

THE CONTRIBUTION OF STATISTICAL MODELS IN THE FIELD OF REAL ESTATE VALUATION

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Testing a model in property evaluation can be a difficult task due to the large variety of these models. The most popular models used in valuation are regression and neural networks. This paper applied a systematic review study and presents 11 types of regression models and 9 types of neural network models applied in real estate valuation. Our aim is to provide a tool for model selection applied in real estate valuation. The selection criteria were based on their applicability, user preferences and price estimation performance. The findings were slightly different from our expectations. Multi-Layer Perceptron (MLP) and Multiple Linear Regression (GLM) are the most applied and popular models in valuation.

Keywords: Regression models, ANN, Performance, Real estate, Models

JEL Classification: J08, J24, J68

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1. Introduction

Statistical models development for valuation in real estate requires knowledge of valuation theory (Șipoș and Crivii, 2008). In this case, an accurate estimation means to cover many characteristics and peculiarities of real estate as possible. Fluctuations in real estate prices, the economic crisis, types of properties, and the purpose of valuation are some of the elements that have led to the search for a model that can be proposed as a substitute for the market approach used by valuation practitioners (Pagourtzi et al., 2003). Thus, for each uncertainty that has arisen, an attempt has been made to resolve it in general, using three methods. The first choice was to apply a new statistical model. In the second option, the solutions foldability of the tested model was taken into account. However, to increase the model performance, they went further by choosing another type of statistical model in the same category, for examples, Hierarchical Linear Model (HLM), Semi-long regression model, multiple regression model and hedonic model. A third approach to improve model performance was to combine several models, often referred to as extensions or disassembled with the full name of the combined models. For example, Ordinary Least Squares (OLS) was developed by adding a geographic system called a graphic information system (GIS). The objectives in the paper is to reviewed the types of regression and artificial neural network models addressed in real estate valuation which will help as to identify the state of use, testability and application of these models. The aim is to encourage tests of statistical models primarily by emerging countries, practitioners and the real estate. It a needed tool and appreciated by investors. These types are divided into a subcategory of the two models (regression and artificial intelligence, AI). Linear regression has been applied in valuation in the United States since the 1950s and 1980s by the UK (Watkins, 1999). The model makes it possible to calculate the value of each component of a property's characteristics that ultimately leads to the property's market price. Din et al. (2001) also applied the simple linear regression model. The striking similarity of the model to the approach applied by appraisers encouraged its use, with benefits in terms of the objectivity of the result and the low cost of the model (Watkins, 1999).

Due to its popularity in valuation, the linear regression model has been stipulated by some researchers as part of the category of traditional methods, being listed and ranked with the market approach. Artificial neural network model is listed among the advanced models used in valuation (Pagourtzi et al., 2003). However, we considered both models to belong to the category of advanced statistical models.

2. Research method

The methodology used in this study is a systematic literature review of the statistical models addressed in global property valuation (Jackson, 2001; Abidoye et al., 2016; Abidoye and

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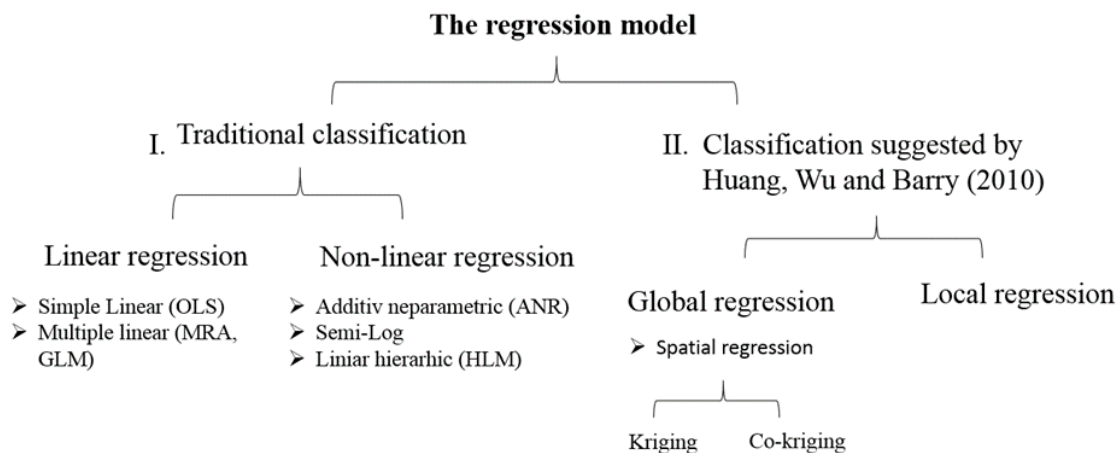
Chen, 2017; Tothăzan and Deaconu; 2020). The articles reviewed were extracted from the Scopus, ResearchGate and Google Scholar platforms. Key words used for finding sources/studies were: statistical models, real estate, accuracy, performance. The search results gave us a large source of over 120 articles from which we retrieved 37 articles. There are other studies on linear regression and ANN that were not included due to lack of specific information for the type used. In the proceeding we selected the type of studies used and we opted for those published in prestigious journals, but we also used articles (fewer) published in conference proceedings or by various universities in the case of studies carried out for the less explored emerging countries. Also, we selected the articles which applied regression model or artificial neural network (ANN) models to test the performance and the accuracy of model in estimating the market price of real estate properties. These articles apply regression and ANN models and they used the performance indicators such as: Coefficient of determination (R^2), Mean Absolute Error (MAE), Mean Absolute Error (NMAE), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), Mean absolute deviation (MAD), Theil's U statistic, Residual Standard Error (RSE) and Root Relative Squared Error (RRSE).

Our paper aims to offer a tool for modelling in real estate. We reviewed studies with types of regression models and neural networks applied in valuation. To this end, we have extracted a classification of several models in the two categories. The results of the studies are presented in separate tables for regression and networks. These tables help to reduce the time taken to inform about the models used in the valuation, the extent of their use in practice and the performance of the models. The final results of the research were recorded with a plus sign to facilitate correlations between data (Knopf, 2006). From the two tables with regression models and networks, we provided an answer on the model most used and appreciated by practitioners and researchers in the field of valuation. The findings on the performance of the models formed the basis for the hierarchy of models applied in the estimation of the market value of a real estate property.

3. The regression model in valuation

From the studies we have gone through, we have come across two criterions of classification. The first criterion takes into account the structure of the model and focuses on the classification of models in the statistical domain. The second classification is based on the logic of the types of features used in the model (general or global). An illustration of the two classifications is shown in Figure 1.

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The contribution of statistical models in the field of real estate valuation*Source: The author***Figure 1. Proposed classifications for the regression model**

The first category of the regression models, is a more traditional one and is divided into two sub-categories, linear and non-linear regression models. Within linear regression, we have addressed Ordinary Least Squares (OLS) and multiple linear regression (MRA). From the category of nonlinear models, here are some models applied in the valuation: Additive nonparametric regression, ANR (Lin and Mohan, 2011), Semi-log regression model (Limsombunchai et al., 2004) and Hierarchical Linear Model (HLM), applied by Arribas et al. (2016).

The second category of models is the one suggested by Huang, Wu and Barry (2010). The authors argued that the statistical model can be classified into global regression models and local regression models. In general, the global model has been characterized by improving the multiple regression model (Anselin, 1993). Thus the spatial regression model is classified into two groups, the first being known as the kriging technique (Diggle and Ribeiro, 2007) and co-kriging (Haas, 1996).

A. Simple (classical) linear regression models

Classical regression also called Ordinary Least Squares (OLS) is the simplest form of regression. It involves capturing changes between two variables, the independent variable and the dependent variable. The linearity of the statistical model is the main feature of all regressions. The database is interpreted by its relationship to the regression line. Each property is assessed on the basis of independent variables corresponding to its characteristics. OLS is a simple regression operating on a single independent variable. OLS calculates the weight for a single variable. The valuation process to be performed requires several calculations to obtain the weights for each variable (Watkins, 1999). It is a good thing to observe the individual behaviour of the independent variables, but we do not know

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the behaviour and importance of the multitude of independent variables when considered as a group. Processing in OLS takes more time and has certain shortcomings for valuating a real estate property (Tudorel and Régis, 2008; James et al., 2017). However, OLS has been applied in property valuation. Rossini (1997) used this model. Arbeláez and Díaz (2016) for research conducted by the Florida Economic University, ran three OLS models, from which they chose the best performing one and operated a performance comparison with three other statistical models. Kestens et al. (2006) attempted to debug this model by applying Spatial autoregression (SAR), but the OLS was not foldable. However, they also highlighted the positive aspects of OLS.

B. Multiple Regression Model (MRM)

The Ordinary Least Squares model (OLS) can't estimate market value when is used with multiple independent variables (Tudorel and Régis, 2008; James et al., 2017). The solution was to use the Multiple Linear Regression, MRA. It allows more independent variables and has proven to be a suitable tool for valuation. It's the best-known model used in valuation, according to Watkins (1999), which tests the correct estimates performed by the model (Lin and Mohan, 2011). One of the oldest researches on the real estate market on the application of multiple regression is Eisenlauer's 1968 work. Bletter (1969) noted the possibility of MRA in estimating a market value for real estate. Further studies for MRA have been applied by Adair and McGreal (1988), Adair (1991), Gallimore and Ward (1992), Adair et al. (1996) and Watkins (1999). D'amato (2004) compared regression performance with a newer statistical model. The results are supportive of MRA. Multiple linear regressions are studying performance in property valuation (Watkins, 1998) and the accuracy of the model its performance (McCluskey et al., 2013). The research paper, signed by Arribas et al. (2016) joins the testing of the MRA in valuation.

Additive nonparametric regression (ANR) and Hierarchical Linear Model (HLM) are the most used nonlinear regression models.

C. Additive nonparametric regression (ANR)

Şipoş and Crivii (2008) note that linear regression is a model that implies certain restrictions in the evaluation. Among these restrictions, the most frequently mentioned is the robustness of the model due to its linear nature. Thus, Selim (2009) applies a nonlinear regression model, called the semi-log multiple nonlinear regression model in the property valuation. McDonald (1997) used local nonparametric local linear regression for price estimation. Limsombunchai et al. (2004) tested a semi-log regression model. Mc Cluskey et al. (2012) and Yacim and Boshoff (2018) discuss two nonlinear regression semi-log and log-log. The results are close to those provided by artificial neural networks. The authors, Lin and Mohan, (2011) choose to test this nonparametric additive regression (NAR) model against the multiple regression model (MRA) and neural network model (ANN) in their study. As results, ANN was far superior to regression models.

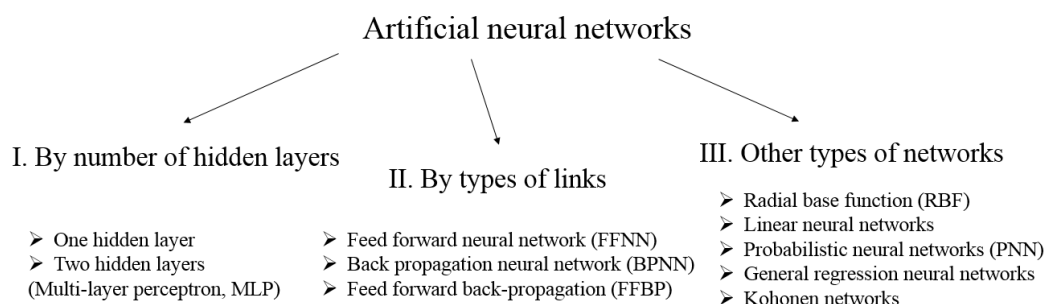
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*The contribution of statistical models in the field of real estate valuation***D. Hierarchical Linear Model (HLM)**

Thibodeau (1998) indicated price as a function of choice and the link between property attributes, the description area ("neighbourhood") and the property submarket. Valente et al. (2007) also referred to two other models such as the spatial simultaneous autoregressive (SAR) model and the spatial conditional autoregressive (AR) model. Arribas et al. (2016) applied the Hierarchical Linear Model (HLM) to property valuation.

4. Artificial neural network model in property valuation

The typology of neural networks is not well specified in network theory. From our research, we have noticed an attempt to perform a case classification based on the differences between networks in terms of the number of hidden layers held, the structure of the neural network, and the way the connections are between neural networks (representation in Figure 2). These links determine specific qualities, the potential of the model and the recognition of patterns. Simply put, they establish the learning capacity of the model (Kathmann, 1993).

*Source: The author***Figure 1. Classification of artificial neural network models****A. Multilayer neural networks**

Called multi-layer perceptron (MLP) or multi-layer perceptron neural network (MLP-NN), it is the most well-known and often applied model in valuation (Hu et al., 2018). The peculiarity of this model is its construction which can be with one or two hidden layers (Wilkowski and Budzyński, 2006). Din et al. (2001) applied a simple neural network model with two hidden layers. García et al. (2008) combined three neural network models, of which the best performing was the multi-layer neural network model. Zurada et al. (2011) conducted a study comparing three artificial intelligence models with two regression models. Among

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these models was MLP. The non-traditional regressions were more successful than the artificial intelligence models. McClusky et al. ran this MLP in both studies published in 2012 and 2013. The results showed that this model is disapproved for estimating apartment and house taxes. The authors also pointed out the limitation of the model due to the black box that hindered the maximum use of the model capacity. Cechin et al. (2014) applied MLP on two samples of 500 and 1600 subjects. Abidoye and Chan (2017) applied MLP using the comparison method between several models (Support vector machine, SVM and integrated moving average, ARIMA). The results show a remarkable performance. Hu et al. (2018) apply MLP five other models. The MLP model is appreciated and proper in additional combinations of models, offering safety and a contribution of improvement within the regression models.

B. Neural networks by how links are made

The model name illustrates the type of connections between the layers of the networks. So we have three types of links:

a) Feed-forward neural network

Feedforward neural network (FFNN) is also called a feedforward logistic network. Early studies applying FFNN include Kathmann (1993), Warner and Misra (1996), and Curry et al. (2002). FFNN model indicates a one-way activation path from the input to the response layer. Limsombuncai (2004) uses a comparison between FFNN and hedonic models to see the performance of price estimation in property valuation. The results show that FFNN is the model with the best prediction. Abidoye and Chan (2017) tested the neural network model on a sample of real estate properties in Nigeria using this ANN model.

b) Back-propagation neural network

The Back-propagation neural network (BPNN) model emerged in 1986. The model is known for its outstanding nonlinear search ability and flexibility on model structure (Zhou et al., 2018). The Back-propagation neural network does not stop making links at the final step but searches for other links to find new answers. The peculiarity of the BPNN model is that the response returned to the black box to give another response. McGreal et al. (1997) addressed a multilayer neural network model that has back-propagation as the linking process between networks, the model being called Multilayer backpropagation (MLBP). Pi-ying (2011) used BPNN, recognizing the performance of the model.

c) Feed-forward back-propagation

Feed-forward back-propagation (FFBP) is often called a feedback network. FFBP is a mix of FFNN and BPNN. The model starts as an FFNN trajectory and then adopts BPNN, so when it reaches the third step (result), the information is sent back for further processing. Nghiep and Ai (2001) tested this model on a sample of 906 subjects and observed higher network performance than multiple regression. Chiarazzo et al. (2014) studied the accuracy of estimating the market value of the ANN. The authors chose to run on FFBP. The results mark the recognition of the market value prediction capability for homes.

TOTHĂZAN H. F. (2022).*The contribution of statistical models in the field of real estate valuation***C. Other types of neural networks**

Wilkowski and Budzyński (2006) and García et al. (2008) compared neural network model types to compute their performance. The study listed the following neural network models: Radial basis functions (RBF), Linear neural networks (Linear Networks), Probabilistic Neural Networks (PNN), General regression neural and Kohonen networks. Multilayer Perception, MLP is known for its good valuation results. Wilkowski and Budzyński's (2006) study was to find the best-performing model. Thus, he compared two types of network models, multi-layer perceptron (MLP) and Networks radial basis functions (RBF).

5. Research results

Table 1, outlines several papers that have applied linear and non-linear regression to real estate's valuation.

Table 1. Regression models applied.

Studies	Year of publication	Model name	Abbreviations type/ Performance
Rosen	1974	Simple linear regression	OLS / ++
Adair and McGreal	1988	Multiple linear regression	MRA / ++
Tay and Ho	1992	Simple linear regression	OLS / +
Worzalla et al.	1995	Simple linear regression	OLS / +
Adair et al.	1996	Multiple linear regression	MRA / +++
Din et al.	2001	Simple linear regression	OLS / +
Nduyen and Cripps	2001	Multiple linear regression	MRA / ++
Limsombunchai et al.	2004	Non-linear multiple regression model semi-log	Semi-long / +++
Gonzalez and Formoso	2006	Multiple linear regression	MRA / +++
García et al.	2008	Simple linear regression	OLS / +
Şipoş and Crivii	2008	Multiple linear regression	MRA / ++
Samaha and Kamakura	2008	Hedonic price regression	HPR +++
Selim	2009	Non-linear multiple regression model semi-log	Semi-long / +++
Zurada et al.	2011	Multiple linear regression	MRA / ++
Lin and Mohan	2011	Additive nonparametric regression	ANR / ++
Mc Cluskey et al.	2012	Simple linear regression	OLS / +
Mc Cluskey et al.	2012	Non-linear multiple regression model semi-log	Semi-long / +++
Mc Cluskey et al.	2012	Non-linear multiple regression model log-log	Log-log / +++
MC Cluskey et al.	2011, 2013	Geographically weighted regression	GWR / +++
Arribas et al.	2016	Hierarchical linear model	HLM /+++
Abidoye and Chan	2017	Hedonic price model	HPM / +++
Abidoye et al.	2018	Autoregressive integrated moving	ARIMA / ++

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Studies	Year of publication	Model name	Abbreviations type/ Performance
		average	
Yacim and Boshoff	2018	Non-linear multiple regression model semi-log	Semi-long / +++
Yacim and Boshoff	2018	Non-linear multiple regression model log-log	Log-log / +++
Yilnazer and Kocaman	2020	Multiple linear regression	MRA / ++

Notes: + good model, ++ model applied in practice, +++ very good results but missing in practice

Source: The author

Among the elements highlighted in the table is the model performance, extracted from the findings of the research we reviewed. These concluded findings are noted with a + sign and illustrate the degree of model performance. As the number of + increases, the model performance will also increase. The table results indicate the accuracy of results from the lowest to the highest for the multiple regression model. However, the nonlinear model excelled over the MRA model. Still, multiple regression remains the most transparent results model.

The comparisons among the models continue in Table 2. For example, Benjamin et al. (2004); Božić et al. (2013) compared the market approach with the statistical model, multiple regression. Table 2 contains the opinion of the researchers and practitioners regarding the network model with the result closest to reality.

Table 2. ANN ranking by performance of models

Studies	Year of publication	Model name	Abbreviations type/Performance
Kathmann	1993	Feed forward network	FFN / +++
Warner and Misra	1996	Feed forward network	FFN / +++
Cechin et al.	2000	Multi-layer perceptron	MLP / +++
Limsombunchai et al.	2004	Ward network	Ward N / ++
Liu et al.	2006	Fuzzy neural network	FNN / +++
Bahai	2013	Feed forward network	FFN / +++
Bahai	2013	Feed forward back-propagation	FFBP / ++
Bahai	2013	Cascade forward network	CFBP / ++++
Chiarazzo et al.	2014	Feed forward back-propagation	FFBP / ++
Abidoye and Chan	2017	Multi-layer perceptron	MLP / +++
Abidoye et al.	2018	Machin learning model	SVM / ++
Zhou et al.	2018	Back propagation neural network	BPNN / ++++
Deaconu et al.	2022	Multi-layer perceptron	MLP / +++

Notation: ++++ (2 studies or more but, encouraging results), +++ (often applied in valuation and very good results), ++ (less applied but, good results), + (applied in valuation, good results).

Source: The author

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A wide variety of neural network approaches have been addressed and carried out in property valuation. Table 2 cover a part of ANN models. Out of these, the most notable are multi-layered networks. Zhou et al. (2018), McGreal et al. (1997) and Pi-Ying (2011) strongly recommend a Back propagation neural network (BPNN). Multi-layer perceptron (MLP) has also been a preference, a model with some age in this approach will increases reliability.

Table 3. Findings on the relevance of models applied in property valuation

Classification	Regression models	Artificial neural networks
The most frequently used model	MRA	MLP, FFN
Most preferred models	HPM, MRA, GWR	MLP, FFN
The most appreciated results	MRA, Semi-log, Log-log, GWR, HLM, HPM	CFBP, BPNN, FNN, MLP

Source: The author

*Notation: **MRA** = Multiple Regression Model, **OLS** = Ordinary Least Squares, **HPM** = Hedonic price model, **GWR** = Geographically weighted regression, **Semi-log** = non-linear multiple regression model semi-log, **Log-log** = non-linear multiple regression model log-log, **HLM** = Hierarchical Linear Model, **MLP** = Multi-layer perceptron, **FFN** = Feed forward network, **CFBP** = Feed forward back-propagation, **BPNN** = Back propagation neural network, **FNN** = Fuzzy neural network.*

Studies show that the most commonly used statistical models are MRA for regression and MLP for networks. In terms of estimation, we encountered several models. MLP and FFN generated results that have encouraged their use in the field of valuation. Representations of regression modelling with favourable results were HPM, MRA and GWR. In addition, we observed many regression models that showed pliability in valuation, e.g. MRA, Semi-log, HPR, Log-log, GWR, HLM and HPM. In terms of the artificial network model, CFBP and BPNN performed the best, followed by FNN, and the most applied model is still MLP. In the literature there are much more models but with less application in the property assessment. Also, the accelerating development of technology always brings new performances of different models.

6. Conclusions

Pagourtzi et al. (2003) identify valuation as a central pawn for all types of business. Valuation quality is a component that is highly valued by all. The globalisation of real estate valuation tends to find a foldable model and its recognition by professional practitioners. We see many models being tested and recognized as successful, trustworthy and applied in many developed countries. Structuring the data in a table gives a view of the state of use, testability and application of these models. In doing so, we have sought to encourage tests of these models primarily by emerging countries. Our research shows many models with

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superior results to those tested in practice, such as non-linear multiple regression, semi-log and log-log (Semi-log, log-log model), Hierarchical Linear Model (HLM) for regression model and Feed forward back-propagation (CFBP), Back propagation neural network (BPNN), Fuzzy neural network (FNN) for the neural network model. These are new opportunities to be tested by both developed and emerging countries. These are opportunities for experimentation by both developed and emerging countries.

Our findings indicate that the most used model for regression is MRA versus GLM for networks. However, our expectations were towards models such as fuzzy and geographical. Nevertheless, the most traditional models in the two categories remain popular, followed by the newly suggested fuzzy and geographic models.

The regression model is considered by some practitioners as a traditional model, having already a history in real estate valuation. Thus, the Ordinary Least Squares (OLS) is the model unanimously recognised and accepted by practitioners. Remarkably results have obtained for the following types of regression models: Semi-long, Log-log, GWR, HLM, HPM. ARIMA and ANR are models applied in practice. MRA is the most commonly used of the regression model types. It has not only been empirically tested by researchers but has also received the attention of practitioners. From the studies reviewed, MRA, HPM and GWR are the most popular regression models for the valuation domain. Variations and diversification of the model can be observed through the choice of applied theory, the preference of new types of regressions and the development of the model by using the mentioned extensions (fuzzy logic and geographic system).

ANN model is viewed as a modern, friendly used and closer the market approach applied in property assessment. Although the timing and number of tests were not favourable for ANN compared to MRA, yet studies comparing the regression model with ANN, most of the results were promising for ANN. The diversity of ANN models and their testing history in valuation is lower as thought to regression, but all ANN models indicated promising results in the studies. Among these notable performances were Feed-forward back-propagation (CFBP) and Backpropagation neuronal network (BPNN), but less applied (Bahai, 2013; Zhou et al., 2018). The Feed forward network (FFN) and Fuzzy neuronal network (FNN) models were also considered in their application and performance in finding real estate market values. Other models that stood out in property valuation are Feed-forward back-propagation (FFBP) and the Ward network (Ward N). The Machine learning model (SVM) is often identifying as an ATM to provide a general opinion on estimating the price of a property.

Our expectations for application preferences, appreciation, and usage stood toward newer models such as fuzzy logic or a geographic approach. The results indicate that the most used, with estimated performance remain the MRA (for regression) and GLM (for neural networks) models, followed by the models we consider to be the dominant ones, fuzzy logic

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and geographical ones. The two tables we provided can be a source for future contributions to the selection and testing of models.

References

- Abodoye B. E., Chan A. C. P., Abidoye A., Oshodi O. S. (2018/2019). *Predicting property price index using artificial intelligence techniques. Evidence from Hong Kong.* International journal of housing markets and analysis. DOI: 10.1108/IJHMA-11-2018-0095.
- Abidoye B. R., Chan A. C. P., 2018. *Hedonic valuation of reale estate properties in Nigeria.* Journal of African Real Estate Research, Vol. 1(1), pp. 1 – 18. DOI: 10.1080/09599916.2017.1286366.
- Abidoye B. R., Chan A. C. P., 2016/2017. *Modeling property values in Nigeria using artificial neural network.* Journal of property research, Vol. 1(1), pp. 122 – 140. DOI: 10.15641/jarer.v1i1.452.
- Abidoye B. R., Chan A. C. P., 2016. *Critical determinants of residential property value: professionals' perspective.* Journal of Facilities management, Vol. 14(3), pp. 283 – 300. DOI: 10.1108/JFM-02-2016-0003.
- Abidoye B. R., Chan A. C. P., 2016. *Artificial neural network in property valuation: application framework and research trend.* Property Management, Vol. 35(5), pp. 554 – 571. DOI: 10.1108/PM-06-2016-0027.
- Adair A. S., Berry J. N., McGreal W. S., 1991. *Land availability, housing demand and the property market.* Journal of property research, Vol. 8(1), pp. 59 - 69. DOI: 10.1080/09599919108724020.
- Adair A., McGreal, 1988. *The application of multiple regression analysis in property valuation.* Journal of valuation, Vol. 6 (1), pp. 57 – 67. DOI: 10.1108/eb008002.
- Adair A. S., Berry J. N., McGreal W. S., 1996. *Hedonic modelling, housing submarkets and residential valuation.* Journal of property research, Vol. 13, pp. 67 – 83. DOI: 10.1080/095999196368899.
- Adair A., McGreal S., Smyth A., Cooper J., Ryley T., 2000. *House price and accessibility: the testing of relationship within the Belfast urban area.* Housing studies, 15(5), pp. 699-716. DOI: 10.1080/02673030050134565.
- Arribas I., García F., Guijarro F., Oliver J., Tamošiūnirė R., 2016. *Mass appraisal of residential real estate using multilevel modeling.* International journal of strategic property management, Vol. 20(1), pp. 77-87. DOI: 10.3846/1648715X.2015.1134702.
- Bao H. X. H., Wan A. T. K., 2004. *On the use of Spline Smoothig in estimating hedonic housing price models: empirical evidence using Hong Kong data.* Real estate economics, Vol. 32(3), pp. 487 – 507. DOI: 10.1111/j.1080-8620.2004.00100.x.
- Benjamim J. D., Guttery R.S., Sirmans C.F., 2004. *Mass appraisal: An introduction to Multiple Regression Analysis for real estate valuation.* Journal of Real Estate Practice and Education, Vol. 7, No. 7, pp. 67-77.
- Bahia H. S. I., 2013. *A data mininig model by using ANN for predicting real estate market: comparative study.* International journal of intelligence science, Vol.3, pp. 162 – 169. DOI: 10.4246/ijis.2013.34017
- Borst R. A., 1991. Artificial neural networks. *The next modelling/calibration technology for the assessment community.* Property Tax Journal, Vol. 10, No.1, pp. 69 – 94.
- Božić B., Milićević D., Pejić M., Marošćan S., 2013. *The use of multiple linear regression in property valuation.* Geonauka, Vol. 1(1), pp. 41 - 45.

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- Brunson A. L., Buttner R. J., Rutherford R. C. (1994), Neural Networks, nonlinear specifications, and industrial property values, *University of Texas at Arlington*, working paper series No., pp. 94-102.
- Calhoun A. C., 2001. *Property valuation methods and data in the United States*. Housing finance international, Vol. 16(2), pp. 12 -23.
- Cechin A., Souto A., González A. M., 2000. *Real estate value at porto alegre city using artificial neural networks*. Proceedings. Sixth Brazilian Symposium on Neural Networks, Vol. 1. DOI: 10.1109/SBRN.2000.889745.
- Chaphalkar N. B., Sandbhor S., 2013. *Use of Artificial Intelligence in real property valuation*. International journal of engineering and technology, Vol. 5(3), pp. 2334 – 2337.
- Chiarazzo V., Caggiani L., Marinelli M., Ottomanelli M., 2014. *A Neural Network based model for real estate price estimation considering environmental quality of property location*. Transportation research procedia, Vol. , pp. 810 – 817. DOI: 10.1016/j.trpro.2014.10.067.
- Cohen J., Cohen P., West G. S., Aiken L.S. *Applied multiple regression/correlation analysis for the behavioral sciences*, 3rd edition, Mahwah, NJ: Lawrence Erlbaum Associates, 2003.
- Curry B., Morgan P., Silver M., 2002. *Neural networks and non-linear statistical methods: an application to the modelling of price-quality relationships*. Computers & operations research, vol. 29, pp. 951 – 969. DOI: 10.1016/S0305-0548(00)00096-4.
- Deaconu A., *Diagnosticul și evaluarea întreprinderii*. Editura Economică, București, 2019.
- Din A., Hoesli M., Bender A., 2001. *Environmental variables and real estate prices*. Urban Studies, Vol. 38 (11), pp. 1989 – 2000.
- Do Q., Grudnitski G., 1992. *A neural network approach to residential property appraisal*. The real Estate Appraisal, December, pp. 8-45.
- Do Q., Grudnitski G., 1993. *A neural network analysis of the effect of age on housing values*. The Journal of Real estate Research, Spring, pp. 253 – 264.
- D'amato M., 2004. *A comparison between mra and rough set theory for mass appraisal. A case in bari*. International journal of strategic property management, Vol. 8, pp. 205 – 217. IBBN: 1648-715x.
- Fletcher M., Mangan J., Raeburn E., 2004. *Comparing hedonic models for estimating and forecasting house prices*. Property management, Vol. 22(3), pp. 189 – 200. DOI: 10.1108/026374704105448986.
- Forys I., Gaca R., 2016. *Theoretical and practical aspects of qualitative variable descriptions of residential property valuation multiple regression models*. The 10th Professor Aleksander Zelias International Conference on modelling and forecasting of socio-economics phenomena.
- García N., Gámez M., Alfaro E., 2008. *ANN + GIS: An automated system for property valuation*. Neurocomputing, Vol 71, pp. 733 – 742. DOI: 10.1016/j.neucom.2007.07.031.
- González S. A. M., Formoso T. C., 2006. *Mass appraisal with genetic fuzzy rule-based systems*. Property management, Vol. 24(1), pp. 20-30. DOI: 10.1108/02637470610643092.
- Goodman A. C., 1978. *Hedonic prices, price indices and housing markets*. Journal of urban economics, Vol. 5(4), pp. 471 – 484. DOI: 10.1016/0094-1190(78)90004-9.
- Goodman A. C., 1978. *Andrew Court and the invention of hedonic price analysis*. Journal of urban economics, Vol. 44, pp. 291 -298. DOI: 10.1016/0094-1190(78)90004-9.
- Hu L., He S., Han Z., Xiao H., Su S., Weng M., Cai Z., 2018. *Monitoring housing rental prices based on social media: an integrated approach of machine-learning algorithms and*

TOTHĂZAN H. F. (2022).*The contribution of statistical models in the field of real estate valuation*

- hedonic modeling to inform equitable housing policies*. Land use policy, Vol. 82, pp. 657 – 673. DOI: 10.1016/j.landusepol.2018.12.030.
- Isakson H. R., 1998. *The review of real estate appraisals using multiple regression analysis*. Journal of real estate research, Vol. 15(1/2), pp. 177 – 190. DOI: 10.1080/10835547.1998.12090922.
- James G., Witten D., Hastie T., Tibshirani R., 2013, *An introduction to statistical learning with Applications in R*. Springer texts in statistics.
- Kathmann R. M., 1993. *Neural network for the mass appraisal of real estate*. Computers, environment and urban systems, Vol. 17(4), pp. 373 – 384. , DOI: 10.1016/0198-9715(93)90034-3.
- Kestens Y., Thériault M., Rosiers F. D., 2006. *Heterogeneity in hedonic modelling of house prices: looking at buyer's household profiles*. J Geograph syst, Vol. 8, pp. 61 – 96. DOI: 10.1007/s10109-005-0011-8.
- Knopf J. W. 2006. *Doing a literature review*. PS. Political Science & Politics, vol. 39 (1), pp. 127 – 132.
- Kuburik M., Tomić H., Mastelić Ivić S., 2012. *Use of Multicriteria Valuation of Spatial Units in a System of Mass Real Estate Valuation*. Preliminary Communicationâ KiG, Vol. 11(17), pp. 759 -774.
- Lenk M. M., Worzala M. E., Silva A., 1997. *High-tech valuation: should artificial neural network bypass the human valuer?* Jurnal of Property valuation Investment, Vol. 15 (1), pp. 8-26. DOI: 10.1108/14635789710163775.
- Lin C. C., Mohan B. S., 201. *Effectiveness comparison of the residential property mass appraisal methodologies in the USA*. International Journal of Housing Market and Analysis, Vol. 4 No. , 2011, pp. 224-243.
- Limsombuchai V., Gan C., Lee M., 2004. *House Price Prediction: Hedonic Price Model vs. Artificial Neural Network*. American Journal of Applied Science, Vol.1 (3), pp. 193 – 201.
- Lin C. C., Mohan A. B., 2011. *Effectiveness comparison of the residential property mass appraisal methodologies in the USA*. International journal of housing markets and analysis, Vol. 4(3), pp. 224 – 243. DOI: 10.1108/17538271111153013.
- Liu J. G., Zhang X. L., Wu W. P., Application of Fuzzy Neural Network of Real Estate Prediction, *Spring-Verlang Berlin Heidelberg*, pp. 1187 – 1191.
- Malpezzi S., 2002. *Hedonic pricing models: a selective and applied review*. Housing economics and public policy, Ch.5. DOI: <https://doi.org/10.1002/9780470690680.ch5>
- McClusey J. W., Borst A. R., 2011. *Detecting and validating residential housing submarkets. A geostatistical approach for use in mass appraisal*. International journal of housing markets and analysis, Vol. 4(3), pp. 290 – 318. DOI: 10.1108/175382711111530400.
- McCluskey W.m Davis P., Haran M., CcCord M., Mcllhatton D., 2012, *The potential of artificial neural networks in mass apparaisal: the case revisited*. Journal od financial management of property and construction, Vol. 17(3), pp. 274 – 292. DOI: 10.1108/1366431211274371.
- McCluskey J. W., McCord M., Davis T. p., Haran M., Mcllhatton D., 2013. *Prediction accuracy in mass appraisal: a comparison of modern approaches*. Journal of property research, Vol. 30 (4), pp. 239 – 265. DOI: 10.1080/09299916.2013.781204.
- Munakata T., Fundamentals of the New Artificial Intelligence, *Springer*, New York, 1998.
- Nghiep N., Al C., 2001. *Predicting housing value: a comparison of multiple regression analysis and artificial neural networks*. Journal of real estate research, Vol. 22(3), pp. 313 – 336. DOI: 10.1080/10835547.2001.12091068.

TOTHĂZAN H. F. (2022).*The contribution of statistical models in the field of real estate valuation*

- Ogwang T., Wang B., 2003. *A hedonic price function for a northern BC community*. Social indicators research, Vol. 61, pp. 285 – 296. DOI: 10.1023/A:1021905518866.
- Pagourtzi E., Assimakopoulos V., Hatzichristos T., French N., 2003. *Real appraisal: a review of valuation methods*. Journal of property investment & finance, Vol. 21(4), pp. 383 – 401. DOI: 10.1108/14635780310483656
- Pontus N., 2019. *Prediction of residential real estate selling prices using neural networks*. KTH Royal Institute of Technology School of Electrical Engineering and computer science, Stockholm, Sweden.
- Rahman A. N. S., Maimun A. H. N., Razali M. N. M., Ismail S., 2019. *The artificial neural network model (ANN) for Malaysian housing market analysis*. Journal of the Malaysian institute of planners, Vol. 17(1), pp. 1-9.
- Rossini P., 1997. *Artificial Neural Networks versus Multiple Regression in the Valuation of Residential Property*. Australia Land Economics Review, 3(1), pp. 1-12.
- Rosen S., 1974. *Hedonic prices and implicit markets: product differentiation in pure competition*. Journal of political economy, Vol. 8(1), pp. 34 – 55.
- Rossini P., 1998. Improving the results of artificial neural network models for residential valuation. *Fourth annual Pacific-Rim real estate society conference*, Perth, Western Australia, pp. 1-18.
- Samaha A. S., Kamakura A. W., 2008. *Assessing the market value of real estate property with a geographically weighted stochastic frontier model*. Real estate economics, Vol. 36(4), pp. 717 – 751. DOI: 10.1111/j.1540-6229.2008.00228.x.
- Sarip G. A., Hafez B. M., Daud N. M., 2016. *Application of fuzzy regression model for real estate price prediction*. Malaysian journal of computer science. Vol, 29(1), pp. 15 – 27.
- Selim H., 2009. *Determinants of house in Turkey: Hedonic regression versus artificial neural network*. Expert system with applications, Vol. 36(2), part 2, pp. 2843 – 2852. DOI: 10.1016/j.eswa.2008.01.044.
- Șipoș C., Crivii A., 2008. *Modelul regresiei liniare pentru evaluarea proprietăților imobiliare*. Revista de evaluare, 2(5).
- Steverson S., 2004. *New empirical evidence on heteroscedasticity in hedonic housing models*. Journal of housing economics, Vol. 13(2), pp. 136 – 153. DOI: 10.1016/j.jhe.2004.04.004.
- Stoean R., 2008. *Rețele neuronale. Neural networks (NN)*. <http://inf.ucv.ro/~rstoean>
- Tay D. P. H., Ho D. K. K., 1992. Artificial Inteligenc and the Mass Appraisal of residencial Apartment, *Jurnal of Property Valuation & Investment*, 10:525-540.
- Trippi, R.R., Turban, E., 1992. *Neural Networks in Finance and Investing: Using Artificial Intelligence to improve real world performance*. Chicago, IL, Probus Publishing.
- Tothăzan H. F., Deaconu A. 2020. Neural Network Artificial Model for Real Estate Appraisal: Logic, controversies, and utility for the Ramanian context. *“Ovidius” University Annals, Economic Sciences Series*, Vol. XX(22), pp. 1093-1100.
- Tudorel A., Régis B., 2008. *Econometrie*. București, Editura Economica.
- Watkins C., 1999. *Property valuation and the structure of urban housing markets*. Journal of property investment & finance, Vol. 17(2), pp. 157-175. Academic paper.
- Wilkowski W., Budzyński T., 2006. *Application of Neural Networks for Real Estate Valuation*. TS86 – Valuations Methods, XXIII FIG Congress, Munich, Germany, October 8-1, 2006.
- Worzala E. M., Lenk M. M., Silva A., 1995, *An explanation of neural networks and its application to real estate valuation*, Journal of Real Estate Research, Vol. 10, No. 2, pp. 185-202.

TOTHĂZAN H. F. (2022).

The contribution of statistical models in the field of real estate valuation

- Yalpir S., 2014a. *Forecasting residential realpage estate valees with AHP method and integrated GIS*. In conference proceedings of people, Building and Enviroment 2014, Czech Republic, pp. 694 – 706.
- Yalpir S., Durduran S. S., Unel F. B., Yolcu M., 2014b. *Creating A Valuation Map In GIS Through Artificial Neural Network Methodology: A Case Study*. Acta Montanistica Slovaca, Vol. 19(2), p79-89.
- Yilmazer S., Kocaman S., 2020, *A mass appraisal assestment study using machine learning based on multiple regression and random forest*. Land use popicy, Vol. 90, pp. 1-11. DOI: 10.1016/j.landusepol.2020.104889.
- Zhou G., Ji Yicheng, Chen X., Zhang F., 2018. *Artificial neural Networks and the mass appraisal of real estate*. International Journal of online engineering (iJOE), Vol. 1(3), pp. 180 – 187.
- Zurada J., Levitan S. A., Guan J., 2011. *A comparison of regression and Artificial Intelligence methods in a mass appraisal context*.
-