	[0.2500 – 1]
Stories	[0.2500 – 1]

3.2 The model description

This paper proposes a cascaded fuzzy analytics-based model for determining the rental values of residential properties based on the factors defined in Table 2. The fuzzy logic engine is capable of taking two input factors and one output factor at a time, which implies the two input factors are considered at a time, as shown in Figure 1.

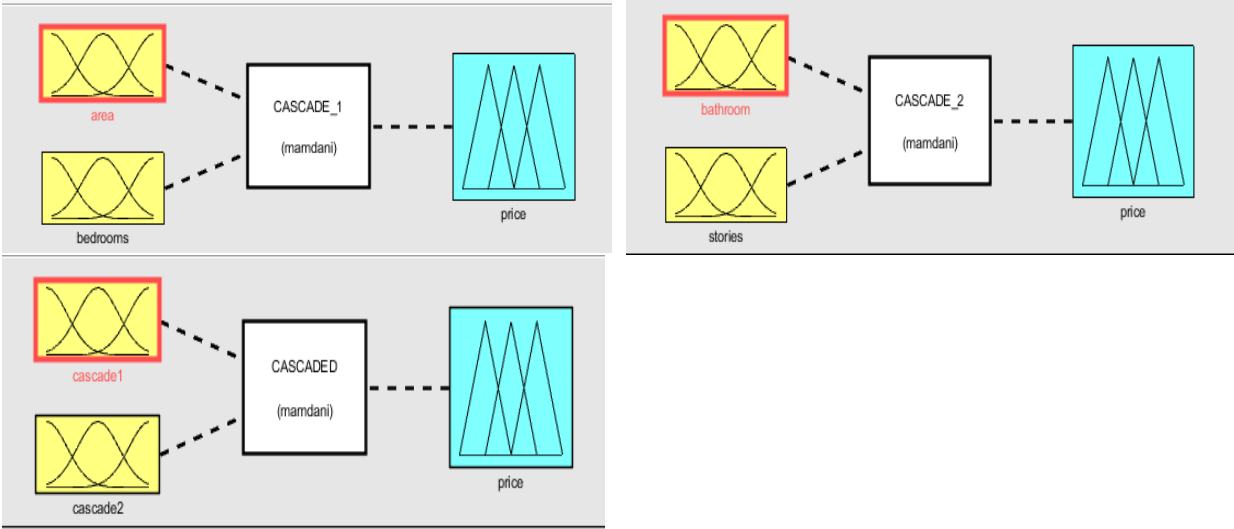


Figure 1. The structure of the Cascaded Fuzzy Analytic model.

From Figure 1, the final Cascaded Fuzzy Analytics model is realized in both CASCADE_1 and CASCADE_2 models by passing them as inputs in order to determine the price of residential property by consumers and estate developers. The triangular membership functions are defined for each of the antecedents (that is, area + bedrooms and bathroom + stories) and the consequent (price) using values defined in Table 2 as shown in Table 3.

Table 3. Membership variables and parameters derivations.

Membership parameters	Lowest	Median	Highest
Consequent (price)	[0.2711 0.4533 0.6355]	[0.4533 0.6355 0.8178]	[0.63556 0.8176 1]
First Cascade			
Antecedent (area)	[0.1176 0.3382 0.5588]	[0.3382 0.5588 0.7794]	[0.5588 0.7794 1]
Antecedent (bedrooms)	[0.3333 0.5000 0.6666]	[0.5000 0.6667 0.8333]	[0.6666 0.8333 1]
Second Cascade			
Antecedent (bathroom)	[0.2500 0.4375 0.6250]	[0.4375 0.6250 0.8125]	[0.6250 0.8125 1]
Antecedent (stories)	[0.2500 0.4375 0.6250]	[0.4375 0.6250 0.8125]	[0.6250 0.8125 1]
Final Cascade			
Cascade_1(price)	[0.5 0.5795 0.6589]	[0.5794 0.6589 0.7383]	[0.6589 0.7383 0.8177]
Cascade_2(price)	[0.5 0.5339 0.5678]	[0.5000 0.5339 0.5678]	[0.5678 0.6016 0.6355]

From Table 3, the Cascade Fuzzy Analytics rule lists are manually generated by human experts using the input and output variables, whose indices are shown in Table 4.

Table 4: The Cascaded fuzzy analytics rules-lists.

Rule Number	First Input Parameter	Second Input Parameter	Output Parameter
1	3	3	3
2	3	2	2
3	3	1	3
4	2	3	3
5	2	2	2
6	2	1	2
7	1	3	3
8	1	2	2
9	1	1	1

3.3 Experimental setup

The minimal hardware and software specifications for validating the proposed Cascaded Fuzzy Analytics model for predicting rental property prices are shown in Table 5.

Table 5: The system specifications.

Parameters	Specification
Operating System	Microsoft Windows 10 Home Edition
RAM	6 GB
HDD	1.0 TB
Discrete simulator	MATLAB R2019b
CPU Processor	AMD RYZEN 3 Radeon Graphics
HD Graphics	2.4 GHz
System type	64-bit OS, x64-based processor
Evaluation	Mean Square Error (MSE)

4 Results and Discussion

The outcomes of applying cascaded fuzzy analytics to the testing datasets for each of the cascades and the eventual cascaded predication of rental property prices are given in Table 6.

Table 6: The model outcomes compared.

Evaluation Metric	Cascaded Model (Proposed)	Multiple Regression Model
CASCADE_1 (MSE)	0.1605 – 0.0499	R = 0.609, $R^2 = 0.320$
CASCADE_2 (MSE)	0.0775 – 0.0184	R = 0.582, $R^2 = 0.339$
CASCADEDED = CASCADE_1 AND CASCADE_2 (MSE)	0.0181 – 0.00016636	R = 0.732, $R^2 = 0.536$

From Table 6, the values of the MSE computed for the CASCADEDED model ranged from 0.00016636 to 0.0181, which outperformed the initial CASCADE_1 and CASCADE_2 models utilized for predicting residential property price values. Similarly, the statistical inference treatment on the datasets showed that the CASCADEDED model better explained the value of residential property at 73.20% when compared to the 60.90% and 58.20% for the original CASCADE_1 and CASCADE_2 models, respectively. The outcomes of both the proposed CASCADEDED and statistical inference models showed that the values of residential property prices

are determined by different factors considered during valuations. The graphical illustrations of the computations for both models are shown in Figure 2.

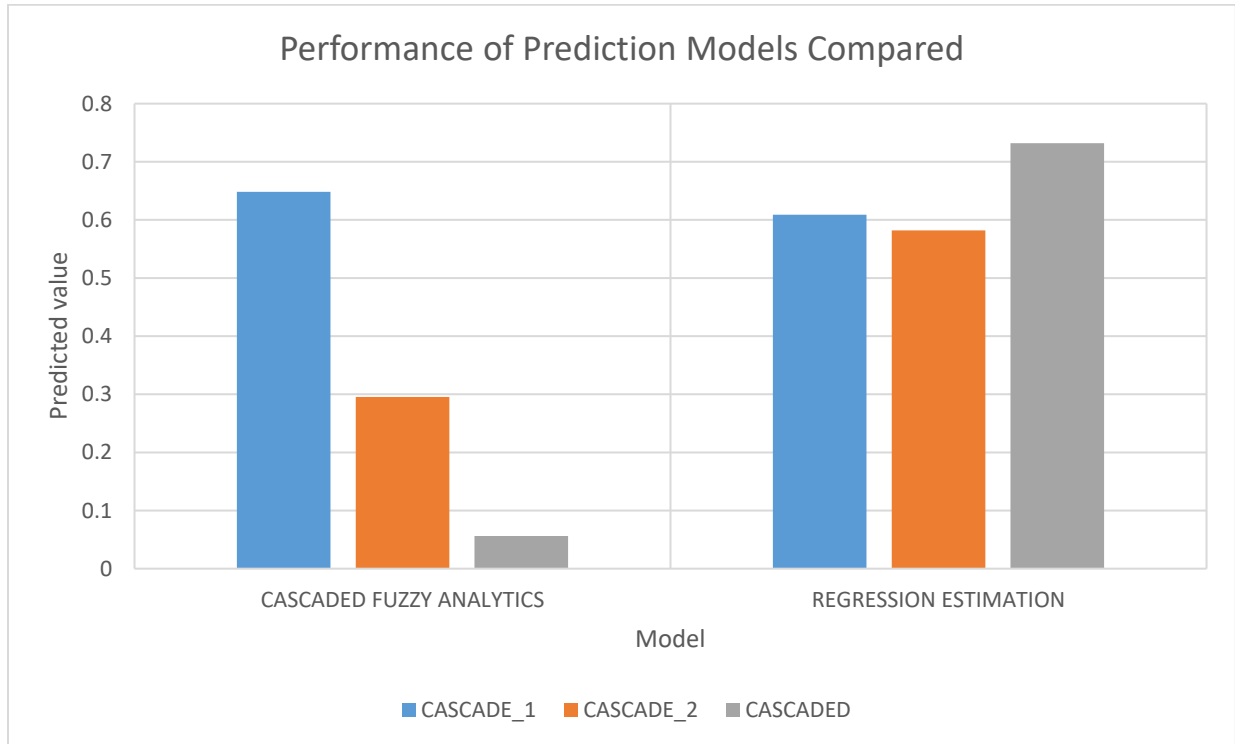


Figure 2: The graphical analysis of model outcomes compared.

From Figure 2, the cascaded fuzzy analytics model performance is the inverse of the regression model because the minimal MSE (0.05628) is desired to attain a good prediction of residential property values as against the regression model a high value of R (0.7320) computed. Also, the performance of both models was compared using the MSE and standard error of estimations. The proposed cascaded fuzzy analytics model (0.05628) was superior to the regression model (0.09619), which implies the superiority of the proposed model in determining residential property prices, as shown in Figure 3.

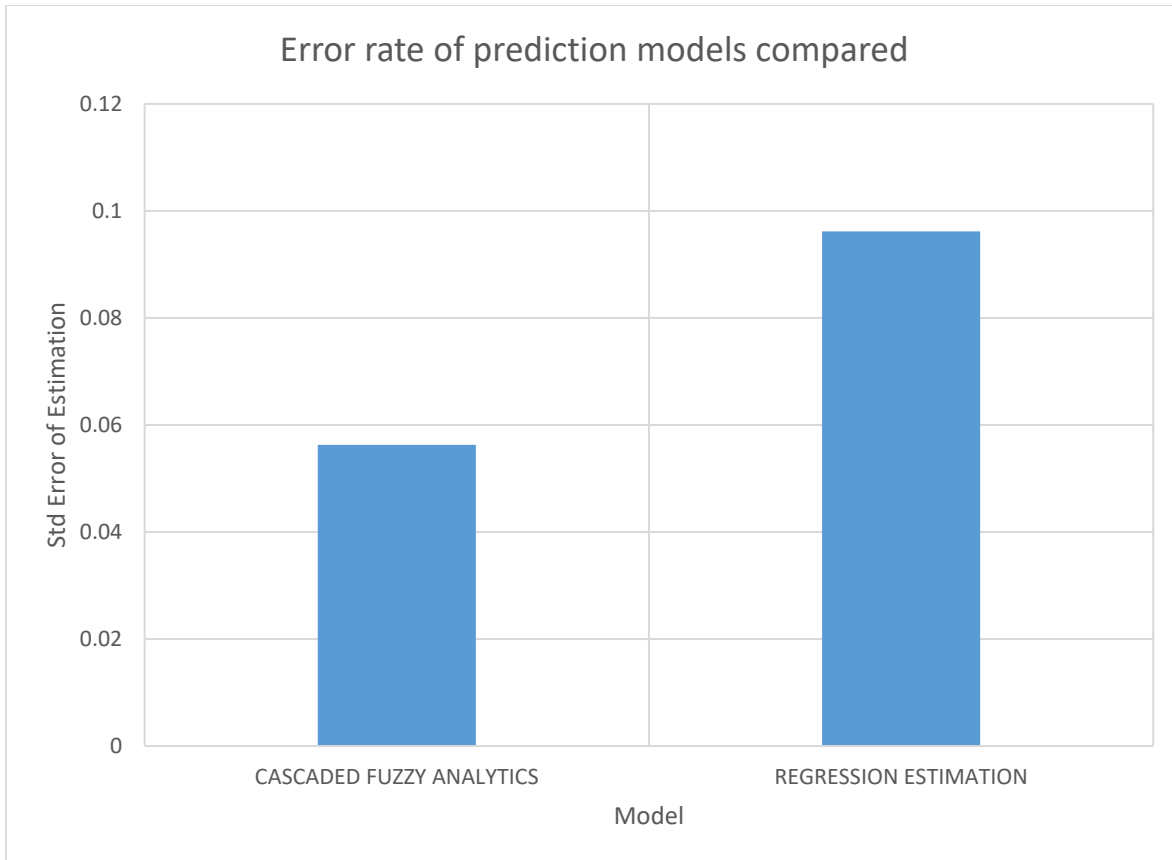


Figure 3: The error rates of estimation models compared.

5 Conclusion

This paper developed a cascaded fuzzy analytics residential rental value prediction based on multiple pairs of determinants and factors. Generally, statistical inferential and hedonic models have dominated research over the years, with large inaccuracies arising from outcomes generated in numerous similar research areas. Using good prediction measures of the MSE and standard error of estimation, the proposed cascaded fuzzy analytics model (0.05628) was superior to the regression model (0.09619). This means that the proposed prediction model for determining residential property prices was superior to several existing statistical inferential models, like regression estimation. In future work, the data can be localized to increase the number of determinants of residential housing prices in order to measure the effectiveness of the proposed model. Also, the proposed model can be extended for crude oil price, FOREX, and inflation rate forecasts.

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