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Real estate and land property automated valuation systems: A taxonomy and conceptual model

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Real estate and land property automated valuation systems: A taxonomy and conceptual model

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April 2018 Abstract

Automated valuation models have been in use at least for the last fifty years in both academia and practice, while a proper definition was coined only in the last decade. This could be mostly backed by the fact that research done on the automated valuation models is mostly empirical and evidently lacking a conceptual framework. This imply two-sided contribution of this paper, a taxonomy and a conceptual framework.

Keywords: automated valuation model; computer-assisted mass appraisal; real estate valuation decision support systems; automated valuation system; non-hierarchical taxonomy; conceptual model.

JEL classification codes: C50 ; D46 ; G32 ; O21 ; R15 ; R20 ; R30 ; L85 ; Q15

1. Introduction

Automated valuation models (AVM) is a very mature topic that has recently reemerged as most important with the rise of digital infrastructure. Therefore, this article provides needed analysis and synthesis of the accumulated body of knowledge, and proposes a conceptual framework.

Amongst scholars, there were already reported collections [1,2] and attempts to classify existing body of knowledge of automated valuation models [3]. Also, a long time lacking theoretical framework has been addressed and efforts were made to formalize and bring a critical discussion on automated valuation models [4]. Interest for automated valuation models has been also present in practice. The first patent emerged in the early 90's [5,6] and since then numbers have been developing until today [e.g. 7]. Besides the patents, the presence of the automated valuation models in practice has been documented by published standard on automated valuation models by International Association of Assessing Officers [8], an organization established almost 85 years ago [9]. The ongoing and future demand in different business areas has been also noted recently [10]. Evidently automated valuation models have been present in all geographies [11] due to the different uses and increasingly available data.

While AVMs have been used for at least the last fifty years in both academia and practice, and although the term emerged in the 70's for land valuation [12] and real estate property valuation [13], a formal definition was coined only in 2003. "An automated valuation model (AVM) is a mathematically based computer software program that produces an estimate of market value based on market analysis of location, market conditions, and real estate characteristics from information that was previously and separately collected" [8]. This definition is broad enough to capture new source of data and new methods. Consequently, this paper opts for this definition. However, as a domain of price estimates far surpasses any unique discipline, a broader term is needed to accommodate future research resulting from a multitude of disciplines.

Relatively late introduction of a proper AVM definition could be backed by the fact that AVM research is mostly empirical. To illustrate that, only very recently contribution is made towards a theoretical framework [4]. Much of the empiricism is also due to the dominant method used for AVM, namely the hedonic price method (HPM). Hedonic model studies can be clearly delineated as local and dependent on case studies. Perhaps unintuitive but comparing common and civil law explains why there is much of empiricism present in AVM research. "Although common-law systems make extensive use of statutes however judicial cases are regarded as the most important source of law, which gives judges an active role in developing rules" [14]. If we look at statement next to the definition of AVM from an already mentioned standard that: "Credibility of an AVM is dependent on the data used and the skills of the modeler producing the AVM", it is possible to make this analogy when a judge is exchanged with a modeler. "In civil-law systems, by contrast, codes and statutes are designed to cover all eventualities and judges have a more limited role of applying the law to the case in hand" [14]. Shifting the paradigm from models to systems or specifically automated valuation systems would position automated valuation research more in a civil-law 'fashion'. Another important issue that emerges from past research is the arbitrary credibility of AVMs based on specific methods. Assuring the credibility of AVM that is based purely on comparing the predictive accuracy of method 'a' versus method 'b' has become a common practice. In addition, as a domain of price estimates has been far surpassed any unique discipline, term that is more generic would be appropriate to accommodate future research coming from multitude of disciplines.

For addressing these two major shortcomings, we propose first a taxonomy that will indicate facets, properties and measurements so as to align the different segments of valuation and to further investigate their regularities leading to a conceptual model. The first would avoid the misleading credibility based only on the methodological approach without considering the object, purpose, available methods, and aspects taken into account and finally the need of the final user of an AVM. The later would bring some clarity and cover all eventualities where an AVM could be applied.

Although included in the above definition of an AVM, it is important to underline the limitations of econometric models as tools for real estate price forecast [e.g. 15,16]. Since they do

not have built-in real estate characteristics or could not be linked to the value of an individual real estate property, they cannot be strictly considered as AVM under the formal definition. Further, studies that aim at price estimation of a part of the property or land are also not included in this survey [e.g. 17]. Lastly, no contextual, temporal or geographical exclusion were made.

The paper is organized as follows: second section elaborates on the origin of AVMs; the third section introduces the reader newly defined facets, properties and measurements of a generic AVM; a special attention on the valuation methods and their classification has been dedicated in the fourth section. The fifth section introduces a non-hierarchical taxonomy based on the newly established matrix of facets, properties and measurements, bring out regularities in the matrix and proposes a conceptual model based on matrix causalities. Lastly, section six concludes on how this paper extends past research and what are the implications for future practice and theory.

2. Origins of Automated Valuation Models

Real estate and land property valuation is about the estimation of property market value. Real estate valuation is a non-trivial process because it involves the consideration of a variety of underlying market factors and the way they affect the value of the real estate and land property at a given time and in a given location. Such factors may include governmental policies, geographical factors or even factors such as fashion, season, etc.

Real estate valuation has evolved in a scientific community since the second half of nineteenth century [9]. While the origin of AVM dates back to the formal development of hedonics in the early seventies. The first published hedonic study [18] was a master thesis on agricultural land values in 1922 at University of Minnesota as argued by Colwell and Dilmore [19]. Its introduction as an empirical estimation method though can be traced back to Court [20]. In 1970, *Computerized Assisted Assessments* term emerged also from land valuation [12]. Few years later the concept is introduced also in real estate property valuation [13] by the term *Model for Automated Assessment* almost identical to the one used now.

The term *Computer Assisted Mass-Appraisal* is also currently used as an equivalent to AVM. It was used for the first time by Carbone and Longini [13] to explain what the automated assessment model could be used for. Considering that any mathematical model designed at performing mass appraisal necessarily involves the use of a computer, the CAM denomination is redundant and will not be used in this paper. Rather, it is the object of the automated valuation process, that is, land and real estate property, which is focused on.

Perhaps the major contribution to the development of the AVM has been in the area of information system discipline. More specifically, new methods and perspective in automated valuation are heavily linked with the emergence of decision support systems (DSS). A formal definition of a DSS refers to a system that improves and supports decision-making capabilities of an individual or group, where each DSS consists of three basic elements: (a) data, (b) model, (c) user interface [e.g. 21]. The term DSS first appeared in a paper by Gorry and Scott Morton [22], although in a 2004 key note speech Andrew McCosh accredits the birth date of the field to 1965, with Michael Scott Morton's PhD thesis, "Using a computer to support the decision-making of a manager" [21]. DDS applications started being developed in real estate in the seventies and expert systems in the eighties [23]. With regard to valuation, the first *Decision Support System for Real Estate Valuation* has been reported in the early 80's [24].

DSS for real estate valuation can be classified as a model-driven DSS type [25,26]. Furthermore, estimating the price of a piece of real estate or land is structured and monotonous decision situation that will further frame this DSS as an automated decision system [26]. Because of these characteristics, the term *Automated Valuation System* seems appropriate. The term has been already introduced [27] but not strictly defined. An automated valuation system (AVS) for real estate and land property would thus be any software consisting of data, model and user interface that will help an individual or organization to generate a price estimate for a single real estate or land property asset through a structured and routine decision process.

In brief, we may say that AVM have to define only a model specification while AVS have to define model use. For example, a hedonic model has dominated automated valuation but also creation of indices [28]. Therefore, similar hedonic model may be used to produce automated valuation for local tax estimates but also for the creation of imputed hedonic index. While both model specifications might be highly similar, their purposes remains very different. To address properly a broad notion of automated valuation use, this paper introduces key facets, properties and their measurements to create a non-hierarchical taxonomy of AVSs. In addition, to link model specification and model use besides introducing AVS taxonomy, it also useful to differentiate between automated valuation approach (Section 3.6.1), automated valuation method (Section 3.6.2) and automated valuation model (AVM).

2.1 Country coverage

Despite differently coined terms by various disciplines, the development of automated valuation systems has been global, with several authors reporting on that [e.g. 11]. Today, AVMs have been widely distributed geographically due to availability of data and idea exchange. However, AVMs have yielded different overall model specifications depending on the countries where they were designed, mainly due to the diversity of available data. The use of AVMs have been academically reported in almost all continents: Africa [e.g. 34], Asia [e.g. 36,37], Australia [e.g. 32], Europe [e.g. 29–33], and North America [e.g. 35].

3. Defining Key Facets and Properties of Automated Valuation Systems

In order to address properly a broad notion of AVM use, this paper introduces AVS as a term and its taxonomy based on key facets, properties and measurements. Proposed taxonomy is non-hierarchical because all AVSs have the same importance and each one has these facets. To introduce facets, simple questions were raised: by whom valuation will be used, for which purpose, what is to be valued, by which means, and in what way a property should be valued? These questions cover the basic understanding of the context in which an AVM is used. These fairly famous questions are often-quoted way to think through problems; they have been repeatedly raised by Cicero, Thomas Aquinas, and Rudyard Kipling and afterwards extended by Samuel Beckett [39]. Properties describe each facet and they are usually mutually exclusive but not necessarily. List of properties is defined or included strictly on the grounds of our literature review [1-116]. First column of Table 1 reports on facets whereas second column reports on their corresponding properties. Lastly, each property is observable by nominal level of measurement (Table 2).

Table 1. AVS' overview of facets and properties

<i>Facets</i>	Properties (abbrev.)
<i>End user</i>	Individual (I _u) Corporate (C _u) Public (P _u)
<i>Secondary purpose of valuation</i>	Local tax estimates (T) Price index (I) Portfolio risk assessment (P _r) Insurance risk assessment (I _r) Landing risk (L _r) Negotiation margin (N)
<i>Object of valuation</i>	Residential (R _o) Non-residential (N _o) Land vacant/brownfield (L _o)

<i>Price response</i>	Sales price (S_p) Asking price (A_p) Bid price (B_p) Construction price (C_p) Rent price (R_p)
<i>Price determinant classes</i>	Site: locational and intrinsic variables (S) Environmental (E) Legal: tenure/ownership structure (L) Fiscal (F) Socio-economic (S_e) Demographic (D)
<i>Approach</i>	Cost (C) Income (I) Comparison (C_o) Probabilistic (P) Non-Probabilistic (N)
<i>Focus</i>	Explanatory (E) Predictive (P)

3.1 End users

AVMs have been very much used in practice by various types of end users. As an indication that identifying the end user of an AVM is of paramount importance for its classification could be partly revealed by the number of individual and corporate filed patents [5–7,40–50]. In addition to *individual* and *corporate* end users, *public* authorities are the third group of end users of automated valuation models.

3.2 Secondary purpose of valuation

“The purpose of an AVM is to provide a credible, reliable, and cost-effective estimate of market value as of a given point in time” [8]. Contrary to this primary purpose of valuation, secondary valuation purpose defines for what AVS will be used. More than several derive from literature review.

Local tax estimates - The first clearly stated use of an AVM was tax assessment [51]. In practice, AVMs has been used from late 70’s in the USA, Denmark, the Netherlands and Sweden [52].

Portfolio (risk) assessment - The use of AVMs can lead to sophisticated risk management systems because its statistical results can be easily integrated in a continually validated risk management system. So, they have also been used for real estate portfolio risk assessment [53]. they also provide a support for institutional investors in determining offering price [8] for a part of the real estate portfolio, for example.

Price index - In general terms, house price indices provide a barometer for the state of the economy [28] and have become indispensable tools for public policy implementation. Governments and institutional investors use them in many ways, hence there is the vast literature on the subject [18,28]. As mentioned earlier because a model with almost identical specification can be used can be used for imputed indices and as AVM, authors consider all imputed indices as AVS.

Insurance risk assessment – Assessing the replacement cost of a structure is a basic requirement for the property insurance business, which is why automated valuation models based on the cost approach have long been used for that purpose. More recently though, AVMs have been designed for monitoring mortgage insurance risk and are becoming increasingly popular among

firms operating in that area of activity [54]. For example, there is an increasing demand to use AVM to help with insurance risk assessments of house exposure to floods [55].

Lending risk - Mortgage lending is the most frequently mentioned AVM's intended use, whereby lenders and mortgage brokers seeking at speeding up the loan decision process from weeks to days by the instant output of an AVM. This avoids the delay arising from an inspection valuation [52]. AVM can be used as a litigation support, for example in a foreclosure litigation [56] which typically involves homeowners suing their lender, alleging wrongful foreclosure or unlawful lending practices.

Land readjustment – AVMs also apply to planning and land-use decisions such as land consolidation. Land consolidation, which involves the reorganization of space through land reallocation, both in terms of ownership and land parcel boundaries, is based on land value assessment because each landowner is entitled to receive a property with approximately the same land value after land consolidation [57].

Real estate investment - Some of the first AVMs have been implemented in support of business development and economic decisions, more specifically real estate investment decisions [23].

Negotiation margin - Lastly, AVMs provide support in determining the listing or initial asking price, which meant at attracting potential buyers and is seen as a starting point for further negotiations. Several authors have contributed to their development [e.g. 57].

3.3 Object of valuation

AVMs are applicable to any type of property for which adequate market and property information are available. However, a major distinction should be made between AVMs designed at estimating land, as opposed to real estate property, values. Both are included in the taxonomy. As a reminder, let us recall that the first application of a hedonic model – although it wasn't termed as such – has been developed for woodland valuation. Besides the methodological and historical emphasizing, all of the introduced facets are shared among both types of products. Furthermore, AVMs for the real estate property can be roughly divided on residential and non-residential (i.e. offices, commercial buildings) real estate property.

Land (vacant or brownfield) - As mentioned above, the first 'object' to have been valued using an automated device is land [12]. It is very much possible that the first AVM developments occurred in land observations because land tend to be much more uniform than any other real estate property type. However, land valuation provide a set of unique problems such as highly speculative nature of transactions and there are few sales for analysis and modelling [8]. Partly this is because land value is most influenced by land-use change on micro-scale. Different valuation approach (Section 3.6.1) can be used for land valuation. For example, with regard to land valuation pertaining to remote locations, AVMs should rely on income potential rather than on sales date [8]. Since Gwartney [12], many authors have reported on AVMs for land property [12,27,57,59–61], also as some patents are filed [e.g. 42].

Residential – Land value AVMs were soon followed by residential real estate property automated procedures [13]. As it is for land, it could be said that residential real estate property has much more uniform characteristics, than for example, commercial property such as casino. This also explains, still today, most AVMs have been specifically designed for residential real estate property [13,31,33,37,62–67] and why residential AVMs have the longest history amongst automated property valuation systems. In real estate valuation, it is a norm to distinguish between detached and attached residential property. In the first category, only self-standing houses on an individual land plot is considered. In contrast, structures where multiple living units are joined together on different forms of ownerships are commonly referred to as attached residential units. The latter category includes many property types: apartments, condominiums, terraced houses and semi-detached houses. Since these two categories differ mainly by their land-to-building ratio, they tend to be reported separately. Also noteworthy are two to four-family residential properties where, quite often, an owner occupies one of the units while renting the others. In such cases, the real estate

asset can be regarded as a small income-producing property [8], with income-based models being substituted for the traditional sales comparison approaches [9]. Another interesting aspect of residential real estate property valuation deals with manufactured or prefabricated housing whereby a residential unit is built in a factory under strictly controlled quality standards. Appreciation and acceptance of future homeowners for prefabricated homes will determine their success, which is already long achieved in some countries, namely Sweden, where they account for a very high share of housing production. Once market conditions for prefabricated homes are known, their value can be modelled as for any other property. However, the main problem with valuing such homes stems from the fact that some of the prefabricated homes are designed to be mobile. This requires that they be valued, and modelled, separately from traditional, fixed houses, and there are some prospective methods [68].

Non-residential - Commercial real estate properties are usually income-producing properties acquired for their ability to generate income [8]. Because of this characteristic estimating value via the income approach using either direct capitalization or discounted cash flow analysis [69] is a viable option. This being said, data availability is often a problem when it comes to commercial and industrial properties, which is why previous attempts to design a valid commercial AVM have more often than not been jeopardized, whatever the valuation approach considered (cost, income, or comparison). For a non-residential property, use is extremely important to estimate its value since the presence of a given attribute will affect value differently depending on that use. For example, closeness to the seaside would have a huge impact on a hotel but not that much on a shopping mall. Several authors have contributed to investigate the value components of non-residential real estate property, either in general [e.g. 30] or with regard to specific uses such as hotels [70] or shopping center [71–73]. Valuing industrial real estate poses problems that are very similar to those encountered with commercial property. Both property uses involving income generation, they tend to be regarded in the literature as a single problematic to deal with [8]. Still, the requirements for land and building characteristics vary tremendously between the two uses while being also the least traded on the market – particularly industrial real estate.

3.4 Price response

Three major data types can be used as price response. Revealed preference data are derived from real market transactions whereas stated preference data are based on the respondents' observations from an experimental environment. Lastly, using revealed and stated data together, called combined preferences, is also a common way to assess willingness to pay. Important to note is that different data types can be estimated by different methods. When working with the revealed preference data for housing amenities most researchers favor hedonic regression analysis [e.g. 61–63] over other methods [e.g. 64,65]. Contrary, price estimates based on combined preference are often an outcome of hybrid models [e.g. 66–70]. As expected, each data type has its advantages and disadvantages. For example, combined preference data is also commonly used when there is a lack of revealed data or in the case where a researcher tries to overcome drawbacks of analysis by including at least two different data sources and types. Further, stated preference data is most useful when introducing a completely new price determinant variable for which obviously there is no real market data. In this case, a survey is used to collect data. It is also important to distinguish between data type and data source. For example, *sales price* (i.e. notary deeds) is a data source that classifies as revealed data type same as *asking prices* (i.e. property websites). Contrary, *bid price* is a data source that is rarely revealed (i.e. foreclosures or governmental tendering). Therefore, sales prices provide revealed preference data derived from real market conditions, which do not include the future preferences of potential buyers or individual preferences pertaining to a new product. They are used by many authors and ground most of existing AVMs. The asking price is defined as the price suggested by a seller but usually considered to be subject to bargaining. In some situations, namely where the sales price is not available, the asking price may be used as a 'biased' substitute for estimating property values. The bid price is the price a buyer is willing to pay for a real estate asset. As with the asking

price, it is usually subject to bargaining. In addition, some approaches rely also on the *construction price* and *rent price* to estimate a market value of a land or property.

3.5 Price determinant classes

Beside the choice of a method, selecting variables plays a vital role in the quality of estimates. Appreciation and depreciation of property prices within a given region is a function of *social-economic*, *legal* (i.e. tenure and ownership structure) and *environmental* dynamics continuously interacting over time and across space [84]. Therefore, intended variables for AVM can be ‘classed’ according to these dynamics. To reflect all aspects that influence property prices, it is necessary to expand or additionally specify mentioned dynamics. Specifically, *fiscal* (i.e. tax reduction incentives) policies that government impose significantly reflect on property prices. Similarly, *demographic* (i.e. population growth) processes directly influence supply and demanded ratio of dwellings and therefore property prices too. In addition, a prominent aspect that dominates any real estate and land property value estimation [85] is *site* itself that could be further decomposed into locational (i.e. accessibility and proximity) and intrinsic variables of land and/or structure. Rarely an AVM would have included all of the above aspects. The importance of variable selection in the design of an AVM drives us back to the issue of measuring the impact of urban externalities. As an example, a governmental body might be interested in assessing if, and to what extent, implementing some costly policy measure impacts on land values. Unless environmental, or socio-economic, attributes are included in the AVM modelling process, such a task would simply prove impossible. Building a land value index that alternately exclude and include such dimensions could provide a reliable estimate of their marginal contribution to value. This being said, making an enlightened choice for price determinant classes is not always possible.

3.6 Approaches

This paper proposes a new classification for automated valuation approaches (Section 4).

4. Classification of Automated Valuation Approaches and Methods

Price estimation models are the core of the automated valuation process. They are engines that drive the accuracy and credibility of the estimate made [8]. Their abundance and increasing variety is stimulating. However, this also ask for classification of AVMs. Ideal classification would be mutually exclusive hierarchical classification in a way that each automated valuation model (AVM) belongs to unique automated valuation method that belongs to unique automated valuation approach. However, this would not be a realistic classification.

4.1 Approaches

Therefore, we introduce two-dimensional framework classification of automated valuation approaches (Figure 1). One dimension responds to the traditional division of valuation approaches (i.e. cost, income and comparison) and second dimension reflects how uncertainty is dealt with (i.e. not included, probabilistic and non-probabilistic). Thus, providing a matrix of nine 2-tuple automated valuation approaches.

First valuation approach to be introduced is the traditional cost approaches, also called scientific appraisal in the 1920s and early 1930s [9]. Within cost approach, models specification requires the estimation of separate land and building values. This approach is dependent on the existing cost tables that should be calibrated to the local market in order to provide a valid indicator of value by the cost approach [8]. Income-producing real property is usually purchased for the right to receive future income. The appraiser evaluates this income for quantity, quality, direction, and duration and then converts it by means of an appropriate capitalization rate into an expression of present worth: market value [8] method is to use a discounted cash flow [69] and models based on rental income [86]. The comparison approach considers either direct real estate price comparison model with certain specification and estimation or calibration technique; or a twostep process, in which comparable real estate prices are identified and adjusted to the subject property. Important to

note, instead of relying only on traditional sales prices this paper opt for the use of different type of real estate price data to emulate real estate value (i.e. sales or transferred, asking, and bidding prices).

While some AVMs put forward deterministic approaches to value estimation (such as the cost approach), others deal with uncertainty using either econometric methods that combine economic and probability theories (e.g. hedonics) or methods derived from other theories dealing with uncertainty. Historically, first AVMs did not have built-in any reflection on uncertainty. For example, construction cost estimates method is still regularly reported in this manner, and therefore it classifies as basic uncertainty approach. Probabilistic approach is related to the use of probability theory. That is the most spread and firstly introduced with hedonic models. As mentioned, there are other theories that explain uncertainty such as fuzzy set theory. Besides methods relying on these theories, non-probabilistic approach also relates to artificial intelligence that has been long time introduced in property valuation [87].

Uncertainty Approach	Non-Probabilistic			
	Probabilistic			
	Not Included			
		Cost	Income	Comparison
		Valuation Approach		

Figure 1. Nine 2-Tuple Automated Valuation Approaches

4.2 Methods

Not every automated valuation method can be framed within unique 2-tuple approach. For example, a Fuzzy Logic method can be used to estimate real estate prices based on cost, income or comparison input and it can be labeled consequently as Cost-Probabilistic, Income-Probabilistic, or Comparison-Probabilistic approach. Similar, direct capitalization method can be classified as Income-Basic in its original form (i.e. uncertainty is not included) or Income-Probabilistic (e.g. in combination with Monte Carlo simulation) or Income-Non-probabilistic (e.g. in combination with artificial neural network) approach.

Construction cost estimates

The cost approach to real estate valuation assumes that the price a buyer will pay for a piece of property should equal the cost of building an equivalent structure. Under the cost approach, the market value for a real estate asset equals the price of land, plus the cost of construction, less depreciation. It yields the most accurate market value when the property is new. The cost approach includes two overall methods: (i) the replacement method, the most frequently applied, assumes the new structure provides the same utility with updated materials and design; (ii) in contrast, the reproduction method considers that an exact replica of the property is built (e.g. an historical building). The cost approach is mainly used for property insurance purposes and for single-use, non-income-producing real estate assets (e.g. schools, churches) as well as for some industrial buildings that are seldom transacted on the market, thereby ruling out the comparable and income approaches.

Direct capitalization

Under the direct capitalization method, market value is obtained by capitalizing in perpetuity the yearly net operating income of a property at a rate (the Overall Cap Rate, or OCR) which is specific to a given property type (same use, quality, state, management), in a given location and at a given point in time. While the OCR is normally derived from the distribution of net-income-to-sale-price ratios for a set of comparable properties, it can also be traced back by computing the weighted average of the cost of borrowed capital (i.e. the debt) and the cost of equity capital, or dividend yield, expressed as the ratio of the first year before-tax cash-flow to initial down payment. The direct capitalization method is mostly relevant for properties which generate stable and predictable income flows over time.

Discounted cash flow

For more complex pieces of real estate (e.g. large, multi-use commercial properties) with highly fluctuating income flows that can shift from positive to negative from year to year, the discounted cash-flow (DCF) method is preferred. Under the latter, the market value of a real estate project or existing investment equals the debt portion of the investment plus the present value (PV), over some investment horizon (i.e. the holding period), of the before or after-tax annual cash-flows of the property from both operations and disposal, capitalized by the market discount rate for that type of asset. As for the discount rate, it is the minimum rate of return a typical investor will accept on his equity considering the level of risk involved in the project.

Hedonic Regression

Empirical applications of the hedonic price method (HPM) date back at least to the late 1930s with work by Court [20] on the automotive industry, followed by Griliches [88]. Colwell and Dilmore [19] argue that the first published hedonic study was a 1922 University of Minnesota master's thesis on agricultural land values. However, it is in the first half of the 1970s that the conceptual basis of the hedonic pricing method was formally developed in a seminal paper by Rosen [89]. According to the hedonic price theory, the price of a complex good, such as housing, mirrors the utility derived from its characteristics, which are implicitly valued by economic agents operating in a market in equilibrium. These implicit, or shadow, prices are referred to as hedonic prices and can be brought out by differentiating the hedonic function with respect to each attribute of the good. Being most of the time derived from transaction prices, that is, from a market in equilibrium, hedonic prices are used as a proxy for both the willingness-to-pay (WTP) of the buyer and the willingness-to-accept of the seller for each component of the good. As for the hedonic function itself, it consists of an envelope curve built out of individual market equilibriums – i.e. at the points of tangency between the supply and demand functions - for each attribute of the good. Consequently, and from a theoretical – although not empirical - point of view, the hedonic function cannot distinguish between the marginal influences that supply and demand factors exert on the overall price of the complex good, both contributions being embedded in the implicit price of a given attribute.

Multiple linear regression analysis (MRA) remains, by far, the most widely used econometric technique for applying the HPM, with regression coefficients derived from MRA corresponding to the hedonic, or implicit, prices of the complex good's attributes. Since Rosen's [89] major conceptual contribution and the ensuing academic recognition of the HPM, the latter has extended to several fields of the social sciences, namely housing economics and real estate, where it is used for measuring various types of urban externalities [38] and for building price indices [90]. Considering its reliability and robustness as a method for both explanatory and predictive purposes, the HPM has gained popularity over the past few decades as an AVM tool [91].

Pros: The HPM is a highly versatile method, which can successfully address numerous economic, social, environmental and public policy issues. With regard to real estate, and housing in particular, applications, reliable estimates of property market values as well as of individual housing characteristics may be obtained. Several functional forms may be used in order to

circumvent the non-linearity problem, which often occurs with real estate data. Well established, the HPM is a scientifically sound, robust approach.

Cons: The main drawback of this method is its reliance on large sets of quality data, which might be a problem in some circumstances, for instance, where data are unavailable or when market transactions are too scarce over space and/or time. Also, a basic assumption of the hedonic price theory is that hedonic prices only reflect what economic agents know about the potential impact of externalities on a given piece of property and in a given spatio-temporal context; asymmetric information may invalidate that assumption. Finally, omitted control variables may generate spatial autocorrelation as well as spatial heterogeneity in the model, thereby invalidating the interpretation of regression coefficients. The use of spatial models though can alleviate the latter drawback.

Adaptive estimation procedure

The adaptive estimation procedure or AEP [13,92] rests on a (negative) feedback framework and is meant at handling the problem of varying economic phenomena over time. Econometric (such as OLS) and other time-series analysis approaches (such as Box-Jenkins [93]) based on long term data assume that the parameters of the explanatory, or decision, variables remain constant over the entire period of analysis. This, however, is rarely the case since the behavior of economic agents will tend to evolve over time, thereby causing coefficients to become obsolete eventually. While there are various ways to address the problem (inclusion of time or cyclical dummy variables, market segmentation, spline regression, etc.), structural changes may occur at unknown points in time. For that reason, there is room for an approach that can adjust for fluctuations in the market response.

Essentially, the AEP method rests on a feedback framework whereby, for every time period t , the predicted market response (\hat{Y}_t) derived from some response model at time $t-1$ is compared with the actual response (Y_t), with the resulting error being fed back into the system so that the parameters of the response model are adjusted accordingly. The revised model is then used to generate the market response at time $t+1$. The whole process is repeated in each period. To summarize, the basic principle behind the AEP is that the error term at time t (ε_t), which can be expressed as the difference between Y_t and \hat{Y}_t , is used to re-estimate the coefficients of the i -th variable of interest for the following period ($t+1$). For that purpose, a feedback filter $A_i(\varepsilon_t)$, is computed and added to the pertaining estimate of the current period ($\hat{\beta}_{it}$) in order to obtain the adjusted parameter for the following period ($\hat{\beta}_{i,t+1}$).

While the AEP method as developed by Carbone and Longini [13] has been mostly applied to marketing issues [92], its use can be extended to any phenomenon involving time series and structural changes that affect predictive accuracy. This is actually the case for property valuation issues; hence its relevance for AVMs. This being said, the more general concept of adaptive estimation may be brought back to a kernel density estimation (KDE) issue [94,95]. The latter consists in smoothing the probability density function of a random variable using a non-parametric approach whereby a positive smoothing parameter h , referred to as the bandwidth and equivalent to the feedback filter in the AEP method, is selected.

Pros: When applied jointly with multiple regression analysis within a hedonic framework, AEP provides an additional device to improve the predictive robustness of the AVM model.

Cons: Applied in isolation on mean or median values time series, the AEP method remains to a large extent an out-of-a-hat prediction tool which simply mirrors past trends while failing to explain the underlying causes of the structural changes in the economy. In addition, and in contrast with hedonics, it cannot yield estimates for individual attributes of the housing bundle.

Discrete choice method

In many life situations, it is thought that choices made by individuals reflect their preferences over different alternatives of goods and services. A choice can be regarded as an outcome of the trade-off between several alternatives described by different attributes and their levels (i.e. prices), that is, made under various constraints (e.g. residential location). In order to insure that a choice is representative of an individual's behavior and to overcome the problem of collecting real choice

data, discrete choice methods (DCM) were developed based on experimentally set hypothetical choice situations [96,97].

The underlying theory of DCM is the random utility theory. Random utility theory assumes that individuals will always choose the alternative with the highest utility. Further, the utility of an alternative is composed of a systematic or observed part and a random part that is not explainable. Because of the random component, the probability that an individual will choose an alternative can be calculated, whereas the exact choice cannot. The most common approach when estimating a discrete choice model is to use a maximum likelihood estimation. This requires that an analyst specifies an objective function or likelihood function in which only the parameters are unknown. The likelihood function is designed to maximize the choice probabilities associated with alternatives observed in the data. In this way the parameters can be estimated by maximizing the likelihood function $L_{NS} = \prod_{n=1}^N \prod_{s \in S_n} \prod_{j \in J_{ns}} (P_{nsj})^{y_{nsj}}$, where y_{nsj} equals one if j is the chosen alternative in the choice situation s that belongs to the set of choice situation S_n faced by a decision maker n out of the total number of decision makers N , and zero otherwise, and P_{nsj} is a function of the data and unknown parameters β .

For consumer products, any DCM can also be used to calculate the willingness to pay (WTP) for all the attributes of the product [98,99]. The simple calculation for WTP equates to the β of the attribute for which the WTP is calculated divided by the β of a monetary attribute. It is, however, not straightforward to implement this method to estimate WTP for a dwelling, because respondents' preferences and financing options are much more complex for a home than for simpler consumer products.

McFadden [100] also introduced DCM in an urban context for valuing location choices. Although the use of DCM to estimate WTP have been mostly applied in environmental valuations, several studies have reported its use for measuring WTP for housing amenities. More specifically, DCM applications range from property physical accessibility [101], to overall energy improvements [102], and to different specific property characteristics [68]. Hence, it is relevant for AVMs.

Pros: DCM can be used for revealed, stated and combined data set. This flexibility makes a big advantage because we can use same method over different data types. Thus, DCM is commonly used to estimate WTP when there is a lack of real market or revealed data or where a researcher tries to overcome drawbacks of analysis by including at least two different data types or sources.

Cons: In hypothetical situations, individuals do not bear the real consequences of their choice. For that reason, biases, referred to as hypothetical biases, are sometimes observed with DCM based on stated data, with the most common being an over-estimation of the willingness to pay. To avoid or reduce these hypothetical biases, it is prudent to anchor hypothetical choice situations in real situations well known by respondents, for instance by providing a detailed description of a decision moment for example.

Fuzzy Logic and other rule-based methods

There are three basic types of information uncertainty, namely ambiguity, discord and fuzziness [103] that are covered by numerous uncertainty theories. Fuzzy set theory [104] treats fuzziness or vagueness that results from the lack of definite, or sharp, distinction due to the human factor in valuation such as the importance of a certain attribute. Fuzzy logic, which was introduced in the 1930s [105], it is just a small part of fuzzy set theory. "Unlike two-valued Boolean logic, fuzzy logic is multi-valued. It deals with degrees of membership and degrees of truth" [106]. Therefore, instead of crisp distinction of classical binary logic on 0 (completely false) and 1 (completely true) fuzzy logic uses a continuum of logical values between 0 and 1. Therefore, fuzzy logic consists of fuzzy sets or boundaries (e.g. near, normal, far) to capture human knowledge and the shape of fuzzy sets or hedges (e.g. very, somewhat, quite) because knowledge is described by language vagueness.

Formally, a fuzzy set A^* can be expressed as $A^* = (x, m_{A^*}(x) | x \in U)$, where $m_{A^*}(x)$ is the membership function that expresses the degree of belonging of the general element x to the fuzzy set A^* given the universal set U . Membership function can have values 0, 1, and between 0 and 1 depending whether $x \in A$, or $x \notin A$, or x partially belongs to A . Also, membership function can

have different form, for example with a triangular membership function fuzzy set of previously mention variable in analytical notion can be written as: $A^1: Near = \{(0, 0); (0.5, 1); (1, 0)\}$; $A^2: Normal = \{(0.75, 0); (1, 1); (1.25, 0)\}$; $A^3: Far = \{(1, 0); (1.5, 1); (2, 0)\}$, where the first digit is the distance in Km to central business district and the second digit is membership value. Its graphical notion will be three overlapping triangles each defined by three points with x and y coordinates represented by first and second digit consecutively. Fuzzy logic is also a rule based system that can be used to rate a property based on the distance to central business district. For example, Rule 1 could be ‘if the distance is near, then rating number is high’. This rule could be expressed as Cartesian product of two fuzzy sets A^* and B^* , where B^* is defined by ranges of rates having values between 1 and 9 and membership values between 0 and 1. Formal expression for Rule 1 is: R^a_1 : If A^1 then B^1 that is $R^a_1 = A^1 \times B^1$ that is $m_{R^a_1}(x, y) = m_{A^1 \times B^1}(x, y) = \min[m_{A^1}(x); m_{B^1}(y)]$. Further, we can make a union of all fuzzy sets R^a (e.g. [107]): If A^1 then B^1 or if A^2 then B^2 or if A^3 then B^3 that is $m_{R^a}(x, y) = \max[m_{A^1 \times B^1}(x, y); m_{A^2 \times B^2}(x, y); m_{A^3 \times B^3}(x, y)]$. Similar to R^a , every attribute that influence a property price can be formalized in the same manner. Fuzzy logic makes also possible the formalization of more complex judgments or the rule r of rules R^* , where r is a rule that connects all rated attributes of a property R^* with price. One possible implementation suggested by Bagnoli and Smith [108] is to create fuzzified weighted importance for each attribute which is multiplied with the rate of each attribute of a comparable property. Multiplied they result in fuzzified degrees of desirability. The subject property desirability is compared to desirability of five properties with revealed prices. Finally, the possibility (not the probability) of market value of a subject property is the surface of membership function define with the price at x coordinate and membership to each of the grouped degrees of desirability at y coordinate.

The introduction of fuzzy logic into real estate practice can be attributed to Gene Dilmore in his conference paper [109]. Further, Peter Byrne [110] elaborated on one possibility of practical implementation of fuzzy logic in real estate analysis. That led to a first insight on how fuzzy logic can be used in real estate valuation [108]. Until now, fuzzy logic systems are used for property, land and commercial valuation [30,37,59,108,109,111].

Pros: Fuzzy logic is simpler to use than most AI alternatives for dealing with complex situations. It is a rule based systems mimic directly human decision that makes these methods very suitable to quantitatively capture the rule of thumbs of expert valuers, which further leads to much relaxed data requirements. It can also be used as an input to other approaches (e.g. HPM) for designing explanatory variables [112].

Cons: Unless decision rules are grounded on statistically valid empirical evidence, fuzzy logic methods may introduce subjectivity in the AVM design thus make it prompt to false market value estimations.

Artificial Neural Networks Methods

Artificial neural networks (ANN) are the most popular approaches to machine learning besides genetic algorithms. The concept of artificial neural network is borrowed from the biological sciences and functions of the human brain. The core of artificial neural network are numerous and simple interconnected processors called neurons that are referent to biological neurons in the brain [106]. Negnevitsky [106] contributes the first basic idea of artificial neural networks to Warren McCulloch and Walter Pitts [113].

The neurons are connected by input links (i). Neuron (N) receives its input signal (x_i) associated with numerical weight (W_i). Input signal can be either raw data or output of another neuron. Neuron also emits output signal (Y) that can be either a final solution to the problem or input to another neuron. The neuron computes the weighted sum of input signals and compares the results with a threshold value (Θ). If the net input is less than the threshold, the neuron output is -1 . However, if the net input is greater than or equal to the threshold, the neuron becomes activated and its output attains a value $+1$ [113]. Formally, the neuron uses activation function $X = \sum_{i=1}^n x_i W_i$ leading to

output $Y = \begin{cases} -1, & \text{if } X < \theta \\ 1, & \text{if } X \geq \theta \end{cases}$ where X is the net weighted input. This type of activation is called a sign function, thus it can be expressed as $Y = \text{sign}[\sum_{i=1}^n x_i W_i - \theta]$ [106]. Besides sign function there are several practical activation functions: step, linear and sigmoid. Next important feature is that a neural network ‘learns’ through repeated adjustments of the weights by repeating an activation function at iteration p that can be formally expressed $W_i(p+1) = W_i(p) + \Delta W_i(p)$. $\Delta W_i(p)$ is the weight correction at iteration p and it is computed as $\Delta W_i(p) = \alpha \times x_i(p) \times e(p)$, where α is a learning rate or a positive constant less than unity and $e(p)$ is an error calculated by the difference between the desired and actual outcome at iteration p [94].

In real estate valuation, artificial neural network methodologies are applied in numerous ways. McCluskey *et al.* [114] brought to light an excellent overview. In addition, various models such as random forest model are applied in automated valuation [62]. Artificial neural network methodologies are also used for different valuation objects [32,33,57,64,66].

Pros: ANN are flexible and relatively easy to conceptualize. They can account for non-linearity in the data and can recognize and match complicated, vague, or incomplete patterns in data. Studies completed indicate that the accuracy of neural networks is comparable to probabilistic approaches in terms of predictive power.

Cons: Common to all artificial intelligence applications in RE valuation is that algorithm generated by algorithm is very hard to interpret if not impossible. In the case of artificial neural networks, the lack of explanatory power is at least halting its use for secondary purpose of valuation or in the all cases when explanatory power is important.

4.3 Hybrids

Lastly, each approach and every method can be combined to form a hybrid model for property valuation. When constructing a hybrid models many potential problems can emerge with each combination having its own characteristics. An overview of hybrid models has been proposed already [115].

Pros: Each hybrid model is design to overcome certain barrier. Therefore, hybrid’s advantages are mostly practical and they are designed to either surmount missing data, or increase robustness of model, or improve its explanatory power.

Cons: In general, it is difficult to control for errors in hybrid models because one model output comes with an error that is used as an input for the other model which output again comes with an error. Therefore, the validation of hybrid models has to be taken with care and customized depending on hybrid model’ features.

5. Taxonomy and Conceptual Model

5.1 The need for a taxonomy

AVM can be implemented in number of different ways. Given that variety of individual, business and governmental users will seek for valuation of different property type and for different intended use, it is not easy to see how various AVMs relate to each other only by looking at different used methodologies and aspects or sets of variables. The underling structures of these AVMs and how they relate to each other can be more easily distinguish if they are collected into taxonomic groups based on previously defined facets and their properties.

5.2 Facets and their regularities

The overview of facets, their properties and their nominal measurement is discussed only with examples that would be sufficient to illustrate their regularities. Examples are selected as the most cited articles for each of the nine 2-tuple approaches. Table 2 is limited only to six examples because there is not enough space to examine each of the hundreds papers and dozens of reported patents.

Table 2. Use of AVS overview matrix of facets, properties and nominal measurement

	Model	[116]	[30]	[53]	[63]	[33]
Facets	Properties (abbrev.)	d	d	d	d	d
<i>End user</i>	Individual (I _u) Corporate (C _u) Public (P _u)	x	x	x	x	x
<i>Secondary purpose of valuation</i>	Local tax estimates (T) Price index (I) Portfolio risk (P _r) Insurance risk (I _r) Landing risk (L _r) Negotiation margin (N)	x	x	x	x	x
<i>Object of valuation</i>	Residential (R _o) Non-residential (N _o) Land (L _o)	x	x	x	x	x
<i>Price response</i>	Sales price (S _p) Asking price (A _p) Bid price (B _p) Construction price (C _p) Rent price (R _p)	x	x	+	x	*
<i>Price determinant classes</i>	Site (S) Environmental (E) Legal (L) Fiscal (F) Socio-economic (S _e) Demographic (D)	x	x	/	x	x
<i>Approach</i>	Cost (C) Income (I) Comparison (C _o) UncertaintyNotIncluded Probabilistic (P) Non-Probabilistic (N)	x	x	x	x	x
<i>Focus</i>	Explanatory (E) Predictive (P)	x	x	x	x	x

*This study relies on valuers' assessment of land and property market value
+Other data

5.3 Conceptual Model

Conceptual model represent the relationships between the facets. The mostly visualized decision support system consisting of decision, end user, interface, data and model has been used as a base to develop a conceptual model for automated valuation system (Figure 2). A grey-dashed line marks this base and represents the functioning of each automated valuation system that is a model-driven DSS as mentioned. All seven facets are described (Section 3) and they are illustrated in figure below. *End user* makes a decision what is the *secondary purpose of valuation* and *end user* defines what the *object of valuation* is. Further, depending on the *object of valuation*, a modeler has to identify an appropriate *price response(s)* and *price determinants* data. This choice, if there is one, is tangled with the *approach* selection because a modeler has also to identify an appropriate automated valuation *approach* given the object of valuation. Selecting former and later is rather an iterative process resembling obviously to the data-model relationship in any model-driven DSS. Together the *object of valuation*, *price response* and *price determinants* represent data feature of a model-driven DSS. Similarly, *approach* and *focus* facets together represent a model feature of a

model-driven DSS. The relationship between an automated valuation *approach* and data related facets is clarified. In addition, when choosing an *approach* a modeler directly influence model's *focus* on explanatory and predictive power. For example, choosing a hedonic regression method classified as comparison-probabilistic approach, a modeler will assure that both explanatory and predictive power of a model are good. However, this is not always the case. While having explanatory or predictive *focus*, a model enables *end-user* to have unbiased judgments for different decisions. Mirroring this consequence, a modeler has to choose the most appropriate *focus* depending on the *secondary purpose of valuation*.

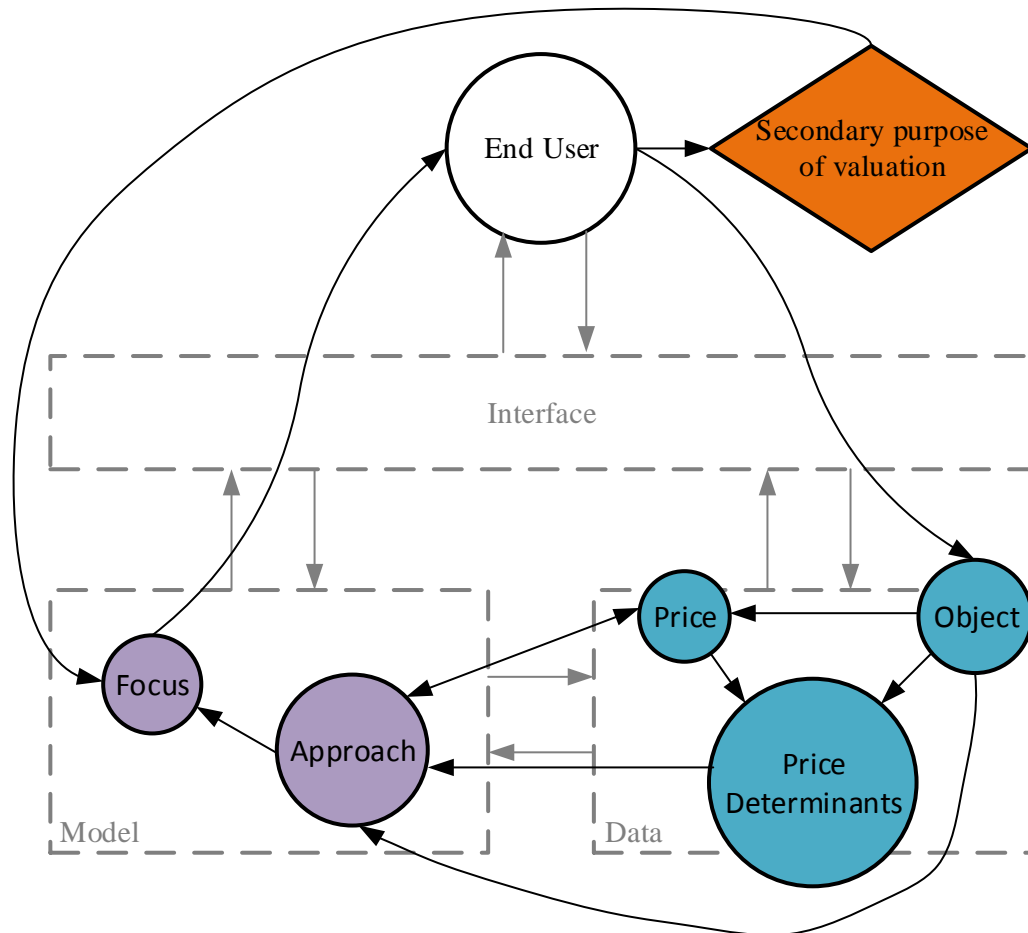


Figure 2. Conceptual model of an automated valuation system

6. Conclusions

AVMs have been in use at least for the last fifty years in both academia and practice. They have been developed to suit different end users for different valuation purposes. Until now, different authors provided dozens of patents and hundreds of academically reported AVMs, business applications, methodological comparisons, AVM definitions, their theoretical basis, and the future trends. AVMs is therefore a very mature topic that has recently reemerged as very important with the rise of digital infrastructure. However, a systematic analysis and synthesis of the accumulated body of knowledge is still missing, as well as the conceptual framework adapted to suit the need of reemerging trend.

This imply two-sided contribution of this paper, a taxonomy and a conceptual framework. In order to address properly a broad notion of automated valuation models' use, this paper introduces automated valuation system as a term and its taxonomy based on key facets, properties and measurements. Proposed taxonomy is non-hierarchical because all automated valuation

systems have the same importance and each one has these facets. Furthermore, conceptual model represents the relationships between the facets. The conceptual model for automated valuation system is based on the visualized decision support system consisting of decision, end user, interface data and model. Both taxonomy and conceptual model came into being after literature review that included a bit more than one hundred references.

The overview of facets, their properties and their dummy measurement is discussed only with examples that would be sufficient to illustrate their regularities. Examples are selected as the most cited articles for each of the newly introduced automated valuation approaches. As mentioned, all indicated facets are visualized in a conceptual model that is again an adapted version of the most visual example of decision support systems.

As mentioned, taxonomy and conceptual model are built upon although relatively broad but selective choice on more than one hundred references. Perhaps a systematic literature review process could additionally validate the proposed taxonomy and conceptual model.

Assuring the credibility of an automated valuation model that is based purely on comparing the predictive accuracy of method 'a' versus method 'b' has become a common practice. Therefore, discussion of the use of the proposed automated valuation has been pushed forward. In addition, as a domain of price estimates has been far surpassed any unique discipline, term that is more generic would be appropriate to accommodate future research coming from multitude of disciplines. Therefore, authors proposed in this paper the first taxonomy and conceptual model of automated valuation systems.

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