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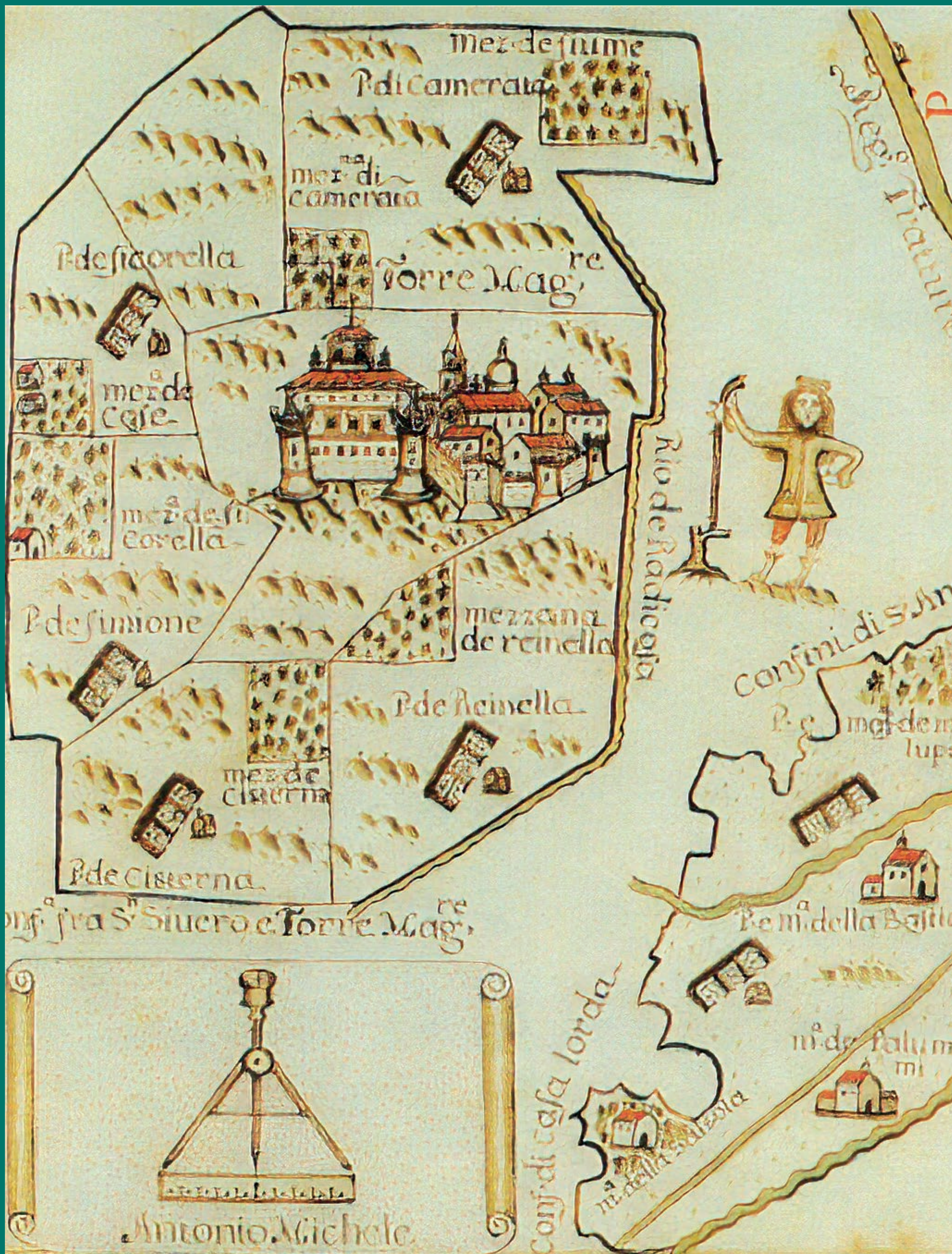

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Urban green infrastructure valuation: an economic method for the aesthetic appraisal of hedges

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Abstract. The paper presents a parametric approach to quantify the economic value of hedges in urban green spaces. The model integrates indexes that allow for an aesthetic estimate of green infrastructure. Both field and desk phases are developed to depict and sample hedgerows in a case study in Italy (Cascine Park, Florence). Street view and Google Maps applications are used in the preliminary steps to spatialize hedges. An equation, incorporating nine variables including financial, dendrometric, and correction factors, is developed to appraise economic value. The results highlight the relevance of species, plant height, and the number of hedge rows for the unitary and total value of green infrastructures. Phytosanitary condition, the presence of gaps in linear traits, and the degree of tree canopy coverage also influence the economic performances of hedges. The technique facilitates application for both researchers and practitioners, potentially allowing for damage estimates and calibrated management of urban green in different locations.

Keywords: hedges, parametric technique, economic analysis, cultural ecosystem services, urban forest, Florence (Italy).
JEL codes: Q51, Q57.

1. INTRODUCTION

Urban Green Infrastructure (UGI) or Urban Green Spaces (UGS) play a vital role in providing various ecosystem services (ES), which enhance urban resilience to climate change and mitigate natural hazards like droughts and floods, contributing also to human health and well-being (Lampinen et al., 2023; Morpurgo et al., 2023). According to Tzoulas et al. (2007:169), UGI can be defined as "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales". Gardens, parks, green walls, urban forests, green alleys and streets, and hedges, both public and private, can be ascribed as examples of

UGI. Even if different type of UGI provide different ES, it is possible to group ES in four major categories: provisioning, regulating, cultural, and supporting services (La Notte et al., 2017). The provisioning function relates to the possible material goods provided by the ecosystem, such as food or water. The regulating role pertains to functions like temperature, noise, pollution, erosion, and climate regulation. The cultural services include the intangible benefits that people obtain from ES through recreation, social relation, cognitive development, and aesthetic experience. Finally, supporting refers to those services necessary for producing all other ecosystem services, such as providing habitat for species and maintaining genetic diversity (Millenium Ecosystem Assessment, 2005).

A large body of literature has investigated the regulating role of ES in supporting biodiversity, pollinators, carbon sequestration, flood protection, and mitigation of heat waves in cities (see, for example, the reviews of Amorim et al., 2021, and Wang et al., 2014). Along with the biophysical quantification of ES provided by UGI, estimations of the economic benefits provided by ES have also been extensively analyzed (Herath and Bai, 2024), focusing on the role of trees and urban forests (Elmqvist et al., 2015; Kim et al., 2021; Majumdar et al., 2011).

Despite a strong interest in UGI analysis, few works have focused on the benefit provided by urban hedgerows from an economic viewpoint. In a context characterized by an increasing urbanization, hedges can represent a viable solution for cities to achieve goals related to mitigating urban pollution, establishing functional biodiversity networks, and enhancing human well-being (Blanusa et al., 2019; Montgomery et al., 2020). Compared to the other UGI, hedges have a relative compact nature, and their growth can be easily controlled through regular pruning, which can also create different shapes thanks to topiary art (Blanusa et al., 2019). If in public spaces hedges are used as perimeters for parks or to delimit roads and paths, they are also highly appreciated in private spaces, where they beautify gardens, provide privacy, and prevent intrusions. These considerations suggest that the aesthetic appreciation of UGI is important also from economic viewpoint. User-friendly tools and techniques available for practitioners and decision-makers can be, in fact, crucial for the economic appraisal of hedges, such as in cost-benefit analysis promoted by public administrations or damage evaluation on public or private green spaces. The increase in biotic and abiotic diseases in hedge species (Biondi et al., 2022; Hansford et al., 2017; Gullino et al., 2021; Kodati et al., 2023) can further justify this interest. However, expeditious economic method based on expert judgments – such as parametric equations – have not been developed for urban hedges. Within these premises, the aim of this paper is to introduce a new parametric technique for the economic appraisal of the aesthetic value for urban hedgerows. A combination of web-based, field-based, and GIS-based application was used to develop and test a new methodology that appraises UGI combining aesthetic and economic valuation.

After a literature review, the methodological section presents a summary of parametric formulae currently applied for trees appraisal. Next, the equation to adapt parametric analysis to hedges is explained and tested in a case study in an urban park in Italy. Finally, the results are reported and discussed, highlighting the strengths, weaknesses, and potential improvements of the proposed method.

2. LITERATURE REVIEW

2.1. Biophysical appraisal of Urban Green Infrastructure

Focusing on regulating services, several studies have examined the importance of UGI from both carbon sequestration (McKinley et al., 2011) and pollution removal (Escobedo et al., 2011) viewpoints. Life Cycle Assessment (LCA) was applied to evaluate carbon dioxide equivalent emissions and removal by afforested areas, tree rows, social allotments, lawns, and hedges in an urban park in the metropolitan area of Milan (Italy) (Nicese et al., 2021). Santiago et al. (2022) employed Computational fluid dynamics (CFD) simulations of UGI scenarios to provide recommendations on the selection of locations and characteristics of trees and hedgerows based on deposition effects and pollution removal. The mitigation effect of vegetation barriers for pedestrians' exposure to airborne particles from traffic was investigated in a study of Tran et al. (2022) focused on Singapore city.

Other research topics related to UGI include biodiversity enhancement and heat mitigation in cities (Endreni, 2018; Francoeur et al., 2021; Roeland et al., 2019). Among several worldwide examples, butterfly species richness in relation to urban park characteristics was analysed by Sing et al. (2016) in the Federal Territory of Kuala Lumpur; Yenneti et al. (2020) depicted mitigation strategies to contrast urban overheating through green spaces and infrastructure in Australian cities.

Most studies investigating UGI focus on the assessment of parks and gardens and their effect on cultural ES (Pinto et al., 2022; Salmond, 2016), with aesthetic appreciation being a major concern (Roy et al., 2012). Among others, Aboufazeli et al. (2022) developed an artificial neural network to predict landscape aesthetic quality in natural ecosystems of urban areas to assist in the planning and management of UGI. With the same objective, multicriteria analysis was used by Ghafari et al. (2020) to provide a ranking of ornamental species in Rasht City (Iran).

Investigations into specific components of UGI mainly focus on trees; however, domestic gardens (Loram et al., 2008) and flowers in street vegetation (Todorova et al., 2004) have also been evaluated.

A few research focus on hedges in urban contexts and their specific ability to provide ES. The benefits of maximizing the capture and retention of airborne pollutant particles have been investigated, considering species, leaf morphology, and canopy density of hedgerows (Varshney and Mitra, 1993). A scenario involving the planting of 100 km of the best-performing species for pollution removal was estimated to quantify avoided damage and costs from health, environmental, and economic viewpoints (Qadir et al., 2021). The effect of reducing urban noise was examined for hedges of Prunus laurocerasus and Laurus nobilis, stressing significant attenuation correlated to the porosity of hedges (Bioacca et al., 2019). Höpfl et al. (2021) explored whether and how traditional rural hedging techniques, hedge types, and hedgerow networks could be adapted to urban green areas. The aesthetic value of hedges in the Bukovynian Carpathian region of Ukraine was defined by Myronchuk et al. (2021); the authors modified a scale for assessing the ornamental characteristics of shrubs to score the value of hedges based on indicators such as crown density, shoot colour, leaf shape and colour, time and duration of flowering, size, colour, and aroma of fruit. ES, as well as ecosystem disservices of hedgerows in urban contexts, were investigated in a literature review developed by Blanusa et al. (2019).

2.2. Economic appraisal of Urban Green Infrastructure and motivation of the study

Despite the biophysical quantification of ES provided by UGI being well-represented in scientific literature, economic appraisal has also been widely analyzed in recent decades, mainly focusing on trees evaluation. Xu et al. (2021) assessed the combination of externalities with the quantification of the total economic value of ES provided in Beijing, including climate regulation, carbon sequestration and oxygen production, water control and conservation, air pollution reduction, noise reduction, and cultural services. This evaluation was conducted using various methods such as the combination of replacement cost, carbon tax, shadow project, afforestation cost, and market price methods. An extensive literature review on the monetary benefits related to the restoration of ecosystem in urban area was implemented by Elmqvist et al. (2015). The authors also stressed how many non-monetary benefits have been empirically defined, mapped, or measured in cities, especially those related to physical and psychological health.

As reported by Price (2003), all the usual methods for valuing non-market benefits and costs may be applied to the aesthetic values of urban trees. Expert judgment, as well as direct methods (e.g. contingent valuation method - CVM) and indirect methods (e.g. travel cost method – TCM and hedonic pricing – HP), have been extensively applied (Chintantya and Maryono, 2018; Tan and Zhao, 2007). For examples, Notaro and De Salvo (2010) evaluated the social benefits due to the presence of cypress landscape in Lake Garda area (northern Italy) through CVM, stressing how the present value of trees' landscape exceeds 100 million €. Majumdar et al. (2011) quantified the willingness to pay for the maintenance of UGS in Savannah (Georgia, USA) in the range of 81-167 M$. Innovative applications of TCM for the monetary evaluation of cultural ES have been developed by different authors (Cetin et al., 2021; Kim et al., 2021; Lamhamedi et al., 2021; Zhang et al., 2020; Zhang et al., 2022). HP has been used to quantify the economic value of UGI, often in combination with Geographic Information System (GIS) techniques (Kong et al., 2007; Zhang and Dong, 2018).

The literature review confirms and strengthens the motivation of the current study outlined in the introduction, namely the implementation of a parametric approach for the economic appraisal of hedgerows. This approach aims to integrate scientific techniques useful for the financial analysis of UGI.

3. METHODOLOGY

3.1. Parametric approaches

Parametric approaches are widely used from scientific, professional, and practitioner viewpoints for the appraisal of UGI and, particularly, urban trees. The development of parametric methods for determining the value of ornamental plants has been prompted by various factors, including the difficulty of identifying some basic elements, i.e. *i*) the interest rate, in the case of application of financial methods, and *ii*) the market price of the area where the tree is located, in the case of applying direct or complementary methods (procedures that quantify the value of the tree by the difference between the value of the asset – land, garden – with the tree and the value of the asset without the tree) (Polelli, 2008). In addition, parametric approaches facilitate the adoption of a sufficiently standardized procedure, allowing use by personnel who may not be particularly specialized in appraisal of compensation, such as for damages inflicted on publicly owned plants in urban areas. The essence of these procedures is outlined by the following steps (Polelli, 2008):

- identification of a certain number of indices, each independent of the other, which are expressive of the elements contributing to the plant's appreciation;
- specification of an assessment scale appropriate to each index;
- linking the indices together through arithmetic operations;
- multiplying the score by the monetary value assigned to the point, generally corresponding to the purchase price of the plant species at a given size.

Different parametric techniques are described in the literature, with a brief overview of some of them provided below (Tugnoli, 2012). The *English method*, or *Helliwell Method*, returns the economic value of a tree by multiplying a base monetary amount by seven factors: size of the tree, life expectancy of the plant, its importance from a landscape perspective, its insertion into the context, the presence of other plants (social condition), health, and a particular factor called Special Factor. This parameter was introduced to account for valuable elements not covered by the other factors (Helliwell, 2008). The *American method*, or *C.T.L.A. method*, attributes a basic monetary value to the tree by multiplying the size of stem (diameter) by a hypothetical Unit Tree Cost. This value is subsequently adjusted based on species, health and location. The basic monetary value can only decrease; it can remain unchanged only for trees of extraordinary and recognized value (Council of Tree and Landscape Appraisers, 2018). The *Australian method*, or *Burnley Method Revised*, is conceptually identical to the C.T.L.A. method but adjusts the value based on the plant's life expectancy, overall appearance, location, and health (Moore and Arthur, 1992).

The *S.T.E.M method*, or *New Zealander method*, uses a points system to assign an economic value to the tree. It considers twenty attributes, with each attribute receiving points from 3 to 27, which are then multiplied by a unitary cost (Flook, 1996). The *Danish method*, or *VAT03 Method*, was implemented to create a model suited to Denmark's specific needs. Parameters used for economic evaluation include the cost of the young plant in the nursery, age, health status, and its integration in the landscape context (Randrup, 2005). In the *Spanish method*, or *Norma Granada*, the tree's generic baseline value is determined by specific factors such as growth rate, longevity, size, health status, and placement in the landscape context (Asociacion Espanola de Parques y Jardines Publicos, 1999). The *Swiss modified method* starts from a base value (the price of the tree in the nursery) and increases it based on vegetative vigour, health, social condition (whether the tree is in a group, row, or isolated), location, and size of the single plant (Ponce-Donoso et al., 2017). This method was later adapted for Italian cities (Pirani and Fabbri, 1988). The *German method* is similar to the Swiss one but introduces an environmental insertion index, which evaluates how well the plant fits into the landscape context, its distance from other trees, and a depreciation factor if the specimen is seriously damaged (Bernatzky, 1978). Finally, the *C.A.V.A.T.* (Capital Asset Value for Amenity Trees) *method* has two versions: Full and Quick. In both versions, the basic value – calculated from the stem diameter – is multiplied by the so-called Unit Value Factor. Life expectancy, location, and other dendrometric variables are then considered. The Full method is widely applied in several contexts worldwide and often includes additional commentary and specifications (Heuch, 2020). It is mainly used to determine the financial value of individual or groups of trees or their replacement value (e.g., in case of damages). The Quick Method is often used to estimate the value of a population of trees for management purposes and is designed for speed in appraisal (Doick et al., 2018). The Full Method comprises seven steps (determining the basic value plus six steps for basic value adjustment), while the Quick Method involves four steps (determining the basic value plus three adjustments) (Doick et al. 2018).

Comparison among methods have been developed in different research studies (García-Ventura et al., 2020; Ponce-Donoso et al., 2017; Watson, 2002). The effect of root pruning on tree value was quantified by comparing C.T.L.A., Burnley Method, Helliwell Method, and S.T.E.M. (Benson et al., 2019). Some works introduced the iTree application in the comparison (Ma et al., 2011). The iTree software (USDA, 2022) is also often applied to quantify ES delivery in UGI in both urban e peri-urban areas (Zanzi et al., 2021). Finally, innovative parametric techniques have been tested, such as introducing Discrete Choice Experiments (Rakotonarivo et al., 2016; Train, 2003) to appraise the utility that the community derives from the enjoyment of aesthetic, architectural, historical, and cultural externalities of trees (Sardaro et al., 2017) or employing Adaptive neuro fuzzy inference system (Jang, 1993) to value solitary trees using vague (fuzzy) evaluation of input parameters based on expert knowledge (Peták et al., 2022).

3.2. Adaptation of parametric approach to urban hedges

The proposed technique to appraise hedgerows in urban area is based on parametric approach. The main differences between the presented method and existing parametric analysis developed for trees (and sometimes shrubs) consists in the possibility of substituting a hedge plant (e.g., if damaged) with another at "prompt effect". Therefore, in the analysis of hedges, no coefficients are needed to adjust the economic value of plant available in nursery to match its (near) mature dimension. Aesthetic appreciation and value are thus based on the utility that people and society attribute to the hedge (Turner et al., 1993). The economic value of the single trait of hedgerow is therefore adapted to its location and health status.

Within these premises, the proposed formula is expressed as follows:

$$V = P_{s,h} \times L \times R \times E \times G \times T \times A \times C \times SF \qquad (1)$$

where V is the value of hedgerow (€). $P_{s,h}$ is the price of a single plant of the same species (*s*) and height (*h*) available at the nursery. The choice of the price should be based on local nurseries or, in other terms, on a similar area and period of appraisal; L and R represent the length (m) and the number of rows of the examined hedge, respectively. E is the plant density expressed as plants per meter (pl/m). G is the hedge vigour expressed as a percentage, ranging from 0 (indicating dieback, leaf loss, etc.) to 1 (indicating a vigorous plant without phytosanitary or health problems). The G factor also takes into account the presence of gaps in the hedge: for example, a vigorous and healthy hedge with one half dead or removed should have a G value of 0.5. The choice of the G parameter can be determined in different ways. From the practitioner's viewpoint, the estimate could be performed through field evaluation, directly attributing a value based on expertise. Alternatively, a Likert scale, linguistic evaluator, or fuzzy scale that can be transformed into numerical judgements could be introduced.

The basic value of the hedge, depending on price, size, and health, will be corrected as a percentage with additional parameters. T represents the probability of attendance at the specific location of the hedge. This value is quantified by merging the population density of the municipality with the degree of rurality. The C.A.V.A.T. method introduces population density divided into classes. In the present work, the same approach is recalibrated for the Italian conditions and its population distribution. Eleven classes are depicted as follows: 1 (<21 inhabitants/km^2), 2 (21÷40 inh./km^2), 3 (41÷60 inh./km^2), 4 (61÷80 inh./km^2), 5 (81÷100 inh./km^2), 6 (101÷150 inh./km^2), 7 (151÷200 inh./km^2), 8 (201÷250 inh./km^2), 9 (251÷300 inh./km^2), 10 (301÷350 inh./km^2), 11 (>350 inh./km^2). The class of rurality is a qualitative index defined in five categories: rural, near rural, periphery, near centre, and centre (Pirani and Fabbri 1998, modified). The two indexes are combined by a cross-tabulation (Table 1) to define a corrective parameter of V ranging from 0% to 50%. This correction range is based on maximum correction values reported in the literature for Italian conditions (Pirani and Fabbri, 1998).

Table 1. Index of attendance probability (T).

Class of population density	Class of rurality/urbanisation				
	Rural	Near rural	Periphery	Near centre	Centre
1	1.000	1.025	1.050	1.075	1.100
2	1.010	1.043	1.075	1.108	1.140
3	1.020	1.060	1.100	1.140	1.180
4	1.030	1.078	1.125	1.173	1.220
5	1.040	1.095	1.150	1.205	1.260
6	1.050	1.113	1.175	1.238	1.300
7	1.060	1.130	1.200	1.270	1.340
8	1.070	1.148	1.225	1.303	1.380
9	1.080	1.165	1.250	1.335	1.420
10	1.090	1.183	1.275	1.368	1.460
11	1.100	1.200	1.300	1.400	1.500

The fruition potentiality as well as aesthetic value also depend on accessibility (A). In urban areas, hedgerows are usually located close to roads and path; thus, accessibility can be defined based on the type of property in the area. The parameter applied in the formula for accessibility is 1 for public areas and 0.6 for private ones. The visual appreciation of a specific (urban) green infrastructure is influenced by the presence of other UGI, such as urban forests, tree rows, shrubs, grasses, etc. The scenic effect of UGI under tree cover decreases its positive impact compared to hedges in open areas. Although there may be positive correlations between hedges and variables related to tree cover that cannot be evaluated in a parametric approach due to their complexity (e.g., habitat connections, ecological corridors, etc.), the parameter C introduces a negative influence on the scenic aspect and adjusts the value V as follows: hedge not covered by trees: $C = 1$; hedge under tree rows: $C = 0.7$; hedge under the canopy of tree groups or urban forests: $C = 0.5$.

According to Helliwell and C.A.V.A.T. methods, additional parameters (special factors – *SF*) can be introduced in the evaluation. Potential *SF* can be either positive or negative. Positive SF include: *i*) being an integral part of a designed landscape, including avenues or designed parks or gardens; *ii*) contributing to the arrangement of an important place or building; *iii*) being located in a school or at its entrance; *iv*) being in a particularly relevant position, such as at the entrance to a public building; *v*) being part of a larger grouping that gives character to the area, such as a long-groomed road; *vi*) serving as a commemorative or memorial hedge; *vii*) being known to have been planted by a notable person. Negative SFs include: *i*) incorrect localization, such as spreading across a narrow path; *ii*) obstruction, such as vigorous thorns on a sidewalk or path; *iii*) shallow roots that damage the sidewalk; *iv*) fruits or seeds that cause discomfort. Each *SF* contributes for +/-10%, with no more than four *SF* allowed in each evaluation (Doick et al., 2018).

3.3. Case study

The parametric method was tested in a case study located in Cascine Park in the city of Florence (Italy) through a combination of web-based, field-based, and GIS-based application. The park spans an area of 130 hectares and features a mix of urban forest and other urban green infrastructure, making it the largest green space in the urban and metropolitan area of Florence and one of the most extensive urban forests in Italy. This selection was made due to its representativeness of national UGI (Sacchelli and Favaro, 2019).

Main roads, cycle roads, footpaths, and squares within the park were thoroughly covered using the Google StreetView application, with images spanning different years between 2015 and 2022. This tool, in combination with photointerpretation on Google Maps application, was used in a preliminary desk phase to accurately locate the hedges. Subsequently, the hedges were georeferenced using QGIS software to create a linear vectorial file (shapefile) of the hedgerows. An attribute table was then associated with the shapefile, and for each feature (single trait), the real presence of the hedge, species, density, depth, height, as well as G and C parameters, were verified and quantified through field sampling conducted in August 2023. The analysis was based on a stratified sample of points defined using the "Random points along line" module in QGIS. The G factor was estimated using a Likert scale with 11 values (ranging from 0 to 10) and then transformed to a 0-1 range.

The probability of attendance for Cascine Park was quantified by cross-tabulating the population density of the Florence municipality (3,534 inhabitants/km^2 as of 2023 – ISTAT, https://www.istat.it/en/– corresponding to class 11 in Table 1) with the class of rurality/urbanisation (near centre, according to Table 1), resulting in a T value of 1.4. Cascine Park is owned and managed by the Municipality of Florence, and all considered hedge lines are public and accessible. Consequently, the accessibility parameter (A) is equal to 1. Positive SF were identified based on proximity to Points of Interest (POI). POI – identified in the list described in section 3.2 – were georeferenced in QGIS. A buffer of 20 meters on POI was created to select point intersected in the buffer. Each selected point was assigned a SF of +10%. Potential negative SF were verified in the field by checking for of presence or absence of impactful characteristics.

For the case study, a statistical analysis using multiple regression was carried out to test correlation among the economic value of UGI and the individual attributes applied in Eq. 1.

The location of the study area, including hedges and POI, is reported in Figure 1.

4. RESULTS

The total length of hedges in the Cascine Park is 31,554 m. For sampling purposes, at least one random point was selected for each vectorial trait, which was depicted by roads intersection and/or variation in hedge characteristics, resulting in a total of 75 traits. For traits with sufficient length, a maximum of three points, spaced out by 80 meters, were randomly selected for each segment. Each random point was investigated along a transect of 20m. In total, 153 sample points were created and implemented. After field analysis, one sample point and its corresponding hedge were excluded due to the presence of flowerbed. Therefore, the total length of transects is thus equal to 3,040 m, which represents 10% of total hedge length.

The hedges in Cascine Park consist of ten species: Berberis julianae, Buxus sempervirens, Laurus nobilis, Ligustrum sinense, Myrtus communis, Prunus laurocerasus, Quercus ilex, Spiraea japonica, Spiraea x vanhouttei, Viburnum tinus. The main characteristics of the hedges, classified by species, are reported in Table 2.

The hedges are mainly composed of single rows (R) (95%): approximately 1,500m are made up of two rows (with Spiraea x vanhouttei, Spiraea japonica, Quercus ilex, Viburnum tinus and Laurus nobilis) and 80m consist of three rows (Quercus ilex).

The most represented specie is Viburnum tinus (6,467m, 20.5%), followed by Spiraea japonica (5,489m, 17.4%), Quercus ilex (5,250m, 16.6%), Prunus laurocerasus (4,196m, 13.3%) and Laurus nobilis (4,130m, 13.1%). Other species each constitute less than 10% of the total

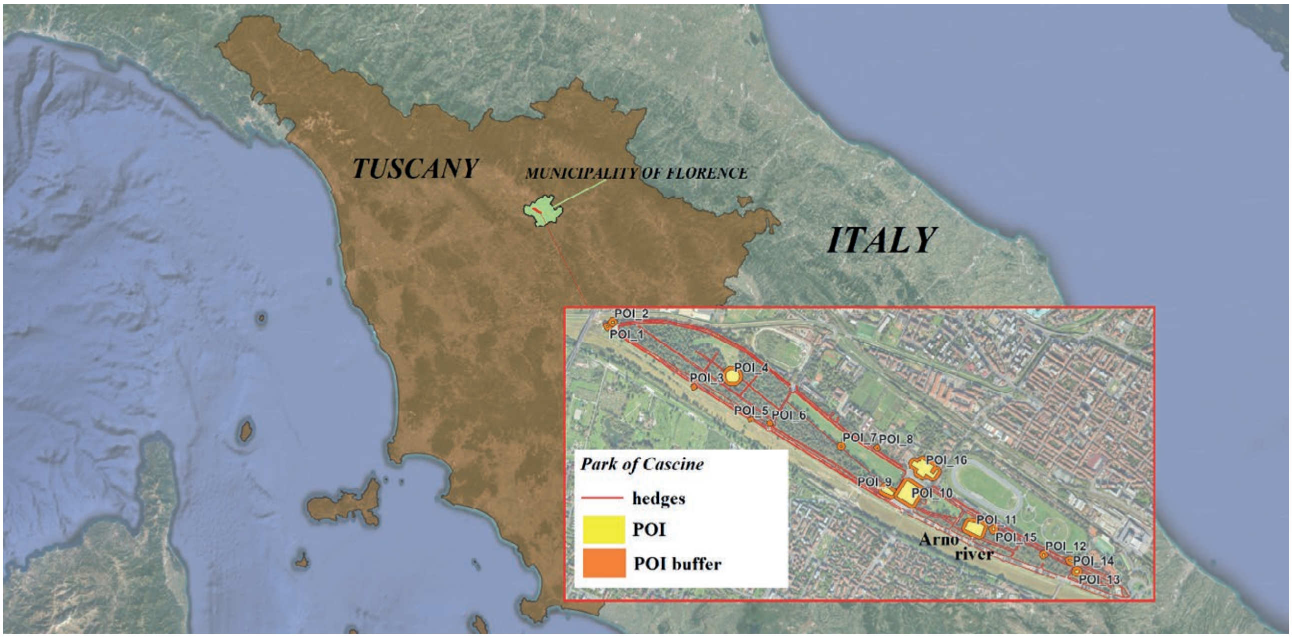

Figure 1. Study area.

Table 2. Characteristics of hedges per species.

Specie	Average height (m)	Average depth (m)	Average density (pl/m)	Average G	Average C	Average SF	Total lenght (m)	Lenght on total (%)
Berberis julianae	0.56	0.44	3.17	0.55	1.00	1.00	2,593	8%
Buxus sempervirens	0.60	0.33	4.27	0.24	0.50	1.00	781	2%
Laurus nobilis	1.07	0.57	2.94	0.73	0.62	1.02	4,130	13%
Ligustrum sinense	1.17	0.35	2.22	0.47	0.51	1.00	2,367	8%
Myrtus communis	0.80	1.00	3.33	0.70	0.70	1.10	27	0%
Prunus laurocerasus	0.71	0.37	1.95	0.38	0.76	1.00	4,196	13%
Quercus ilex	1.68	0.92	2.32	0.78	0.70	1.01	5,250	17%
Spiraea japonica	1.22	0.77	2.77	0.59	0.69	1.01	5,489	17%
Spiraea x vanhouttei	0.80	1.60	3.33	0.65	0.70	1.10	255	1%
Viburnum tinus	0.94	0.56	2.80	0.72	0.65	1.02	6,467	20%
Total values (weighted on lenght)	*1.07*	*0.61*	*2.65*	*0.62*	*0.69*	*1.01*	*31,554*	*100%*

length. Analysis of species characteristics highlights that the greatest average height is associated with Quercus ilex (about 1.70m), followed by Spiraea japonica, Ligustrum sinense, and Laurus nobilis. However, the greatest depths are linked to Spiraea x vanhouttei and Myrtus communis (1.60m and 1.00m, respectively). Buxus sempervirens shows the highest density in the rows (more than 4 plant per linear meter).

Hedge vigour (G) exhibits good values for Quercus ilex (0.78), Laurus nobilis (0.73) and Viburnum tinus (0.72), while lower values are reported for Buxus sempervirens (0.24), Prunus laurocerasus (0.38) and Ligustrum sinense (0.47). Berberis julianae results always located out of coverage (C=1), whereas Buxus sempervirens is placed under the canopy (mainly in the urban forest of the park: C=0.5). Other species have intermediate values, ranging from C=0.76 for Prunus laurocerasus to 0.51 for Ligustrum sinense.

All traits with Myrtus communis and Spiraea x vanhouttei are located within a buffer of 20m from POI (average SF=1.1). No traits with Berberis julianae, Ligustrum sinense, Prunus laurocerasus or Buxus sempervirens present an increase in V due to special factors (SF=1). Negative SF are not observed.

The base price of sample points for the year 2023 was established by consulting detailed catalogues and price lists of nurseries in Pistoia district (Tuscany), located 30km from the study area. This district is one of the most developed and productive nursery regions at the national level. The base price, defined by specie and height, is reported for all sample points in Appendix A.

From an economic viewpoint, the total value of the hedges in the park is about 1,973,000 € (Table 3). The highest performances are achieved by Viburnum tinus and Quercus ilex, each with a total value exceeding 500,000 €. Spiraea japonica (375,394 €), Laurus nobilis (200,902 €), and Berberis julianae (115,850 €) also demonstrate significant economic relevance. Myrtus communis and Buxus sempervirens have the lowest total values. The average (unitary) value for species shows significant relative importance for Spiraea x vanhouttei (135.80 €/m), followed by Quercus ilex (112.90 €/m) and Viburnum tinus (106.07 €/m). Conversely, poor unitary values are obtained by Buxus sempervirens (13.71 €/m) and Ligustrum sinense (20.76 €/m).

Results can also be reported at a spatial level. Figure 2 shows the percentage of each species within every hedge trait.

Buxus sempervirens (Figg. 1 and 2b) and Ligustrum sinense (Figg. 1 and 2d) are mainly or exclusively located under the canopy in urban forest (as confirmed by the C index in Table 2). Myrtus communis has a very limited distribution (25 m) in the northwestern corner of the park (Fig. 2e). Berberis julianae is sited in the hedge along the Arno river (southwestern orientation) (Fig. 2a), while Spiraea japonica mainly occupies the northern hedges along the main roads (Fig. 2h). Spiraea x vanhouttei is used as an ornamental hedge in the main square of the study area (POI_10; Figg. 1 and 2i). Other species such as Laurus nobilis (Fig. 2c), Prunus laurocerasus, (Fig. 2f), Quercus ilex (Fig. 2g), Viburnum tinus (Fig. 2j) are widely distributed throughout the Park.

Figure 3 presents the main characteristics of hedge traits.

The highest hedges (Fig. 3a) are represented by Quercus ilex in the southwestern trait along the river, as well as by Laurus nobilis and Spiraea x vanhouttei close to POI_10. In this latter area, greater depths are highlighted (Fig. 3b). The geographic representation of trait vigour is shown in Fig. 3c: in confirmation of Table 2, Buxus sempervirens exhibits the lowest G factor. Values below average are also reported for Prunus laurocerasus,

Table 3. Economic value of hedges per specie.

Specie	Total value - V (€)	Average V value (€/m)
Berberis julianae	115,850	44.69
Buxus sempervirens	6,007	13.71
Laurus nobilis	200,902	42.55
Ligustrum sinense	51,906	20.76
Prunus laurocerasus	72,511	32.31
Myrtus communis	2,349	85.52
Quercus ilex	538,549	112.90
Spiraea japonica	375,394	74.71
Spiraea x vanhouttei	34,060	135.80
Viburnum tinus	575,856	106.07
Cascine Park	*1,973,385*	*72.20*

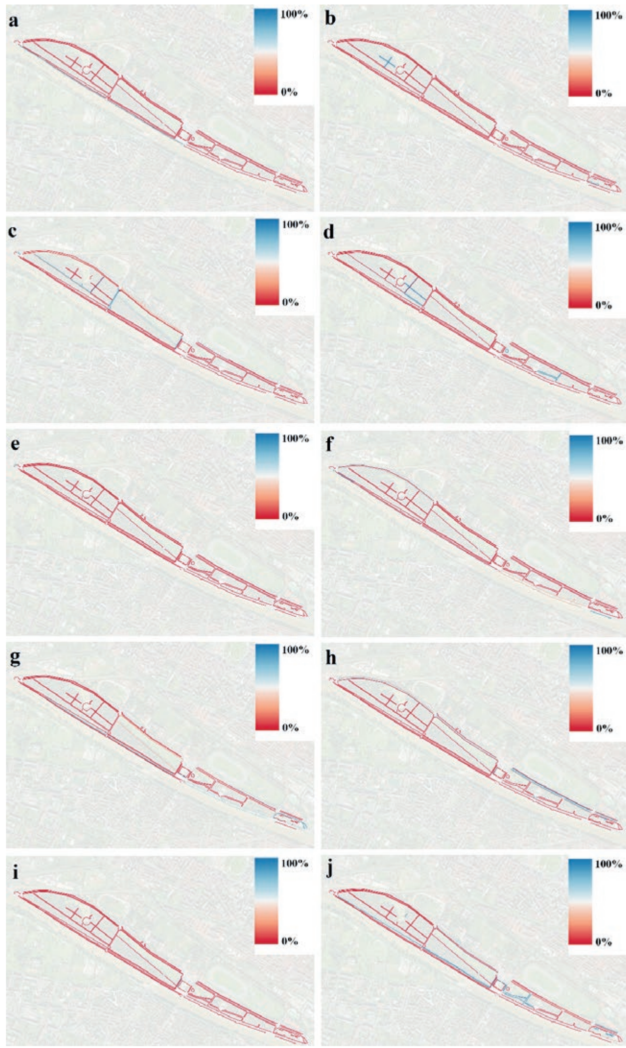

Figure 2. Percentage of species per hedge trait: a) Berberis julianae, b) Buxus sempervirens, c) Laurus nobilis, d) Ligustrum sinense, e) Myrtus communis, f) Prunus laurocerasus, g) Quercus ilex, h) Spiraea japonica, i) Spiraea x vanhouttei, j) Viburnum tinus.

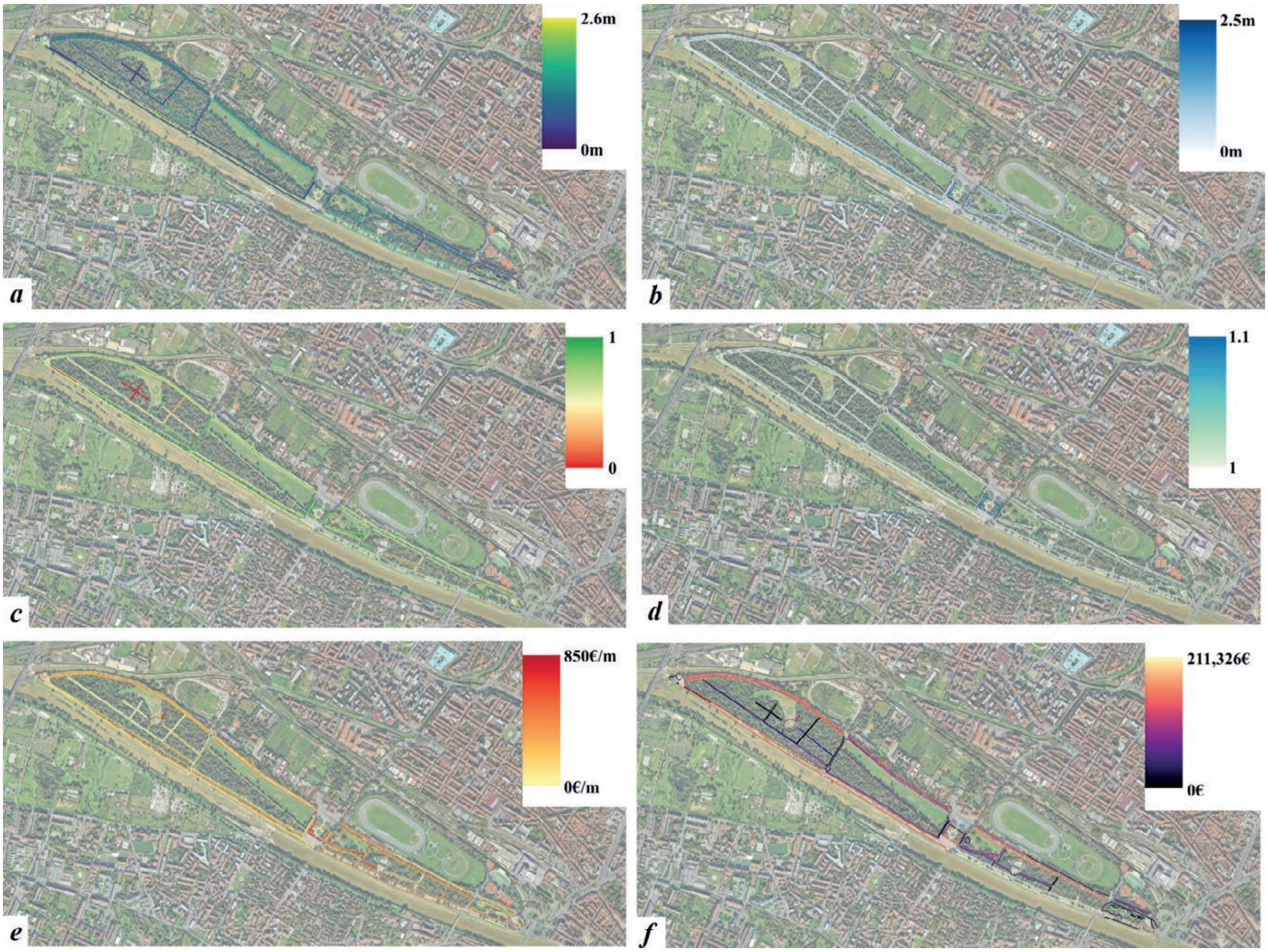

Figure 3. Spatial representation of hedge characteristics: a) height, b) depth, c) G factor, d) Special Factor, e) unitary value, f) total trait value.

Ligustrum sinense and Berberis julianae. Field analysis reveals, however, that low G scores for Ligustrum sinense and Berberis julianae are mainly due to gaps in the hedges resulting from phytosanitary problems. On the other hand, Buxus sempervirens and Prunus laurocerasus demonstrate widespread drying and insect attacks.

The main influence of SF (Fig. 3d) is concentrated in specific traits close to POI_1, POI_2, POI_10 and POI_14.

The combination of all these factors leads to the economic value of the hedge. The unitary value (Fig. 3e) seems to be particularly affected by the presence of POI, as well as the height of the hedge, which directly determines the base price. In addition to these indices, the total value of traits is obviously influenced by the length (Fig. 3f).

To confirm the above considerations carried out with image analysis, a multiple regression was conducted. This analysis examined the statistical correlation between the economic value (both unitary and total) and hedge variables. The constant value of Equation 1, namely accessibility (A) and probability of attendance (T), as well as the base price (which is obviously correlated with economic value), were excluded from the evaluation. Depth was introduced to assess its potential link with the results, despite not being part of Equation 1. The statistical outputs are presented in Table 4.

The statistical analysis confirms the importance of length for total value quantification, as indicated by the very low adjusted R^2 in column "Total value – b", as well as p-value<0.05 and 0.01 in the "Unitary value – a" and "Total value – a" columns. In cases of potential significative correlation (see the adjusted R^2 values in columns "Unitary value – a", "Unitary value – b" and "Total value – a"), plant height emerges as the most important variable for determining both unitary and total value (p-value<0.01). The number of rows seems to be signifi-

Table 4. Statistical correlation among economic value and hedge characteristics.

Variable (symbol in brackets)	Unitary value - a[1]	Unitary value - b[2]	Total value - a[3]	Total value - b[4]
Lenght (L)	-2.17**	Not considered	10.05***	Not considered
Height (h)	3.74***	3.55***	2.73***	2.02**
Depth (not present in Eq. 1)	-0.78	-0.69	0.21	-0.08
Rows (R)	3.60***	3.42***	0.63	0.64
Density (E)	0.51	0.56	0.64	0.21
Vigour (G)	0.73	1.35*	1.82**	-0.65
Coverage correction (C)	1.65*	0.80	1.87**	1.62*
Special Factors (SF)	0.12	0.66	0.85	-1.06
Adjusted R^2	*0.59*	*0.57*	*0.67*	*0.17*

Note: [1]unitary value (€/m), "lenght" variable included; [2]unitary value (€/m), "lenght" variable excluded; [3]total value (€), "lenght" variable included; [4]total value (€), "lenght" variable excluded; *p-value<0.1; **p-value<0.05; ***p-value<0.01.

cant only for unitary value. Other correlations, such as those with the coverage correction factor and vigour, are medium or low. Depth is not relevant for the economic analysis. Statistics in Table 4 also reveal, contrary to visual evaluation, that Special Factors seem to be not significant for economic output, as well as density.

The sign correlation clearly confirms intuitive trends, also for the C index. Coverage negatively affects both unitary and total values (note that C=1 indicates the hedge is out of coverage).

5. DISCUSSIONS

The results of the study provide a total value of the hedges in the Cascine Park of 1,973,000 €. The findings highlight the significance of height in determining the economic value of hedges, particularly in terms of unitary value. Length, intuitively, influences total value positively. Its negative influence on unitary value may be due to the purchase cost of species and varieties (more expensive species could be planted in limited spaces, but this aspect should be investigated in future analysis). The number of rows also significatively influences the value. Depth was introduced in the analysis to test its influence in parametric approach; depth seems not to be correlated with V, allowing the focus to remain on height in field sampling and avoiding the inclusion of additional dendrometric variables. The absence of correlation between depth and V is probably due to low relation between depth and length. Depth depends in fact on the planting scheme and does not significantly vary during the lifespan. Other indexes, such as hedge vigour (G), seem to have a reduced impact on V, stressing the complexity of variables that can influence the importance of hedges. The G factor impacts the results through both phytosanitary diseases and gaps in plant coverage within a single trait. While this streamlined approach simplifies field sampling for operators, future adjustment to the approach may warrant splitting the terms to separately control both variables. In the case study area – in fact – two species with G values below the average score are mainly affected by unclear gap (Ligustrum sinense and Berberis julianae); other species are strongly influenced by pathogens. Buxus sempervirens presents extensive damage from box tree moth (*Cydalima perspectalis* Walker), one of the major factors causing injuries to the specie in Italy (Badano et al., 2019; Bella, 2013; Ferracini et al., 2022). Prunus laurocerasus has also been affected by health diseases in recent years (Marchi et al., 2011; Quaglia et al., 2014; Vettraino et al., 2016). Recent extensive damages occurring to species in urban greenery in the Florence-Pistoia metropolitan area puts the use of the species as hedge plants at risk (Biondi et al., 2022). A certain statistical significance for V quantification is also related to coverage (C).

The method used in this study can be applied to plan potential interventions for hedges management. The parametric application allows to define current and potential economic values of hedges, focusing on traits that could be managed to increase aesthetic appreciation. For example, Table 5 reports V quantified with current data and modified by setting the value of G at its maximum (1), indicating a hypothetical condition of optimal vigour.

The species most affected by pathogens, such as Buxus sempervirens and Prunus laurocerasus, reveal the highest gaps in economic value potential. However, in absolute terms, Viburnum tinus and Spirea japonica exhibit a greater delta from current to hypothetical values due to a combination of their G factor (0.72 and 0.59, respectively) and widespread diffusion. The good G score obtained by Quercus ilex (0.78) leads to a V differ-

Table 5. Comparison between current and potential value based on G factor.

Specie	V with current G (€)	V with potential G (€)	V difference (€)	V gap (%)
Berberis julianae	115,850	199,108	-83,257	42%
Buxus sempervirens	6,007	47,324	-41,317	87%
Laurus nobilis	200,902	251,253	-50351	20%
Ligustrum sinense	51,906	89,233	-37,327	42%
Myrtus communis	2,349	3,356	-1,007	30%
Prunus laurocerasus	72,511	196,756	-124,245	63%
Quercus ilex	538,549	63,1268	-92,719	15%
Spiraea japonica	375,394	593,444	-218,049	37%
Spiraea x vanhouttei	34,060	53,293	-19,232	36%
Viburnum tinus	575,856	797,836	-221,980	28%
Total	*1,973,385*	*2,862,870*	*-889,485*	*31%*

ence that is half that of to the previous species, despite accounting for 17% of the total hedge length.

The parametric method can also be applied for damage quantification. Following the appraisal state of the art, damage quantification in UGI is typically developed using a complementary approach. Total damage (D, expressed in €) is computed as:

$$D = (V - V^{*}) + X \qquad (2)$$

where V is the value of hedgerow without damage, V^{*} is the value of damaged hedgerow, and X comprises extra costs (e.g., costs of felling and eliminating the old plant(s), expenses for the supply and planting of new subject(s), expenses for the work of arranging and preparing the land, expenses for the restoration of urbanization works and artefacts, and street furniture).

6. CONCLUSION

The presented study, to the best of the authors' knowledge, stands as the first parametric method available in international scientific literature for appraising the economic value of hedges in urban green areas. The model allows for the adjustment of financial index with dendrometric and additional factors, thereby incorporating aesthetic relevance into the economic evaluation. The parametric approach facilitates the sampling of hedgerows, allowing for expeditious economic evaluation, quantification of damage, and analysis of the potential convenience of management. In particular, the improvement of vigour and health conditions of individual traits, as well as the substitution or replacement of individual plants, can be assessed through the quantification of current and potential values, laying the foundation for cost-benefit analysis in urban green spaces.

In the case study area, the parametric approach was applied in combination with a desk phase based on web applications such as Street View and satellite imageries. These apps can favourite large-scale investigations (e.g., for an entire city or administrative area); however, the model can also be fully and easily applied through direct field sampling in individual public or private parks and gardens, allowing for a multiscale approach.

In large-scale analysis (e.g., evaluation of hedge for an entire city), some parameters could be quantified semi-automatically or through desk analysis and GIS. The class of rurality/urbanisation could be computed by classifying the real distance from the city centre or rural areas. The localisation of hedgerows on plein air or under the canopy cover of street trees/urban forest could be defined by merging the kernel density of trees and the distance from roads/paths.

For future evaluations, improvements, and modifications to the method, several enhancements can be considered. The proposed formula for calculating the value of hedges currently assigns equal weight to all parameters. Future refinements could involve adjusting these weights based on the subjective opinions of practitioners, stakeholders, or specific local conditions. Weighting of parameters could be developed through different techniques; among these, the Analytic Hierarchy Process (AHP) can be proposed and evaluated due to its wide application for scoring variables in decision-making problems (Saaty, 1990).

Another weakness of the approach, common to several parametric techniques, is the potential subjectivity in choosing the value of each parameter. However, among the variables proposed in Eq. 1, price (P), length (L), number of rows (R), density (E) and accessibility (A, based on private/public property of hedge) are clearly measurable and definable in an objective way. The parameter C considers trees coverage (hedge out of coverage, hedge under tree rows, or hedge under the canopy of tree groups); thus, through the analysis of the canopy projection onto the ground and the spatial distribution of trees, C can also be objectively defined. The probability of attendance of a specific place (T) combines population density and class of rurality, with the latter categorised based on its distance from the city centre. Special factors (SF) can be evaluated by the distance (or if included in a defined buffer) from relevant and important landscape, avenues, parks, places, buildings, commemorative or memorial hedges etc. (positive SF); negative SF can be assessed based on the presence or absence of impactful characteristics, as demonstrated in the case study.

In the case of updated image coverage (e.g. for Street View application), future lines of research should be directed to G factor quantification to decrease subjectivity in evaluation. The G variable could be extracted from screenshot of images, cut along hedge margins, and post-processed in image-editing software to compute the vitality of plants. One possibility is to quantify red, green, and blue waves length to compute greenness indexes (Grilli et al., 2022).

Seasonal variability in economic value, such as that observed in deciduous species for both hedges and trees, is not considered in this study, as it is assumed the potential irregularities in aesthetic value are already considered in the base price. Future research should address this aspect.

Moreover, applying the model in further areas and cities is recommended to analyse results under different geographical conditions and species. Even with suggested improvements, the model represents a valuable tool for policymakers, decision-makers, researchers, and practitioners in hedge analysis.

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Appendix A. Price list of sample points.

Sample point ID	Height (m)	Specie	Price (€/plant)
0	0.9	Viburnum tinus	34.00
1	0.9	Ligustrum sinense	16.00
2	1.7	Ligustrum sinense	30.22
3	0.9	Ligustrum sinense	16.00
4	0.7	Ligustrum sinense	12.44
5	1.95	Viburnum tinus	144.00
6	0.8	Laurus nobilis	7.00
7	1.75	Viburnum tinus	120.00
8	0.9	Ligustrum sinense	16.00
9	1.1	Ligustrum sinense	19.56
10	0.65	Laurus nobilis	5.06
11	0.7	Laurus nobilis	5.44
12	0.65	Laurus nobilis	5.06
13	0.6	Laurus nobilis	4.67
14	0.7	Viburnum tinus	16.50
15	1.5	Spiraea japonica	49.50
16	1	Spiraea japonica	33.00
17	0.4	Prunus laurocerasus	7.11
18	1.5	Spiraea japonica	49.50
19	1.5	Spiraea japonica	49.50
20	0.8	Laurus nobilis	7.00
21	0.8	Spiraea x vanhouttei	29.07
22	1.75	Laurus nobilis	30.00
23	2.5	Quercus ilex	92.00
24	0.8	Spiraea x vanhouttei	29.07
25	1.85	Spiraea japonica	51.05
26	0.8	Viburnum tinus	34.00
27	0.8	Viburnum tinus	34.00
28	0.5	Viburnum tinus	10.50
29	1	Viburnum tinus	51.00
30	0.7	Viburnum tinus	16.50
31	0.65	Viburnum tinus	16.50
32	0.8	Quercus ilex	10.00
33	0.75	Quercus ilex	6.80
34	1.85	Laurus nobilis	30.00
35	0.65	Laurus nobilis	5.06
36	0.65	Laurus nobilis	5.06
37	1	Laurus nobilis	12.50
38	0.55	Berberis julianae	16.92
39	0.6	Prunus laurocerasus	10.67
40	1.7	Prunus laurocerasus	50.00
41	0.5	Prunus laurocerasus	8.89
42	2.5	Quercus ilex	92.00
43	2.3	Quercus ilex	66.00
44	2.5	Quercus ilex	92.00
45	2.5	Quercus ilex	92.00
46	2.5	Quercus ilex	92.00
47	0.65	Berberis julianae	20.00
48	0.55	Berberis julianae	16.92
49	0.5	Berberis julianae	15.38
50	0	Prunus laurocerasus	0.00
51	0	Prunus laurocerasus	0.00
52	1.6	Laurus nobilis	20.00
53	0.65	Viburnum tinus	16.50
54	2.6	Quercus ilex	92.00
55	2.6	Quercus ilex	92.00
56	2.6	Quercus ilex	92.00
57	*0*	*flowerbed*	*0.00*
58	0.4	Prunus laurocerasus	7.11
59	0.6	Prunus laurocerasus	10.67
60	0.4	Prunus laurocerasus	7.11
61	2.5	Prunus laurocerasus	100.00
62	0.8	Myrtus communis	34.00
63	0.7	Spiraea japonica	23.10
64	0.65	Spiraea japonica	21.45
65	0.9	Spiraea japonica	29.70
66	0.8	Viburnum tinus	34.00
67	0.9	Viburnum tinus	34.00
68	0.6	Viburnum tinus	16.50
69	2.3	Quercus ilex	66.00
70	0.9	Viburnum tinus	34.00
71	2.4	Quercus ilex	66.00
72	0.8	Quercus ilex	10.00
73	0.55	Quercus ilex	5.34
74	0.7	Buxus sempervirens	24.95
75	0.4	Viburnum tinus	6.20
76	0.45	Viburnum tinus	6.20
77	0.45	Viburnum tinus	6.20
78	0.85	Quercus ilex	10.00
79	1.7	Viburnum tinus	120.00
80	1.5	Viburnum tinus	120.00
81	1.3	Quercus ilex	24.00
82	1.85	Spiraea japonica	51.05
83	1.75	Spiraea japonica	57.75
84	0.9	Prunus laurocerasus	16.00
85	0.8	Prunus laurocerasus	16.00
86	1	Spiraea japonica	33.00
87	0.5	Prunus laurocerasus	8.89
88	2.3	Laurus nobilis	50.00
89	0.65	Prunus laurocerasus	11.56
90	1	Spiraea japonica	33.00
91	0.8	Spiraea japonica	26.40
92	0.65	Laurus nobilis	5.06
93	0.8	Viburnum tinus	34.00
94	1.5	Laurus nobilis	20.00
95	0.85	Viburnum tinus	34.00
96	1.9	Ligustrum sinense	33.78
97	1	Ligustrum sinense	17.78
98	0.5	Buxus sempervirens	17.82
99	0.5	Buxus sempervirens	17.82
100	0.5	Buxus sempervirens	17.82
101	0.7	Laurus nobilis	5.44

Sample point ID	Height (m)	Specie	Price (€/plant)
102	0.5	Laurus nobilis	3.89
103	0.9	Laurus nobilis	7.00
104	1.7	Ligustrum sinense	30.22
105	0.9	Ligustrum sinense	16.00
106	0.7	Laurus nobilis	5.44
107	0.65	Viburnum tinus	16.50
108	1.6	Viburnum tinus	120.00
109	0.7	Viburnum tinus	16.50
110	0.8	Buxus sempervirens	28.51
111	1.1	Spiraea japonica	36.30
112	0.55	Quercus ilex	5.34
113	0.7	Viburnum tinus	16.50
114	0.6	Viburnum tinus	16.50
115	0.8	Quercus ilex	10.00
116	0.95	Spiraea japonica	31.35
117	1.1	Viburnum tinus	51.00
118	0.5	Viburnum tinus	10.50
119	0.65	Quercus ilex	6.80
120	0.7	Quercus ilex	6.80
121	1.2	Spiraea japonica	39.60
122	1.1	Spiraea japonica	36.30
123	1.1	Spiraea japonica	36.30
124	0.75	Spiraea japonica	24.75
125	1.1	Spiraea japonica	36.30
126	0.8	Spiraea japonica	26.40
127	1.7	Ligustrum sinense	30.22
128	0.4	Ligustrum sinense	7.11
129	2	Spiraea japonica	66.00
130	1.85	Quercus ilex	66.00
131	1.85	Laurus nobilis	30.00
132	2.5	Laurus nobilis	85.00
133	0.9	Ligustrum sinense	16.00
134	0.6	Ligustrum sinense	10.67
135	0.95	Viburnum tinus	34.00
136	0.9	Viburnum tinus	34.00
137	1	Viburnum tinus	51.00
138	0.6	Viburnum tinus	16.50
139	1.8	Viburnum tinus	132.92
140	1	Viburnum tinus	51.00
141	1.8	Viburnum tinus	132.92
142	0.7	Viburnum tinus	16.50
143	0.95	Viburnum tinus	34.00
144	0.75	Viburnum tinus	16.50
145	1.85	Spiraea japonica	51.05
146	0.95	Viburnum tinus	34.00
147	1.8	Viburnum tinus	132.92
148	0.65	Viburnum tinus	16.50
149	0.8	Laurus nobilis	7.00
150	0.9	Laurus nobilis	7.00
151	0.65	Laurus nobilis	5.06
152	2.3	Ligustrum sinense	40.89

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Comparing traditional and machine learning techniques in apartments mass appraisal in Fortaleza, Brazil

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Abstract. Mass appraisal has significant applications, such as urban planning, real estate appraisal, and property tax. Due to the challenges of analyzing massive models, they are often developed using semi-automatic assessment methods and machine learning techniques. This article explores different appraisal model methods that utilize statistics and machine learning. It also looks at incorporating spatial information to see if the chosen method can effectively capture the typical spatial dependency of the real estate market. This can help reduce the spatial autocorrelation observed in the residuals. The study compared nine machine learning methods with traditional statistical approaches using a dataset of over 43,000 apartments in Fortaleza, Brazil. The results of the machine learning algorithms were similar. The XGBoost minimized spatial autocorrelation. The easiest interpretations were with MRA, M5P, and MARS techniques. Although, these techniques had the greatest residual spatial autocorrelations. There is a trade-off between the methods, depending on whether the aim is to improve accuracy or provide a clear explanation for property taxation.

Keywords: semi-automatic assessment methods, mass appraisal techniques, machine learning.
JEL codes: O18, R33.

1. INTRODUCTION

The real estate market is a segment of the economy, and as such, the importance of traded goods is measured through the sales prices reached because of buyer and seller agreements. This market presents macro and microeconomic aspects. Macroeconomic aspects are related to government decisions, the conduct of the economy, international influences, interest rates, and national and regional economic growth, among others. Microeconomic aspects are linked to the pricing decisions of real estate agents (companies and families), and they are related to local sociocultural issues.

The price of a property is proportional to its utility, measured as a quality index. Market agents consider several elements, including the property's physical attributes, spatial context (location), and market conditions.

Physical attributes refer to the property's characteristics, such as size, number of rooms, building standard, and age. The location aspect includes accessibility and neighborhood quality and suggests the product's spatial immobility. The market condition consists of the current preferences in social and cultural terms, the economic context, and the transaction terms, such as payment method, interest rate, and time of sale.

Mass appraisal, a systematic process to value multiple properties simultaneously using standardized methods and statistical models, is crucial for efficient and consistent property valuation, especially for taxation and urban planning. Mass appraisal methods should start from a representative sample of price data for the most diverse building typologies. De Cesare et al. (2023) highlight the relevance of systematizing data collection in forming a real estate market observatory. In general data used is collected from buyers and sellers, real estate agents, internet portals, and official government information. With this data, conducting an Exploratory Spatial Data Analysis is advisable to ensure the representativeness of prices throughout the study area. After this stage, automated valuation models (AVMs) can be employed. Due to the heterogeneous nature of properties, several attributes must be considered simultaneously in the appraisal models, assuming different weights in the formation of prices for each kind of property, and it is more common to develop models for one specific segment (for land, houses, commercial properties, and so on). The hedonic pricing theory is the theoretical basis behind price modeling (Rosen, 1974; Sheppard, 1999). A hedonic price model represents the price as a function of the property attributes. Nevertheless, these attributes are not directly priced, and the relationship between attributes and property prices can be understood as indirect or implicit prices (Rosen, 1974).

In practical terms, enough data must be collected to build pricing models. Several techniques could connect a set of independent variables to a dependent variable (in this case, the market price) through an equation. The objective is to develop a numerical model explaining relationships and estimating values. In the traditional approach, coefficients are estimated through multiple regression analysis (MRA). Several conditions (assumptions) must be checked to ensure the quality of the regression model. Among them are homoscedasticity, linearity of the relationship, absence of perfect multicollinearity (especially using several explanatory variables), non-existence of serial or spatial correlation, and lack of significant, un-explicated errors (outliers). In the presence of one or more of these statistical problems, the model loses performance or is even invalidated.

2. LITERATURE REVIEW

A relevant question in the real estate market is to estimate the influence of location (a non-directly measured attribute). Consequently, it is essential to verify and control spatial dependence. A literature review was conducted by searching in SCOPUS database. We select journal papers in English, not including conferences or preprints, using the query:

("semi-automatic valuation" OR "automatic valuation methods" OR "AVM" OR "mass appraisal" OR (("property price" OR "house price" OR "housing price"))) AND ("Spatial Error Regression" OR "decision trees" OR "Multiple Adaptive Regression Splines" OR "M5 pruned" OR "ensemble decision trees" OR "Random Forest" OR "Quantile Random Forest" OR "Gradient Boosting Machine" OR "XGBoost" OR "CATBoost" OR "LightGBM" OR "Deep Learning" OR "machine learning" OR "artificial inteligence" OR "artificial intelligence")

In a first view, there was removed papers about other issues, such as energy, covid and sustainable construction, among others, resulting in a sample of 281 papers, in the 2004 – 2024 period. We selected articles with comparative studies and then selected journals with the highest IF (after JCR). These articles are cited in Table 1.

Hedonic price models based on MRA have been used for a long time (in urban markets, at least since 1970). Following the literature, some overviews on property valuation modeling indicate that there are still several shortcomings in traditional hedonic-MRA models (Wang and Li, 2019; Jayantha and Oladinrin, 2020; Geerts and De Weerdt, 2023), especially about locational attributes and the consideration of the spatial behavior of real estate market (Heyman et al., 2018; Rico-Juan and La Paz, 2021; Chen et al., 2023; Rey-Blanco, 2024). Likewise, the need to verify spatial dependence also has long been pointed out, and different alternatives, such as geographically weighted regressions (GWR), Spatial Regressions, and regression-kriging, have been proposed (Anselin, 1988; Can, 1992; Dubin, 1992; Hengl et al., 2007).

Table 1. Some research comparing the prediction performance among various models.

Authors and goals	Techniques	Data
Zurada et al. (2011) - comparison among regression, ML, and other Artificial intelligence (AI) models	Regression models: MRA, SVM-SMO (Support Vector Machines using Sequential Minimal Optimization), additive regression, M5P trees, and AI-based methods (MBR, neural networks, RBFNN)	222,000 tax assessment of residential properties in Louisville, Kentucky, using 143 variables
Antipov & Pokryshevskaya (2012) - first attempt to use Random Forest in residential estate mass appraisal.	Random Forest, MRA, CHAID, CART, KNN, Artificial Neural Networks (MLP and RBF), and Boosted Trees.	2,848 two-room apartments in Saint-Petersburg, Russia, using 17 variables.
Park & Bae (2015) - investigate improving the accuracy of machine learning techniques in housing price prediction.	C4.5, RIPPER, Naïve Bayesian e AdaBoost	5359 townhouses housing data in Fairfax County, Virginia
Reyes-Bueno et al. (2018) - evaluating less subjective methodologies	Linear regression, M5P, MARS	410 land plot sales transactions - 2003–2009 - rural sector of the Vilcabamba parish, southern Ecuador
Oliveira (2020) - comparing ML techniques for land parcels appraisal	MRA, Random Forest, and XGBoost	8,209 land sales and listing prices in Fortaleza, Brazil - 2015-2019 with 39 variables
Ho et al. (2021) - comparing ML techniques for real estate appraisal	Machine learning algorithms: GBM, RF, and SVM	about 40,000 housing transactions in 18 years, Hong Kong
Rico-Juan & La Paz (2021) - investigate the precision and non-linear relationships between housing prices and housing attributes in the real estate market.	Machine learning: AdaBoost, CatBoost, Decision Tree, Nearest Neighbours, Random Forest, and XGBRegressor. Hedonic and Quantile regression.	About 56,000 dwelling individuals sold on the observation market in 5 years in Spain.
Iban (2022) - investigates eXplainable Artificial Intelligence (XAI) methods that can be integrated with mass real estate appraisal studies.	Tree-based ML regressors, RF, XGBoost, LightGBM, and Gradient Boosting, were compared with multiple regression analysis.	1002 samples and 43 independent variables, Mersin, Turkey
Hu et al. (2022) - considering spatial autocorrelation in modeling house prices with machine learning algorithms	Linear regression and RF in four models: alone, with Local Moran's I (LM) /Local spatial autocorrelation (SA) measures; geocoding coordinate variables (x,y) and spatial eigenvectors	17,028 single-family house sales in 2016-2017 in Fairfax County, Virginia
Baur et al. (2023) - investigate multiple models with different numerical presentations and baselines, textual descriptions, and improvement analysis of the model in predicting property prices with additional features input.	Linear regression, Elastic net, Support Vector Regression, Random Forest, and a Gradient Boosting Algorithm (LightGBM)	30,218 rental apartment offers in Berlin, and 33,610 house purchase offers in Los Angeles
Hurley & Sweeney (2024) - investigate the impact of address mislabeling on predictive performance (with a more distinguished post-code)	Text Mining of Price Prediction Features and in sequence AVM, using Hedonic regression and GAM and Machine Learning Approaches: Decision Trees, K-Nearest Neighbors, and RF	5,208 property sales - from January to November 2018, Dublin, Ireland

Source: Cited Authors.

Mass valuation models accentuate these issues, which have a broader range of attributes, many properties to be assessed, and comprehensive spatial coverage (often the entire city or a region). Furthermore, some models must be rebuilt or renewed regularly. For instance, the modeling for tax purposes has an annual period.

Thus, in the case of mass appraisal, it is not productive to work with "manual" techniques, and techniques should be used with some degree of automation. The increasing use of machine learning (ML) in this field indicates promising options. Property appraisal has undergone a significant transformation in recent years with the advent of Machine Learning techniques (Ho et al., 2021). These methods have revolutionized how properties are valued, making the process faster, more accurate, and less subjective. Studies provided by Antipov and Pokryshevskaya (2012), Wang and Li (2019), Alfaro-Navarro et al. (2020), Hong et al. (2020), Al-Qawasmi (2022), Renigier-Biłozor et al. (2022), Rico-Juan and La Paz (2021), Iban (2022), Kayakuş et al. (2022), Yağmur et al. (2022), Baur et al. (2023), Belmiro et al. (2023), Bilgilioğlu and Yılmaz (2023), Gunes (2023) and Doan et al. (2024) show an overview of the potential in developing applications. In short, one can see that machine learning algorithms are more flexible, and they have lower demands for data. Table 1 shows previous studies and research which compares prediction performance between various models.

3. RESEARCH METHOD

In this paper, we compare different Machine Learning techniques for the mass appraisal of properties in Fortaleza, Brazil. According to the Brazilian Institute of Geography and Statistics (IBGE, 2022), Fortaleza is the fourth-largest city in Brazil, with 2.4 million inhabitants in 2022. Its rapid urbanization makes it an ideal location for this case study. We analyze the performance of several machine learning models, including linear regression, decision trees, random forests, and neural networks, and evaluate their effectiveness in predicting property values. In addition to performance metrics known in machine learning and evaluation institutes such as the International Association of Assessing Officers (IAAO, 2013), we tested the spatial autocorrelation among models' residuals as an indication of poor specification regarding the lack of more spatial proxies' variables to explain the observed prices. In addition, we assessed whether there were significant differences between the models using the Wilcoxon paired test. In Brazil's taxation system on property transfer, apartments are the typology that most appear in real estate transactions. Thus, the accuracy of the predictions of market values must be easy to implement, explain, and update, and regression models must be avoided in taxation. Our results provide insights into the strengths and limitations of different techniques and can inform policy decisions related to property valuation in Fortaleza and other cities facing similar challenges. We do not focus on the interpretation of explanatory variations of the model, which is the objective of another study.

The methodological process followed is shown in Figure 1.

3.1. Data collected

The data set of 43,585 records was obtained from the listed prices, and actual sales of apartments in 2017 and 2021 were recorded in the Real Estate Market Observatory maintained by the Local Finance Secretary of Fortaleza. The original dataset was randomly split into a training set with 32,688 samples and a test set with 10,897 samples with stratification by seven classes of observed prices. All chosen models used these same split datasets.

Fortaleza, the capital city of the State of Ceará, located in the northeast of Brazil, has nearly 2.4 million inhabitants, the fourth largest population in the country, and occupies an area of 312.21 km² (IBGE, 2022). It is a very touristic city, bathed by the Atlantic Ocean in the north and east with 34 km of coastline. As provided in the Constitution of the Federative Republic of Brazil (1988), tax lia-

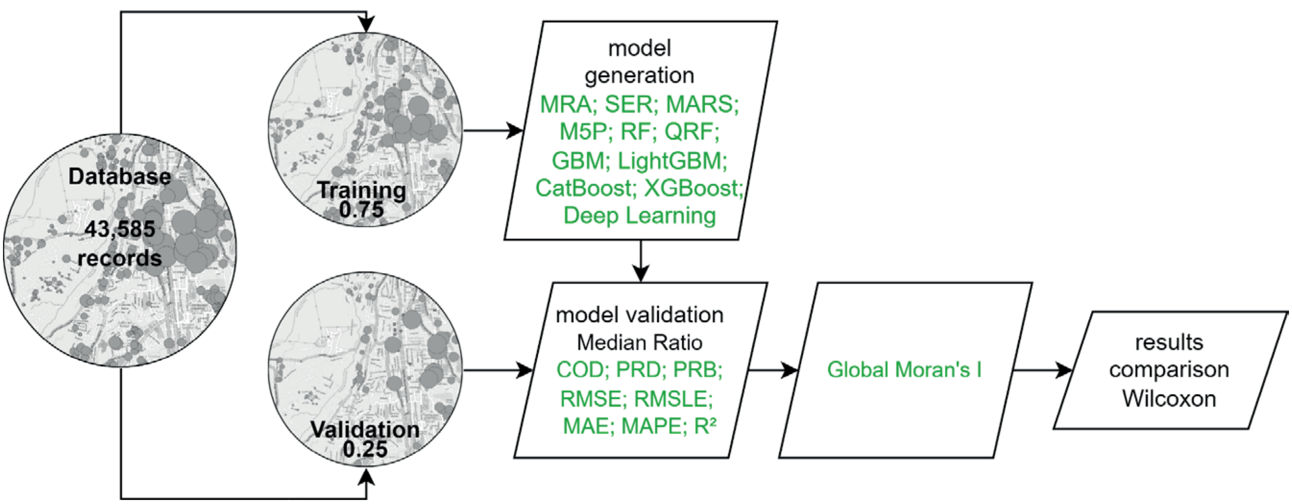

Figure 1. Graphical representation of the methodological process followed.

bility is based on the property's value, and municipalities manage real estate cadastral systems. Fortaleza is known for its georeferenced property base, an urban observatory of property values, and machine learning techniques in real estate taxation (Eguino and Erba, 2024).

The apartment buildings considered for this analysis vary widely in location and characteristics. The sample includes apartments with an average private area of 96.59m², ranging from 30m² to 883m², ranging from 1 to 7 bedrooms, and with prices per square meter ranging from US$ 209/m² to US$ 3,502/m². It includes high-end luxury apartments along the northern coast, near the hotel area, with modern amenities, security, and robust infrastructure, including shopping centers, businesses, and services. Conversely, condominiums are sparse in the southern and southwestern regions of the city, as they need more infrastructure and are generally in poorer condition. The dataset encompasses a wide range of building ages, standards, and features, including minimum lot areas and well-suited areas for leisure and swimming pools, as well as the presence of elevators. In lower-standard condominiums, the presence of these amenities is uncommon. This variability in the data ensures a more comprehensive analysis of the factors affecting apartment values in different areas of the city.

Figure 2 shows the spatial distribution of the initial sample and categorized price per square meter. As can be seen, the most expensive apartments are in the north of the city, close to the seafront, with good urban infrastructure, hotels, and public facilities. Despite an extensive coastline, prices are low in the city's eastern part. This occurs due to the need for more infrastructure, urban equipment, and high air salinity. In the geographic center of the city, there is the airport, which prevents the presence of tall buildings in its surroundings. The poorest region is in the town's southwest, with few tall buildings.

3.2. Explanatory variables

The choice of explanatory variables for a mass real estate valuation model depends significantly on the

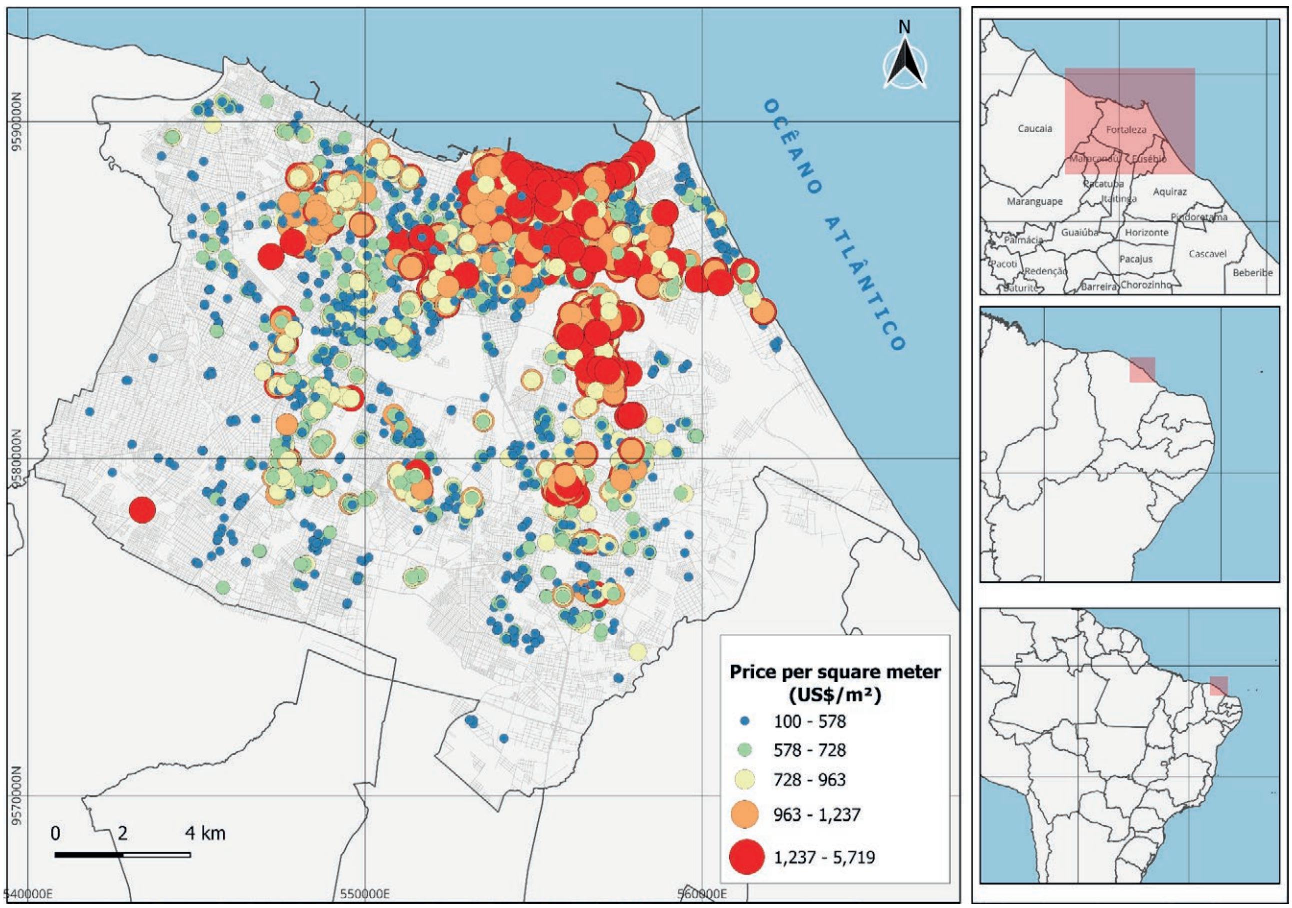

Figure 2. Observed listed prices and sale transactions of apartments in Fortaleza from 2017-2021.

researcher's prior knowledge of the market in that region under study. In addition, geographic information systems (GIS) are of fundamental importance in creating new "spatial proxies" variables that can capture the spatial dependence observed in real estate market datasets. For example, in the northern part of the city, in the Meireles neighborhood, there is an important tourist hub with a promenade for walking that is only 3 km long, offering a beautiful view of the city's coastline and high urban density in its surroundings, with little availability of vacant lots. It is where the leading hotels and high-end luxury apartments are located. Using Euclidean distance, the explanatory distance variable to this promenade ("distbm") was calculated for each sample data point. It is expected that the greater this distance, the less valuable the apartment will be. On the other hand, the city is known for its extreme income concentration, reflected in the presence of informal settlements scattered throughout its territory, with a greater prevalence in the southwest region. In some of these areas, the crime rate is higher, which can negatively impact the prices of nearby apartments. Similar to the "distbm" variable, the "distassp" variable was established to capture the negative effect on the observed prices. Using GIS techniques, a kernel density estimation raster was calculated to capture the concentration of apartment buildings in the geographic space. The aim was to establish zones of higher demand, which could increase the prices of available properties ("vertdens" variable). Other distance variables to value hubs were used: "distpv" and "distsh". The first refers to the Euclidean distance from the apartment to the nearest hub chosen from the following categories: squares, schools, universities, recreational parks, and public cultural facilities. The second refers to the Euclidean distance to the nearest shopping mall, given its significant relevance in providing products and services in the surrounding area and its positive impact on apartment prices. Other variables were chosen based on the physical attributes of the apartment or its condominium, such as the number of bedrooms, floor position, private area, building age, condominium lot area, presence of an elevator and pool, and indication of being on the top floor. The number of bathrooms did not exist in the municipal property cadastre, so it was not used. The Dependent variable was the natural logarithm from price. Table 2 shows more details about the predictor variables used in the research.

3.3. Techniques applied in this study

The authors utilize ten estimation methods to compare models with Multiple Regression Analysis (MRA) results, including Spatial Error Regression (SER), decision trees (Multiple Adaptive Regression Splines and M5 pruned), ensemble decision trees (Random Forest, Quantile Random Forest, Gradient Boosting Machine, XGBoost, CATBoost, and LightGBM) and Deep Learning. We present some basic concepts about them.

3.3.1. Multiple analysis regression and spatial regression

The multiple regression analysis (MRA), which estimates parameters using the method of ordinary least squares, was chosen as the baseline model. As this method violates some of its assumptions, especially regarding homoscedasticity and the presence of spatial autocorrelation in the residuals, it also used a Spatial Error model (SER). The matrix notation for the SER model is given by Eq. 1:

$$y = X\beta + u \quad (1)$$

Where **u** is an error vector that follows an autoregressive process, λ is the spatial autoregressive parameter, **W** is the spatial weight matrix, and ε is a vector of errors (Anselin, 1988):

$$u = \lambda W u + \varepsilon \quad (2)$$

The spatial weight matrix was a first-order, standardized contiguity queen matrix (**W**). The estimate for λ considered the heteroscedasticity with estimation by the Generalized Method of Moments (GMM) based on Arraiz et al. (2010).

Multiple regression analysis and spatial error models assume a linear relationship between variables, which does not always occur in hedonic price real estate markets. Additionally, the effectiveness of the SER model is affected by the choice of the spatial weight matrix, being computationally intensive for large datasets, and by the lack of a transparent methodology for out-of-sample prediction.

3.3.2. ML techniques

There are two main functions that can be developed by an ML application: estimate values (predictive goal) and classify after some attribute using supervised and unsupervised approaches. In some cases, both options are used. Several machine learning approaches could be used in mass appraisal applications. To name some of them, applications used in real estate applications include decision trees, such as Multiple Adaptive Regres-

Table 2. Description and descriptive statistics of the predictor variables assessed in the models.

Variable	Description	Min	Median	Mean	Max
age	Age in years	0	5.74	10.60	66.76
distpv	Nearest distance to main urban amenities in m	1	272.47	363.46	2,795.92
distassp	Distance to the nearest precarious settlement	1	224.15	282.46	1,379.06
distsh	Distance to the nearest shopping center in m	1	1,136.34	1,367.98	6,231.17
distbm	Distance to the beach (north of the city) in m	1.79	4,144.86	5,185.59	16,442.75
income	The mean income of the head of the family in Brazilian minimum wage	0.63	5.74	7.13	29.96
landarea	The total area of the land parcel in m²	143	4,580.52	6,286.20	5,7718
maxind	Maximum allowed floor area ratio (FAR)	0.47	2.5	2.32	3
parcelarea	The proportional area of a land plot in m² related to the apartment	4.5	43.46	77.80	40,012.5
privarea	Private property size in m²	30	76.66	96.58	883.32
test	Length in m of the front of the land parcel.	5.5	61	73.60	379.32
totalarea	Total area in m²	32.16	126.97	152.56	2,278.95
vertdens	Verticalization density measure. Indicates the concentration of unities in the neighborhood	0.01	0.1587	0.24	0.9982
xcen	X coordinates in UTM of the normalized geographic position	-1.06	0.28	0.17	0.98
ycen	Y coordinate in UTM of the normalized geographic position	-0.98	0.4	0.25	0.91
bedroom	Number of bedrooms	1	3	3	7
floor	Apartment' floor	0	5	7	31
garage	Number of garages	0	2	2	15
nfloors	Total number of floors in the building	2	14	13	32
elev	Presence of one or more elevators - dummy	0	1	0 or 1	1
pool	Presence of swimming pool - dummy	0	1	0 or 1	1
lastfloor	Property is on top floor position - dummy	0	0	0 or 1	1
standardi	Finishing standard - set of dummies (1-rustic, 2-proletarian, 3-economical, 4-simple, 5-medium, 6-superior, 7-fine, 8-luxury).			1-8	
$year_i$	Real estate transaction year - set of dummies for 2017-2021			0 or 1	
sale	Effective sale – dummy			0 or 1	
listing	List price – dummy: 0 = sale's price; 1 = asking price			0 or 1	

Source: Authors.

sion Splines (MARS) and M5 pruned (M5P); Deep Learning; Ensemble Decision Trees, like Random Forest (RF); Quantile Random Forest (QRF); Gradient Boosting Machine (GBM) and its optimized implementations such as XGBoost, CATBoost, and LightGBM. All of them are essential alternatives.

In general, ML models provide better accuracy in their predictions than hedonic pricing models and their variants, as long as they are trained with a large volume of high-quality data that is representative of the population under study. They are capable of identifying complex non-linear patterns that traditional methods may not capture. They have high scalability for deployment in environments that require quick and accurate responses, such as those in governmental property taxation departments. On the other hand, such models are known as "black boxes" because they are difficult to interpret, making it impossible in some cases to directly extract the marginal contribution of each explanatory variable to the observed price under "ceteris paribus" conditions. Additionally, ML models can overfit the training data, losing the ability to generalize to new data (overfitting).

3.3.3. Decision trees

In direct words, a Decision Tree (DT) is a non-parametric supervised learning approach used in statistics and machine learning to develop classification and regression as a predictive model to conclude a set of observations by partitioning the feature space (if-else conditions). Tree models in which the target variable can assume a discrete set of values are called classification trees. In these structures, leaves are class labels, and branches represent connections of features that lead to those class labels. Decision trees where the target variable can be continuous (usually real numbers) are called regression trees. DT has the advantage of being more intuitive and easier to interpret than other machine learning models. Depending on the number of nodes and depth, each decision criterion chosen by the algorithm can be easily visualized graphically, facilitating the understanding of the entire decision-making process. However, they can easily overfit the training data, capturing noise and leading to poor performance on new data. Pruning and ensemble decision trees (e.g., Random Forest and XGBoost) are techniques necessary to mitigate this problem. The more robust algorithms described below were used in this research instead of this approach.

3.3.4. Multiple adaptive regression splines

Multiple Adaptive Regression Splines (MARS) is a decision tree that combines recursive partitioning with spline fitting to model the relationship between a set of input (predictive) variables and dependent variables (Friedman, 1991; Friedman and Roosen, 1995). Data is modeled by separate piecewise linear segments (splines) of differing slopes known as essential functions. MARS generates basis functions by searching stepwise, where an adaptive regression algorithm selects the locations of the knot (endpoints of the segment) (Reyes-Bueno et al., 2018). The regions between submarkets are continuous. Some recent studies using MARS include Al-Qawasmi (2022), Reyes-Bueno et al. (2018), and Wang and Li (2019). For the model used in MARS, the best combination of hyperparameters was obtained using the “RandomizedSearchCV” method with ten folds for cross-validation, with a maximum degree of interaction (degree) from 1 to 3, and a maximum number of terms in the pruned model (“nprune”) from 1 to 100. The strategy to evaluate the performance was the lowest RMSE. The best results were obtained with a “nprune” of 21 and a degree of 1. Although MARS can capture non-linear relationships more flexibly than M5P, the resulting model still lacks the ability to capture complex interactions compared to ensemble techniques due to its reliance on local linear fits.

3.3.5. M5 pruned

M5 pruned (M5P) is a model tree algorithm developed to predict continuous variables by applying regression that can exploit the local linearity of the data. For this purpose, model trees generate subsets by choosing attributes to minimize the intra-subset variation in the class values down each branch and maximize the expected error reduction (Zurada et al., 2011). There are three significant steps when applying the M5P methodology: (1) tree construction, (2) tree pruning, and (3) tree smoothing (Reyes-Bueno et al., 2018). The regions between submarkets are often discrete. For the model used in this research, the best combination of hyperparameters was obtained using the “RandomizedSearchCV” method with ten folds for cross-validation, with a range of minimum number of instances from 0 to 1000. The strategy to evaluate the performance was the lowest RAE. The best results were 50 as the minimum number of cases per leaf. Inside subM5P generates segments and exploits the local linearity of the data within those segments, which can be a limitation in situations where the relationships between variables are not locally linear, as it does not adequately capture the true nature of the interactions between variables. Within each submarket, M5P exploits the local linearity of the data, which can be a limitation in situations where the relationships between variables are not locally linear, as it does not adequately capture the true nature of the interactions among variables.

3.3.6. Random Forests

Random forests (RF) or random decision forests are an ensemble learning method for classification, regression, and other tasks that operate by building several decision trees at training time. For classification tasks, the output of the RF is the class selected by most trees. For regression tasks, the mean or average prediction of the individual trees is returned. Random decision forests correct for decision trees’ habit of overfitting to their training set. RF outperforms regular decision trees, but their accuracy is lower than gradient-boosted trees. Data characteristics, however, can affect their performance. Random Forests, like other machine learning and deep learning algorithms, are often named “black box” models because they generate reasonable predictions for a wide range of data while requiring little configuration. However, the analyst cannot understand the logic behind them.

RF is a combination of predictor trees such that each tree depends on the values of a random vector assessed independently and with the same distribution for each of these. It is a substantial modification of bagging that builds a vast collection of uncorrelated trees and averages them. The method combined the idea of applying the general technique of bootstrap aggregating (bagging) technique to develop trees and the random subset of attributes to build a collection of decision trees with controlled bias and variance. The selection of a random subset of features is an example of the random subspace method, which is a way of conducting stochastic discrimination (Breiman, 2001).

For the model used in this research, the best combination of hyperparameters was obtained by the "RandomizedSearchCV" method with 5-fold for cross-validation. The strategy to evaluate the performance was the lowest MAPE. The best results were 15 features selected when looking for the best split ("max_features") and 556 trees in the forest ("n_estimators").

3.3.7. Quantile random forests

A very known extension of RF is the Quantile Random Forest (Wang et al., 2022) which estimates not only the mean or average of the target variable in each leaf but also the entire distribution of it in terms of quantiles for all individual trees. This makes it possible to compute the empirical quantile estimates of the target distribution and even confidence intervals for the predictions. This can be useful in mass appraisal for tax purposes, where one seeks to minimize over-taxation risks. In addition to requiring more computational resources than RF, QRF needs larger datasets to accurately predict quantiles and capture the entire distribution of the variables of interest. We perform the QRF algorithm with the same hyperparameters as the RF model but take median predictions from each tree.

3.3.8. Gradient boosting machine

Gradient boosting machine (GBM) is a machine learning technique used in regression and classification models. It gives a prediction model in the form of weak prediction models, typically decision trees. The decision trees are weak learners but are trained together and sequentially, each trying to correct the error from its predecessor (gradient-boosted trees). It usually outperforms Random Forest. A gradient-boosted trees model is built in a stage-wise fashion as in other boosting methods, but it generalizes the different techniques by allowing optimization of an arbitrary differentiable loss function. Gradient boosting is typically used with decision trees (especially CART trees) of a fixed size as base learners (Friedman, 2001). XGBoost often provides higher accuracy and performance than RF and QRF due to its use of boosting, which iteratively adjusts the errors of previous models. Additionally, its implementations can leverage GPU usage, significantly improving execution speed. One of the significant challenges for researchers using this technique is the need to utilize and test numerous hyperparameters for optimal performance.

In the GBM model, the best combination of hyperparameters was obtained by the "RandomizedSearchCV" method with 10-fold for cross-validation. The strategy to evaluate the performance was the lowest RMSE. The best results were 4,984 trees, with a learning rate (shrinkage) of 0.05, a maximum depth of each tree ("interaction. depth") of 7, and a minimum number of observations in the terminal nodes ("n.minobsinnode") of 15.

Notable extensions (alternatives) of GBM include XGBoost, LightGBM, and CatBoost. Because of this, we prefer to use these algorithms instead of the traditional GBM. Again, hyperparameter tuning was performed by "RandomizedSearchCV" with 5-folds for cross-validation. Each of these algorithms had its own optimized set of hyperparameters. However, this time, a more extensive set of hyperparameter possibilities were tested, such as the maximum depth of the trees, the minimum number of samples required to split an internal node, minimum loss reduction required to make a further partition on a leaf node of the tree (gamma), etc. (Jabeur et al., 2021; Iban, 2022).

3.3.9. Deep Learning

Deep Learning (also known as structured deep Learning, hierarchical Learning, or deep machine learning) is a ramification of machine learning based on artificial neural networks that try to model high-level abstractions of data using a deep graph with multiple processing layers (whence "deep learning" composed of various linear and non-linear transformations). Deep learning algorithms transform the inputs using more layers than shallow learning algorithms. A processing unit, such as an artificial neuron, converts the signal at each layer, whose parameters are "learned" through training. Deep learning algorithms are applied to supervised, semi-supervised, and unsupervised learning tasks (Ganaie et al., 2022).

Using deep Learning for mass assessment is challenging because their results are not fully interpretable ("black-box models"). While machine learning models already have several libraries to allow the influence of each predictor variable on the target, this has yet to happen for deep learning models. Hyperparameter tuning must be done with caution so as not to cause overfitting. This research used a structure with three intermediate layers, one input layer, and another output layer. The Relu function was adopted as the activation function in the first four layers, while the last used a linear function.

3.4. Model performance

The evaluation of results was based on specific metrics, including root mean square errors (RMSE), mean absolute errors (MAE), mean absolute percentage errors (MAPE), Coefficient of Dispersion (COD), Price Related Bias (PRB), and Price-Related Differential (PRD). While RMSE, MAE, and MAPE are commonly used measures in machine learning applications, the International Association of Assessing Officers (IAAO) suggests the other three. According to the IAAO Glossary (IAAO, 2013):

- Coefficient of Dispersion (COD): the average deviation of a group of numbers from the median expressed as a percentage of the median. The standard is a COD of 15 or less.
- Coefficient of Price Related Bias (PRB): shows the percentage by which assessment ratios change whenever values are doubled or halved. For example, a PRB of -0.03 would mean that assessment levels fall by 3% when the value doubles. The PRB should range between -0.05 and +0.05. PRBs outside the range of -0.10 to +0.10 are considered not acceptable.
- Price-Related Differential (PRD): calculated by dividing the mean by the weighted mean. The statistic has a slight bias upward. Price-related differentials above 1.03 show the assessment of regressivity; price-related differentials below 0.98 show the assessment of progressivity.

Finally, we compute the difference between predictions for each algorithm pair and apply the Wilcoxon test to see if the observed differences are statistically significant.

3.5. Measurement of spatial autocorrelation in the residuals

Spatial autocorrelation refers to the degree of similarity between the values of a variable at geographically proximate points. Tobler (1979) referred to that as "The First Law of Geography": "Everything is related to everything else, but near things are more related than distant things". The spatial autocorrelation among the independent variables and in the dependent variable violates several basic assumptions of classical regression (Anselin, 1988; Griffith, 1996). Spatial autocorrelation can imply spatially correlated residuals, which violates the assumption of independence of errors. In mass appraisal, it is widespread for specific clusters to exhibit more significant variance in residuals, violating the principle of homoscedasticity. It can also occur that certain areas have more substantial and similar residuals, which may indicate a specification error where relevant independent variables are not present in the model. The presence of spatial autocorrelation in the residuals suggests that the models used may not have fully captured the spatial structure of the data. As a result, this could lead to inaccurate inferences and an underestimation or overestimation of the impact of explanatory variables. Except for the Spatial Error Model (SER), which used its own spatial weights matrix, all other models utilized the UTM coordinates of the condominium centroid of the apartment, as well as other previously described spatial proxy variables.

Thus, in addition to the performance metrics described above, we calculated the spatial dependency that might still be present in the residuals. The expectation for a good mass appraisal would be that the selected spatial proxy variables capture all that dependency. Thus, we calculated Moran's I statistic for each set of residuals' algorithms under the null hypothesis of no spatial autocorrelation:

$$I = n\frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(\varepsilon_i - \underline{\varepsilon})(\varepsilon_j - \underline{\varepsilon})}{\sum_{i=1}^{n} (\varepsilon_i - \underline{\varepsilon})^2} \qquad (3)$$

Where n stands for the number of observations, ε_i are the residuals of the algorithms, and w_{ij} are the elements of the spatial neighborhood matrix between observations i and j. Using the Moran scatterplot, verifying the level of spatial dependence between the residuals was also possible.

4. RESULTS AND DISCUSSION

Initially, we estimated an MRA model with all the variables in Table 1, but we kept only those statistically significant at 5%. The results from MRA and SER are in Appendix A (Table A1). Both had the natural logarithm of price as the dependent variable, resulting in a similar R-squared. However, MRA indicated the presence of heteroskedasticity in the Breusch-Pagan test. In the SER model, we observed that the spatial autoregressive parameter (λ) was statistically significant at 1%, even though the chosen spatial weights matrix could not eliminate the spatial autocorrelation among residuals (Figure 3).

The Table A2 in the study presents the results of the MARS model for property evaluation in Fortaleza, Brazil, using the natural logarithm of price as the dependent variable. Among the key findings, it is observed that being in the districtPAPICU decreases the logarithm of the price by 0.1488743 units, suggesting a significant

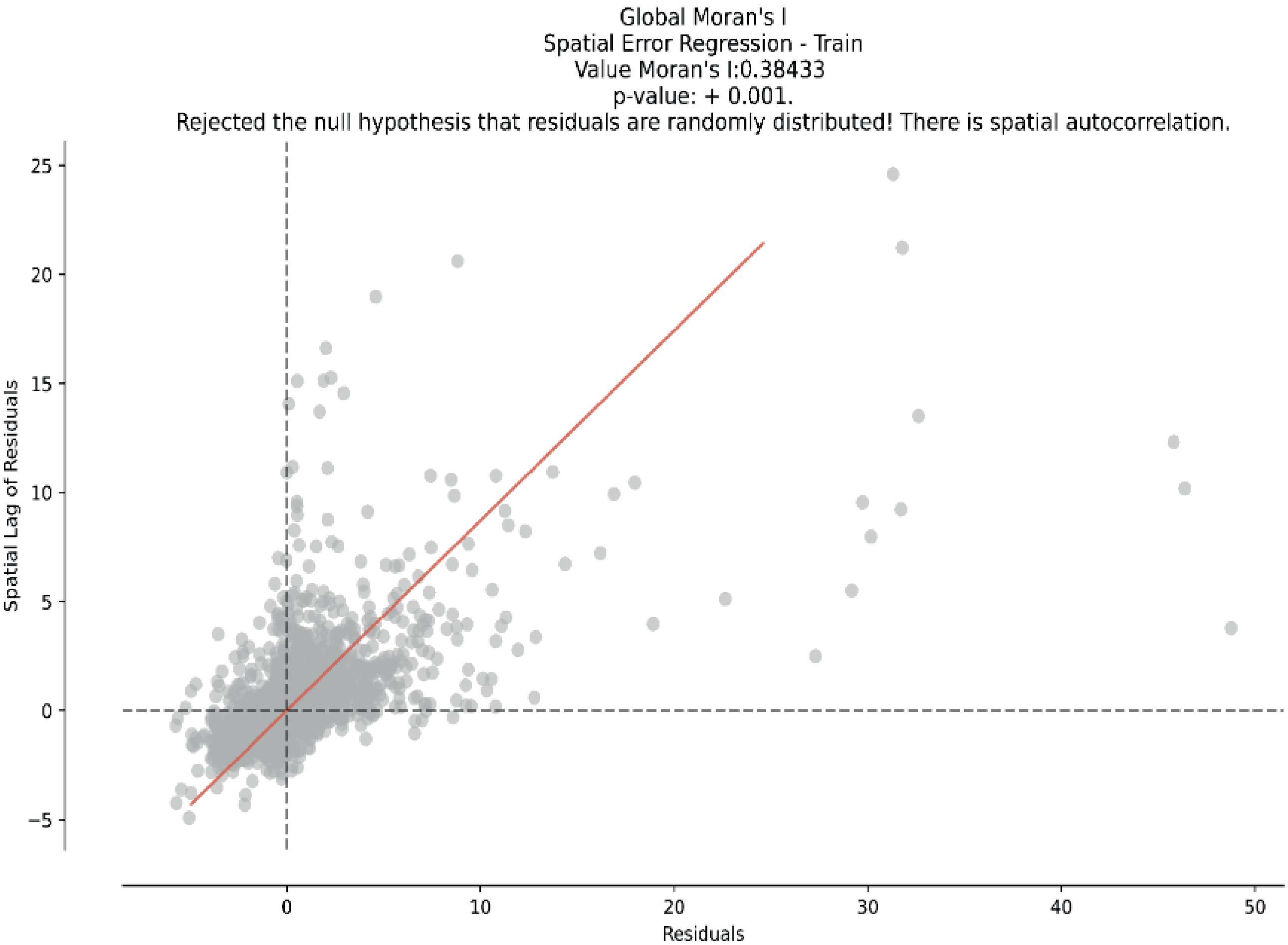

Figure 3. Spatial dependency analysis – model Spatial Error Regression (SER).

negative impact on property values in that area. The presence of a pool increases the logarithm of the price by 0.1010973 units, indicating considerable added value. Transformed variables such as h(14.68-income) and h(income-14.68) capture nonlinear effects of income on price, showing that an income less than 14.68 decreases the price by 0.0090807, while a higher income increases it by 0.0087215. Similarly, property age is reflected in h(27.56-age) and h(age-27.56), where an age less than 27.56 years increases the price by 0.0175039 units, and an older age decreases it by 0.0016117 units.

Additionally, temporal variables h(2020-year) and h(year-2020) show that transactions before 2020 decrease the price by 0.0081761 units, while transactions after 2020 increase it by 0.0691490 units. Normalized geographic coordinates also play an important role, where h(0.38-ycen) and h(ycen-0.38) indicate that a location with a Y coordinate less than 0.38 decreases the price by 0.1600824 units, and a greater Y coordinate decreases it by 0.4244964 units. These results provide a detailed view of the factors influencing apartment prices, allowing appraisers and market analysts to better understand the dynamics of the real estate market in the studied region.

Appendix B (Table B) shows the selected performance metrics for comparing the various models. The median ratio evaluates the overall appraisal level, considering the ratio between observed and predicted values. Values less than one indicate that the predicted values are lower than the observed ones. On the other hand, values greater than one indicate that the predicted values are more significant than the observed ones. For this metric, the results were similar for all models. As for the coefficient of dispersion (COD), the Random Forest and XGBoost models showed the best results (8,98%), indicating better uniformity in their predictions. The MARS, MRA, Deep Learning, and SER models had the worst results on this measure. The price-related differential (PRD) is a measure of the vertical iniquity. It

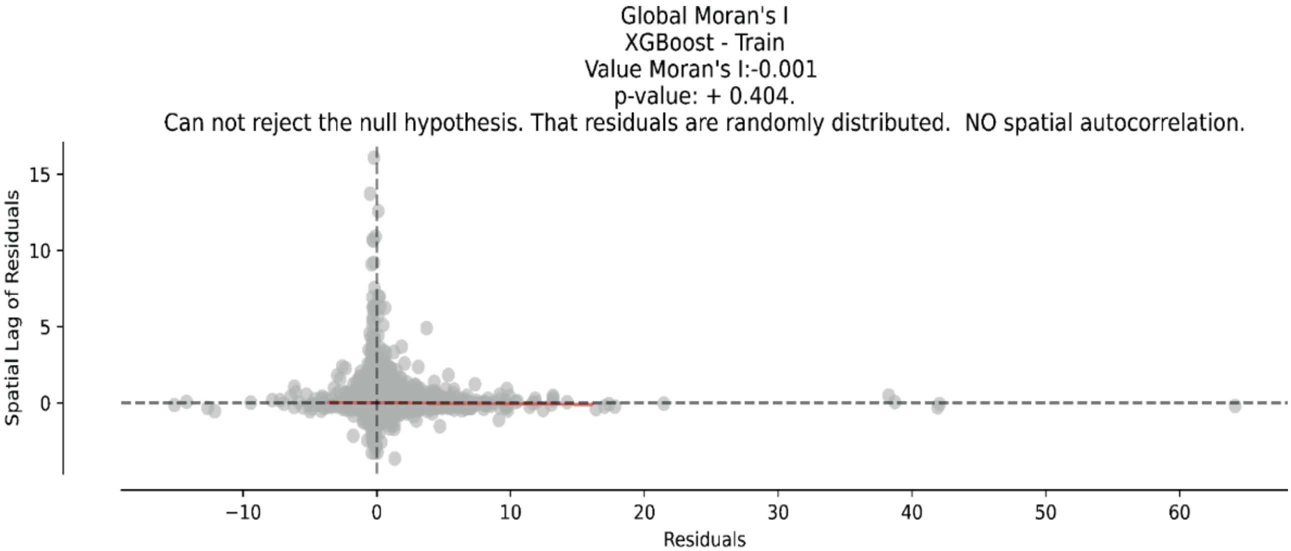

Figure 4. Spatial dependency analysis – model XGBoost.

measures whether high and low-value properties have the same appraisal. IAAO (2013) suggests that its value should be between 0.98 and 1.13. If it is outside this range, the model is regressive. That is, properties with higher observed prices had their predicted values lower than properties with lower prices. The presence of regressivity in mass valuation models is the worst possible situation for property taxation. Regressivity occurred in MRA, MARS, and Deep Learning. Another measure of vertical uniformity is the coefficient of price-related bias (PRB). By this measure, all models showed regressivity, although they are between -0.05 and +0.05, as recommended by the IAAO.

As previously mentioned, metrics like RMSE, RMSLE, MAE, MAPE, and R-squared are commonly measured in machine learning applications to assess the accuracy of machine learning models. They are also in Table B and complete the first part of the comparative study. GBM resulted in the best RMSE, followed by LightGBM and XGBoost, while MRA, MARS, and M5P were the worst. Root Mean Squared Log Error (RMSLE) is a better metric than RMSE in the presence of outliers. M5P, MARS, and MRA still show the worst results, while GBM, CATBoost, and XGBoost offer the best results. In contrast to the RMSE, mean absolute error (MAE), individual differences between observed and predicted prices are weighted equally in the average. Therefore, MAE is also less sensitive to outliers. XGBoost, RF, and CatBoost were the best, while MRA, MARS, and M5P were the worst. XGBoost, RF, and QRF had the best metrics in Mean absolute percentage error (MAPE), while MARS, MRA, and M5P were the worst. RF, GBM, LightGBM, and XGBoost had the same and the best R-squared (0.96), while MRA had a very discrepant value concerning the others, of only 0.88.

The last column in Table A1 has Global Moran's I statistic used to measure spatial autocorrelation among residuals. Moran's I statistic is interpreted against a reference distribution under the null hypothesis of complete spatial randomness. The spatial weights matrix used was queen contiguity order 1 for all models. The null hypothesis was not rejected only for the XGBoost model, meaning there is no spatial autocorrelation in the residuals (Figure 4).

The MARS and M5P models showed higher statistics with significance for spatial autocorrelation at 1%. It might suggest that the regression analysis did not consider another spatial proxy. The SER model also shows an inadequate specification of the chosen contiguity matrix. We understand that ensemble decision tree-based machine learning models are more capable of correcting spatial autocorrelation by taking advantage of the proxy variables used, randomly selecting subsets of the original training data through bootstrapped sampling and combining predictions from multiple decision trees. This became clearer with the XGBoost model, the only one to show no spatial autocorrelation in its residuals with p-value=0.404 (Figure 4). In a way, this would even be expected since gradient boosting machine algorithms are based on the iterative use of new models that try to minimize the errors of previous models, which would explain the low Moran's I index.

Finally, it is essential to know if statistical differences among performance metrics are presented in Appendix C (Table C). It shows the paired Wilcoxon test performed on the residuals of each model. It is observed that the MRA model, chosen as a baseline, had statistically similar residuals with the MARS, QRF, GBM, and Deep Learning models by the Paired Wilcoxon test. Notably, the XGBoost model was the only one to reject the null hypothesis that there is no significant difference between residuals at 5% of significance with all other models.

5. CONCLUSIONS

The study compared traditional and machine learning (simple and ensemble) techniques for mass property appraisal in Fortaleza. More than 43,000 data points for apartment values were evaluated using eleven techniques with varying levels of complexity. The initial set of independent variables selected was 36, including location and intrinsic property variables. The performance of the models was analyzed using the same subset of the data for validation.

Pointing to a possibility that outperformed the others could have been more evident. There is an equilibrium among the performance results of the different machine learning algorithms. However, the XGBoost model showed slightly better performance in several aspects, such as minimizing spatial autocorrelation and achieving statistically significant differences in residuals compared to other models. The MRA, M5P, or MARS techniques have good interpretability, although they have been shown to have a more spatial autocorrelation among residuals than the other methods. Their results highlight the importance of considering heteroscedasticity, spatial autocorrelation, regressivity, and better adjustments for property valuation. The spatial error model (SER) showed a high spatial correlation in the residuals, possibly due to the poor specification of the spatial weighting matrix; in addition, its use for mass evaluation needs to be improved by the need to predict out-of-sample data.

In Brazil, property tax is based on the property's market value, and municipalities manage it through real estate cadastral systems. Machine learning and other AVM (automated valuation models) are highly scalable in environments requiring quick and accurate responses, such as government property taxation departments. When it comes to interpreting the model, traditional techniques like MRA (multiple regression analysis), SER (structural equation modeling), M5P, or MARS (multivariate adaptive regression splines) are more understandable and transparent for people and for defending decisions in a tribunal. However, these techniques have been shown to have more spatial autocorrelation among residuals than machine learning models and result in regressive predictions. While machine learning models offer better performance and less spatial autocorrelation, the transparency and interpretability of classical techniques make them valuable for practical applications in property taxation, where clear communication and defense of valuation decisions are crucial.

Lastly, it is essential to underscore the significance of mass property assessment for land policies, particularly those related to urban spaces that profoundly impact the real estate market. Specific urban policy instruments can help mitigate the detrimental effects of real estate speculation, such as gentrification and housing deficits. Therefore, advancing research on mass property evaluation is essential to equip municipal administrators with efficient mechanisms to aid in land administration.

In future work, the authors plan to employ Explainable Artificial Intelligence techniques that aim to simplify the complexity of property taxation for end users. These new models will capture asymmetry in observed prices and other unobservable and non-linear effects between attributes. In essence, this study indicates the need to delve deeper into the search for more interpretable, less regressive models that are scalable for implementation in property taxation in large cities, where the heterogeneity of properties is more pronounced, with large clusters showing spatial autocorrelation. These aspects will help improve mass property valuation estimates and enhance taxpayer acceptance of the taxation itself.

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APPENDIX A. RESULTS OF MRA, SER, AND MARS MODELS.

Table A1. Regression Results for MRA and SER models

Variable	Coefficients		Variable	Coefficients	
	MRA (OLS)	SER (GMM)		MRA (OLS)	SER (GMM)
intercept	8.8663 *	8.8529 *	bedroom	0.0084 (0.0015)	0.0163 *
parcelarea	-1.24E-05 *	-1.26E-05 *	garage	0.0317 *	0.0305 *
income	0.0120 *	0.0118 *	ln_privarea	0.3680 *	0.3670 *
vertdens	0.1830 *	0.1919 *	ln_totalarea	0.3021 *	0.3061 *
distpv	-8.40E-06 (0.0137)	-1.09E-05 (0.1556)	lastfloor	0.0689 *	0.0799 *
distassp	4.88E-05 *	3.93E-05 *	floor	0.0065 *	0.0065 *
distbm	-1.34E-05 *	-1.49E-05 *	age	-0.0097 *	-0.0098 *
elev	0.0372 *	0.0488 *	a2018	0.0095 *	0.0026 (0.3697)
pool	0.1085 *	0.0938 *	a2019	0.0075 (0.0335)	0.0003 (0.9242)
nfloors	0.0104 *	0.0103 *	a2020	0.0230 *	0.0187 *
standard3	0.0989 *	0.1833 *	a2021	0.0792 *	0.0719 *
standard4	0.3631 *	0.3979 *	sale	-0.0626 *	-0.0759 *
standard5	0.5058 *	0.5163 *	listing	0.0528 *	0.0407 *
standard6	0.6890 *	0.6667 *	Lambda (λ)	n/a	0.6389 *
standard7	0.8583 *	0.8574 *	R-squared	0.9386	0.9380
standard8	1.1789 *	1.1219 *	Observations	32,688	32,688

Source*:* Authors. Notes: The dependent variable is the natural logarithm from price. *Shows P-values < 0.01; otherwise, values in parentheses are the P-values.

Table A2. Regression Results for MARS model

Variable	Coefficients	Variable	Coefficients	Variable	Coefficients
Intercept	7.7533639	h(14.68-income)	-0.0090807	h(1-floor)	-0.0329661
districtPAPICU	-0.1488743	h(income-14.68)	0.0087215	h(floor-1)	0.0058125
pool	0.1010973	h(0.0908-vertdens)	-1.8229510	h(27.56-age)	0.0175039
of	0.1154500	h(vertdens-0.0908)	0.1308400	h(age-27.56)	-0.0016117
h(2020-year)	-0.0081761	h(distbm-125.04)	0.0032095	h(4.8820-ln_privarea)	-0.4324477
h(year-2020)	0.0691490	h(1708.96-distbm)	0.0033438	h(ln_privarea-4.8820)	0.6268375
h(0.38-ycen)	-0.1600824	h(distbm-1708.96)	-0.0032261	h(4.40769-ln_areaed)	-0.2502487
h(ycen-0.38)	-0.4244964	h(18-pvtp)	-0.0235340	h(ln_areaed-4.40769)	0.2851514
h(53.31-cotat)	-0.0051410	h(2-garage)	-0.0236326		
h(cotat-53.31)	-0.0000217	h(garage-2)	0.0693027		

Source*:* Authors.

APPENDIX B. PRELIMINARY RESULTS OF DEVELOPED MODELS IN THE TEST SET

Table B. Regression Results for MRA and SER models (p-values between parentheses)

#	Model	Median Ratio	COD (%)	PRD	PRD Status	PRB	PRB Status	RMSE	RMSLE	MAE	MAPE (%)	R^2	Global Moran's I* (P)
1	MRA	1.00	13.89	1.038	Regressivity	-0.019	Regressivity between +/- 5%	197,400.28	0.18	77,416.86	13,90	0.88	0.37474 (0.001)
2	SER	1.00	11.01	1.025	Normal	-0.011	Regressivity between +/- 5%	137,965.35	0.15	60,292.53	11.02	0.94	0.38433 (0.001)
3	MARS	1.00	14.19	1.045	Regressivity	-0.022	Regressivity between +/- 5%	177,807.97	0.19	75,590.82	14.20	0.90	0.32921 (0.001)
4	M5P	0.99	13.78	1.026	Normal	-0.007	Regressivity between +/- 5%	164,919.99	0.20	71,138.19	13.67	0.92	0.28474 (0.001)
5	RF	1.01	8.98	1.019	Normal	-0.011	Regressivity between +/- 5%	121,314.74	0.13	48,558.11	9.05	0.96	-0.0097 (0.010)
6	QRF	1.00	9.18	1.018	Normal	-0.009	Regressivity between +/- 5%	129,928.75	0.14	49,908.67	9.18	0.95	-0.01903 (0.001)
7	GBM	1.00	9.24	1.018	Normal	-0.011	Regressivity between +/- 5%	113,640.60	0.13	50,229.93	9.25	0.96	-0.01252 (0.001)
8	LightGBM	1.01	10.52	1.022	Normal	-0.016	Regressivity between +/- 5%	114,551.80	0.14	54,026.65	10.60	0.96	0.00919 (0.006)
9	CatBoost	1.01	9.15	1.020	Normal	-0.013	Regressivity between +/- 5%	127,548.82	0.13	48,832.36	9.21	0.95	-0.02712 (0.001)
10	XGBoost	1.00	8.98	1.020	Normal	-0.013	Regressivity between +/- 5%	116,633.77	0.13	48,542.72	8.96	0.96	-0.001 (0.404)
11	Deep Learning	1.01	12.09	1.051	Regressivity	-0.045	Regressivity between +/- 5%	138,462.94	0.17	61,889.17	12.25	0.94	0.15635 (0.001)

Source: Authors. Notes: *Global Moran's I was performed over the training sample; values in parentheses show P-values.

APPENDIX C – WILCOXON TEST

Table C. Wilcoxon signed-rank test on residuals (p-values in parentheses).

	MRA	SER	MARS	M5P	RF	QRF	GBM	LightGBM	CatBoost	XGBoost	Deep Learning
MRA		28654871 (0.002)	29287516.5 (0.222)	10764694 (0.000)	28273101 (0.000)	29387804 (0.359)	29621056 (0.836)	28776431.5 (0.005)	28924854 (0.020)	28080357 (0.000)	29606772.5 (0.802)
SER			29152309 (0.102)	8112396 (0.000)	26330696 (0.000)	28932765 (0.021)	29264854 (0.197)	26362893 (0.000)	26818224 (0.000)	28868465 (0.012)	28811277 (0.008)
MARS				12006409.5 (0.000)	29140611 (0.095)	29377956 (0.344)	29292579.5 (0.228)	29551878.5 (0.677)	29140611 (0.095)	28617181.5 (0.000)	29509893 (0.586)
M5P					4378069 (0.000)	6370087.5 (0.000)	6920394 (0.000)	5432615 (0.000)	4378069 (0.000)	5506569.5 (0.000)	8206475 (0.000)
RF						24311550 (0.000)	28713742 (0.003)	28938424 (0.022)	28360664 (0.0000)	19623564.5 (0.000)	27151928 (0.0000)
QRF							29681109.5 (0.981)	2779046 (0.000)	27826249 (0.000)	27070630.5 (0.000)	29682344 (0.984)
GBM								29051187.5 (0.052)	29067581 (0.056)	28791992 (0.00**6**)	29447044.5 (0.4619)
LightGBM									29497222 (0.559)	24482096.5 (0.000)	26983269.5 (0.000)
CatBoost										1644228 (0.000)	5852011 (0.000)
XGBoost											28031575 (0.000)
Deep Learning											

Note: Bolded values represent significance with p-value < 0.01.

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Integrating the Capital Asset Pricing Model with the Analytic Hierarchy Process and the Delphi Method: a proposed method for estimating the discount rate in constrained real estate development initiatives

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Abstract. The legislative framework on territorial and urban planning has become increasingly rich and complex in the European Union, particularly Italy. The structured – and often hindering – system of division of responsibilities between the central State, Regions, local institutions, and organisms generates different levels of administrative verification. The environmental and landscape constraints by which each Public Administration with jurisdiction over the territory exercises its powers strongly impact territorial management and negatively affect investments. Over the years, this has been one of the main reasons behind the significant dilation of the risk and the time required to obtain the necessary authorizations to start construction, producing "business risk." Based on this premise, this work presents a methodological investigation of the relationships between environmental and landscape constraints, the regulatory framework involving the building, and its Market Value. This is finally aimed at finding suitable methods and procedures to formulate a reasonable discount rate considering the constraints and the related regulations that operate on an asset. A multi-step method integrating the Capital Asset Pricing Model, Analytic Hierarchy Process, and Delphi Method is proposed to assess the discount rate component related to urban risk.

Keywords: landscape, environmental, constraints, real estate finance, multi-criteria analysis, capital asset pricing model.
JEL code: R51.

1. INTRODUCTION

In recent years, the discipline of land governance – all urban planning, landscape, environmental, and building regulations that affect settlement transformations – has become increasingly cumbersome and complex (Battisti et al., 2020).

This complexity is widely recognizable within the European Union. In Italy, it is worsened by the articulated – and often dampening – division of competencies between the central State, Regions, Local Authorities, and other sectorial Institutions with specific scopes. This strongly affects land management and urban planning, negatively affecting real estate investments.

In Italy, in addition to municipal-level provisions (General Regulatory Plan and its regulations, Executive Urban Plans), real estate also depends on a complex system of national and regional laws related to establishing constraints. The system of constraints arises from various sector plans that have joint effectiveness and impose different levels of administrative verification, customarily attributed to specific competencies of public institutions due to the type of matter concerning the constraint.

This complexity significantly affects real estate initiatives connected to urban plans, as well as new construction or building renovation initiatives, particularly where changes in intended use and extensions are envisaged (Oppio et al., 2020); in this regard, the frequent change in the law related to the "regulatory framework of constraints" must also be considered. Indeed, they can impact the regulatory context of already-started authorization processes for productive transformations.

It should be noted that the relationship between constraints and territory is tendentially (not univocally) dynamic: the "regulatory framework of constraints" is constantly changed and updated, modifying the possibilities of intervention on an asset (this happens and produces effects even when real estate authorization processes are underway).

Over the years, this has been one of the causes of the significant extension of the time required to obtain authorizations that allow the start-up of real estate initiatives. In other words, "business risk" grows significantly due to the complex and variable procedural process for approving plans/projects in areas/buildings under constraints (Chong et al., 2009; Chun et al., 2004; Riberio et al., 2017). One more negative factor is the numerical scarcity of personnel employed in Public Administrations dealing with this burdensome workload, which very often results in a delay in the time to complete the investigation and analysis of the Plans and Project to approve (Martinelli and Mininni, 2021); the timeframes provided for by the laws and regulations, based on which the financial assessment of real estate initiatives is performed, are often widely exceeded with repercussion on the economic returns.

The resulting uncertainty, which thus characterizes every real estate initiative in Italy where constraints are present – albeit in different measures depending on the cases and territorial contexts – must be taken into account when proceeding to evaluate a property on which a transformation initiative (real estate development, new construction or refurbishment) and thus an investment opportunity may be envisaged, also in light of the financialization of the real estate sector, which requires transparency on the investment risks on which the profitability of initiatives depends (Chambers et al., 2019; Domian et al., 2015; Sun et al., 2021).

Italy's complex constraint-regulatory system significantly affects the return on real estate initiatives, with significant effects on the Market Value of the asset being transformed (Battisti and Campo, 2021). There is scientific literature related to the study of estimation methods of appropriate discount rates that commensurate the return on industrial capital with the risks and duration of the real estate development initiative (An and Deng, 2009; Brueggeman et al., 1984; Conner and Liang, 2005; Larriv and Linneman, 2022; McDonald, 2015; Napoli et al., 2017; Sagi, 2021; Stokes and Cox, 2023).

In real estate appraisals, the discount rate is a crucial parameter for understanding the investment's return (based on the ability to generate financial/economic flows in both private and public spheres). Still, it is also problematic to define all the factors influencing the investment's risk (inflation trends, condition of financial markets, monetary policy, possibility of alternative investments), which must be considered in its assessment. Unlike financial investments, real estate investment is characterized by high inhomogeneity and fixed position. This makes each investment unique and non-repeatable and requires a specific risk/return profile assessment for the rate's choice (Cannon et al., 2006; Peng, 2016; Ross and Zisler, 1991).

The complex legislative and regulatory system that affects settlement transformation and, thus, the real estate sector has specific effects on the component of the discount rate that scientific nomenclature refers to as "regulatory/administrative risk" (Case et al., 2011; Saaty, 2004). The relationship that links the constraints with the administrative system operating within a given territory (Italy in the case of the study presented) and its corresponding effects on expected returns is a topic of Research that has been the subject of renewed interest in recent times.

Based on the above, this paper investigates the relationships between constraints, the body of laws and regulations to which a building is subject if constrained, and Market Value. The aim is to research methods and procedures for formulating an appropriate discount rate related to the constraints and regulatory measures on an asset.

More in detail, the article presents the results of a research work whose objectives are: i) to create a taxonomy of constraints (landscape, environmental, urban planning) operating on the territory, taking the Italian case as a reference; ii) to perform the methodological definition of a multi-step evaluation procedure, integrating the Analytic Hierarchy Process (AHP) (Linstone and Turoff, 1975; Saaty, 2001), the Delphi Method (DM) (Gordon, 1994; Sharpe, 1964) and the Capital Asset Pricing Method (CAPM) (Alves, 2013; Bartholdy and Peare, 2005; Battisti and Campo, 2021) to ponder the capacity of the various types of constraints to place at certain levels of risk the legitimacy of programs/projects of real estate initiatives. Operationally, the AHP implemented through a DM (to gain experts' opinions about constraints) allows the construction of urban risk indices that, suitably processed, can generate a "fictitious Beta" to implement the CAPM to determine a discount rate that takes into account the appropriate remuneration of the capital (in equity) necessary for the start of the real estate initiative, which can be with certainty transformed/valued only on the sidelines of a complex administrative authorization process.

The proposed procedure is intended to be a functional procedure for the "build-up" approach, where the cap-rate is constructed by considering the incidence of different performance differentials. Through this clarification on the administrative conditions of the asset, the assessment can significantly contribute to the definition of the basket of investments for institutional, qualified, and private investors, given the transparency of real estate players depending on the risks of the action.

While referring to the Italian case, the definition of the method represents an international-level contribution to the implementation of the Highest and Best Use (HBU) (Colavitti and Serra, 2021) as a methodological approach recognized by the Royal Institution of Chartered Surveyors (RICS) in the appraisal of the Market Value of assets that: *i*) need to undergo a transformation; *ii*) have not yet obtained the enabling titles the intervention; *iii*) are characterized by the presence of constraints and/or limitations arising from the laws/regulations in force; in this sense the model is also applicable, subject to appropriate operational declination, in extra-national contexts.

Therefore, in the following: in Section 2, a literary review of the materials and methods investigated in the Research is proposed; in Section 3, the proposed method integrating AHP, DM, and CAPM is illustrated; in Section 4, the expected results of the proposed multi-step method are discussed, and conclusions of the present work are drawn.

2. MATERIALS AND METHODS

A constraint – in detail environmental, landscape, and zoning constraints – is a tool of protection that can completely prohibit, limit, or regulate in detail the transformations of an area and/or a building. Hence, only some constraints lead to the total inhibition of any territorial and/or building transformation. In most cases, a constraint creates pre-conditions for a territorial transformation (both at an urban and building scale).

In general, territorial constraints, which regulate territorial management/transformation, fall into 3 categories: "environmental" constraints, "landscape" constraints, and "zoning" constraints. The latter derive from specific territorial plans aimed at the functional protection of specific territorial infrastructures/equipment.

The individuation of the constraint can occur through delimitations on the maps of the respective competent authorities. Constraints can be established or placed through specific provisions, such as national/regional decrees and laws or landscape plans to regulate this complex theme (European Commission, 2005). Delimitations can be: i) punctual: localized on a single building or a portion of a single building; ii) linear: a buffer zone traced in parallel to the route of a linear element (rivers, power lines); iii) areal: a wide perimeter of any shape, defined according to the specific needs (landscape-related).

In section 2.1, we report a synthesis of the European references for the environmental and landscape constraints; section 2.2 provides a taxonomy of the main constraints from Italian legislation; and finally, section 2.3 summarizes the methods used for estimating the rate in the following paragraph 3.

2.1. Synthesis of the reference European framework

The European Union considers natural resources to be an essential contribution to ecosystemic balance and regions' attractiveness, recreational value, and life quality. This is the primary motivation behind the need for protection and valorization (European Commission, 2020).

Environmental preservation and protection are performed through safeguarding ecological diversity, hydric resources, reconstitution, and protection of ecosystems, including ecological networks, all vulnerable areas with high ecological value, and wetlands, which are part of those networks. To achieve this goal, several ecological elements must be individuated: proximal natural areas, hydric resources, therapeutic climates, and abandoned industrial areas to be redeveloped. Their care requires adequate protective measures, which result in direct constraints or prescriptions of constraints by the Member States.

The legislative framework currently includes several hundred Directives, regulations, and decisions regarding the environment. However, the effectiveness of environmental policy in the European Union largely depends on its national, regional, and local implementation.

At the same time, in some areas, the European Union has directly established regulations in the Member States. The ones with the greatest (territorial) impact are below.

Natura 2000 network

Natura 2000 (European Commission, 2020) is an ecological network of areas that involves all the countries in the European Union and is aimed at guaranteeing long-term protection of habitats and (animal and vegetal) species of community importance due to being rare or endangered. It consists of Special Protection Areas (SPA) and Sites of Community Importance (SCI, which become Special Areas of Conservation, SAC, after the designation process). Natura 2000 derives from two Community Directives on biodiversity: the Birds Directive, which is related to the conservation of wild birds, and the Habitats Directive, which involves the preservation of natural and semi-natural habitats, as well as wild plants and animals. Based on these two Directives, the two typologies of areas are individuated and recognized: the Birds Directive leads to the institution of SPAs, while the Habitats Directive establishes the institution of SACs. In Italy, the Natura 2000 network consists of 2,299 SCIs, 27 of which have already been designated as SACs and 609 as SPAs. The strong point of the Natura 2000 network is to strengthen the synergies and the balance between nature conservation and biodiversity-respectful human activities. For example, protecting animal and vegetal species related to open mountainous environments is strictly related to preserving traditional agricultural activities, such as pasturing and non-intensive agriculture; hence, these activities are welcome and desirable in those sites. The conservation of sites within the Natura 2000 network also contributes to human well-being through the supply of the ecosystemic services that we depend on – the food we eat, potable water, and fuels – but also through the protection from disasters, such as floods and storms, and the conservation of a stable climate. SPAs and SACs include both completely natural and semi-natural environments (such as traditional rural areas and pastures), often located close to settlements, and can represent a natural shelter for citizens.

Sites of Community Importance (SCI)

The concept of Site of Community Importance (SCI) was defined by Community Directive n. 43 of 21st May 1992 (92/43/CEE), the Council Directive on the Conservation of natural habitats and of wild fauna and flora, also known as the Habitats Directive, adopted in Italy in 1997. According to this Directive, each Member State of the European Union must compose a list of sites (the so-called pSCIs, proposed Sites of Community Importance) that have natural habitats and vegetal and animal species (excluding the birds, protected by Directive 79/409/CEE, or Directive Birds). Based on these lists and through coordination with the States, the Commission drafts a list of Sites of Community Interest (SCIs). Within six years from the declaration of SCI, the area must be declared a Special Area of Conservation (SAC) by the Member State. The goal is to create a European network of SACs and Special Protection Areas (SPAs) for biodiversity conservation, denominated Natura 2000.

Special Protection Areas (SPAs)

Special Protection Areas are located along the migration routes of avifauna. They are aimed at the conservation and organization of suitable habitats for the conservation and management of the populations of migratory wild birds. These areas are individuated by the Member States of the European Union (Directive 79/409/CEE, known as Birds Directive) and, together with Special Areas of Conservation, they make up the Natura 2000 network. All the plans or projects with potentially significant impact on the sites, with no connection and use for their management, must be subjected to the procedure of Environmental Impact Assessment.

Important Bird and Biodiversity Area (IBA)

According to the criteria defined at the international level, Important Bird and Biodiversity Areas (IBAs), previously Important Bird Areas (IBAs), is an area that is considered an important habitat for the conservation of populations of wild birds. As of 2022, there are around 13,600 IBA worldwide, scattered across almost all countries. The individuation of the sites is the responsibility of BirdLife International, which developed the program. These sites are small enough that they are completely preserved and differ from the surrounding area by characteristics, habitats, or ornithological importance. The recognition of a site as IBA requires the presence of at least one of the following characteristics:

- host a relevant number of individuals of one or more globally endangered species;
- be part of a vital area typology for the conservation of specific species (such as wetlands, arid pastures, or the cliffs where marine birds build their nests);
- be a zone with an exceptionally high number of migrating birds.

In Italy, 172 areas have been classified as IBAs, with an overall surface of 4,987 hectares. Currently, only 31.5% of the total land of IBA is designated as Special Protection Areas (SPAs), and an additional 20% has been proposed to be a Site of Community Importance (SCI).

Wetlands of International Importance

The Convention on Wetlands of International Importance (UNESCO, 1971), especially as a habitat for waterfowl, was signed in Ramsar, Iran, on 2nd February 1971. The deed was signed during the "International Conference on the Conservation of Wetlands and Waterfowl," promoted by the International Wetlands and Waterfowl Research Bureau (IWRB), with the collaboration of the International Union for Nature Conservation (IUCN) and the International Council for Bird Preservation (ICBP). The international event led to an institutional turning point in international cooperation for habitat protection, recognizing the importance of the areas defined as "wetlands." These ecosystems have a significantly high degree of biodiversity and represent a vital habitat for waterfowl.

Protection of Cultural and Landscape Heritage in Europe

Concerning landscape, the European Landscape Convention (Council of Europe, 2020) is the first international treaty to be devoted exclusively to the European Landscape as a whole. The Convention was adopted by the Committee of Ministers of the Council of Europe in Strasbourg on the 19th of July 2000. It was open for signature by the Member States of the organization in Florence on the 20th of October 2000. It aims to protect, manage, and plan European landscapes and promote European cooperation.

It is applied to the whole territory of the States: to natural, rural, urban, and periurban spaces. Hence, it equally recognizes exceptional, daily, and decayed landscapes. Currently, 32 Member States of the Council of Europe have ratified the Convention, and 6 signed it. For the first time, the Europe Landscape Convention, signed in Florence on the 20th of October 2000, considers the "landscape" as an autonomous legal form. In the previous international treaties, it had received indirect protection, almost as a reflection of the protection of the cultural heritage (in the UNESCO Convention of 1972); that is, it was attracted into the sphere of environmental protection (e.g., in the 1971 Ramsar Convention on wetlands).

2.2. Taxonomy of constraints in the Italian legislative framework

This section reports a synthesis of the constraints-related regulations, which act on the territory through Laws or higher-level planning tools from which they are directly transposed, impacting the possibilities, modalities, and procedures of urban and building transformations allowed by Municipal urban planning.

Concerning landscape, in Italy, the legislative framework on the protection of landscape, which the European Convention is part of, has a rich story, starting from the Constitution itself. Italy is indeed the first State where the protection of landscape (and the historical and artistic heritage) is one of the main principles of the Constitution. Article 9 of our Fundamental Charter reports two main statements: first, the landscape-cultural heritage binomial is a constitutive element of the national identity; secondly, its protection represents a "primary public function," or rather a primary function of the "Republic," at all its levels: State, Regions, and local institutions.

Cultural and Landscape constraints

They are limitations and, in some cases, specific regulations of the Italian legislation on areas with a particular historical, environmental, or cultural value. In Italy, three typologies of landscape constraints exist: areas constrained with a provision by the competent Authority, areas protected by a Law, and typological categories. The primary legislative reference is represented by the Legislative Decree n. 42/2004 (with its changes and additions), defined as "Code of the Cultural and Landscape Heritage".

Protection of heritage with artistic and historical importance

In this case, the limitations do not affect areas but buildings. This typology of constraint, too, is regulated by the Code of the "Cultural and Landscape Heritage".

In addition to landscape constraints, the Italian legislative framework also includes several environmental constraints.

Hydrogeological constraint

Royal Law Decree n. 3267/1923 "Legislative reorganization and reform on mountain woods and land," which is still in force, subjects "the lands of any nature and in-use destination that, due to forms of use in contrast with the laws established by Articles 7-8-9 (tillage, changes in crop types, and pasturing), may undergo denudation, lose stability, or affect water regimes" (Article 1) to a hydrogeological constraint.

The primary purpose of the hydrogeological constraint is to preserve the physical environment and, hence, to guarantee that all the interventions that affect the territory do not compromise its stability, nor start erosion phenomena, etc., with the risk of public damage, especially in hilly and mountainous areas. The hydrogeological constraint regards lands of any nature and in-use destination but is mainly affixed to mountainous and hilly areas and may involve woodland or non-woodland areas. It must be highlighted that hydrogeological constraints do not always correspond with woodland or forestry constraints, which are also regulated by the Royal Law Decree n. 3267/1923.

Flooding and landslide regulations

The Hydrogeological Structure Plan (in Italian denomination Piano per l'Assetto Idrogeologico, P.A.I.) is a fundamental tool of territorial government, established by Law 183/1989. P.A.I., depending on the risk of overflow and landslide risk, can impose limitations on land transformation activities, regardless of whether the hydrogeological constraint exists or not. When watershed planning is started in any region, it represents its thematic and functional base. The P.A.I., drafted under Article 17, paragraph 6 ter, of Law 183/89, and of Article 1, paragraph 1, of Law Decree 180/98, converted with amendments by Law 267/98, and of Article 1 bis of Law Decree 279/2000, converted with amendments by Law 365/2000, has the value of Sector Territorial Plan and is the knowledge, legislative, and technical-operational tool for the planning and programming of actions, interventions, and implementation norms concerning the defense from territorial hydrogeological risk. Following the coming into force of the Consolidated Environment Act (Legislative Decree 152/2006), this subject is regulated by Articles 67 and 68 of the latter. The P.A.I. has three main functions: i) knowledge acquisition, which includes the study of the physical environment and the anthropic system, and the recognition of existing territorial and urban plans, hydrogeological and landscape constraints; ii) regulatory and prescriptive function, destined for the activities connected with the protection of land and water, until the assessment of the hydrogeological risk and the following constraining activity, through extraordinary and ordinary provisions; iii) planning function, providing possible intervention methodologies aimed at risk mitigation, estimating the required financial commitment, and establishing the time distribution of interventions.

Protected areas

The first regulatory tool to establish key principles for the institution and management of protected areas is certainly Law 394/1991 on protected areas, the "Framework Law on protected areas." Law 394/1991 submits specific territories to a special protection and management regime.

According to the provisions of Article 2, Law 394/1991, protected areas are classified according to their characteristics into: i) national parks, constituted by land, river, lake, or marine areas that contain one or more ecosystems being untouched or also partially altered by anthropic interventions, and one or more physical, geological, geomorphological, biological formations whose international or national relevance for naturalistic, scientific, aesthetical, cultural, educational, and recreational values, requires the State's intervention for their conservation to present and future generations; ii) regional natural parks: land, river, lake areas, and also sea stretches overlooking the coast, with naturalistic and environmental value, which constitute a homogenous system for the natural configuration of the places, landscape and artistic values, and traditional cultures of local populations, within one Region or across multiple adjacent Regions; iii) natural reserves: land, river, lake, or marine areas that contain one or more naturally relevant animal and vegetal species, that is they contain one or more important ecosystems for their biological diversity or for the conservation of genetic resources. Nature reserves can be national or regional, depending on the relevance of their values; iv) protected marine areas: this category encompasses the areas defined by the Geneva Protocol, related to the Mediterranean areas detailed in Law 127/1985 (including the ratification of the protocol related to special protected Mediterranean areas, open for signature in Geneva on the 3rd of April 1982) and those defined according to Law 979/1982 (Provisions for the safeguard of the sea).

Zoning constraints

In territorial and urban planning, constraints are mainly established through the individuation of areas or buffer zones, which represent limitations to building activity, for the protection of relevant general interests (such as safety, hygiene, and health) directly imposed by the Law or urban planning tools, and regarding specific parts of the territory, located near artifacts or places involving public use (streets, highways, railway lines, graveyards, etc.). They are mainly distancing impositions. Zoning constraints are different, as they can be absolute or relative. Some typologies of zoning constraints include minimum distances to protect the road belt, minimum distances to protect the railway track, distances from airports; cemetery area respect; buffer zones for power lines, aqueducts, and methane pipelines; buffer zones for military works; buffer zones for water extraction points, at the service of human consumption; buffer zone for sewage treatment plants, buffer zones for radio and television broadcasting stations.

2.3. Analytic Hierarchy Process, Delphi Method, and Capital Asset Pricing Model

This section aims to synthesize an outline of the structures of AHP, DM, and CAPM (Fig. 1).

These methods have already been widely tested in the scientific literature and used in common practice.

AHP is a multi-criteria decision support system that compares several alternatives according to quantitative and qualitative criteria based on pairwise comparisons (Saaty 2004; Saaty 2001). Among the various multi-criteria analysis methods available in the scientific literature, AHP has been considered as it allows, also thanks to Saaty's semantic scale, an easy pairwise comparison between the elements that constitute the evaluation. Such a comparison allows for defining an order of importance for the various constraints that may intervene in a settlement transformation initiative.

The AHP process is broken down as follows:

– it starts with the definition of different alternatives to be ranked and decision criteria, that is, the factors to consider in the decision;
– the "evaluation problem" must be structured according to a hierarchy: first is the general goal, from which specific goals derive, then criteria are defined from specific goals, and indicators are associated with them. It is possible to attribute specific importance to each criterion through weight. Through a pairwise comparison related to the importance of each factor at every level (performance of the alternatives with respect to a single criterion, criteria with respect to specific goals, and specific goals with respect to the general goal), it is possible to insert dominance coefficients in the pairwise comparison matrix, using Saaty's semantic scale. Saaty's semantic scale allows one to make a "weighted" judgment based on one's co-knowledge and experience regarding the comparison of evaluation items;
– after defining the problem and establishing criteria and alternatives, it is necessary to set the A matrix, an n x n matrix with the pairwise comparisons between the selected criteria, to attribute to each of them a preference degree (weight) with respect to the others. As mentioned above, preference degrees are attributed according to Saaty's scale;
– to guarantee an objective attribution judgment for the criteria preference degree, the decision-maker's opinion might be inadequate. For this reason, AHP is often supported by ad-hoc methods or tools for evaluating the degree of preference. These include the analysis of experts' points of view, carried out by Delphi Method, described in the following section;
– after acquiring the experts' opinions, it is possible to attribute a weight to each criterion and hence proceed with calculating the vector with the criteria priorities. The latter, too, are hierarchized according to the degree of preference. After calculating the vector with the criteria priority, the following step is the verification of its Consistency Ratio (*CR*), which is equal to:

$$CR = \frac{CI}{RI} \tag{1}$$

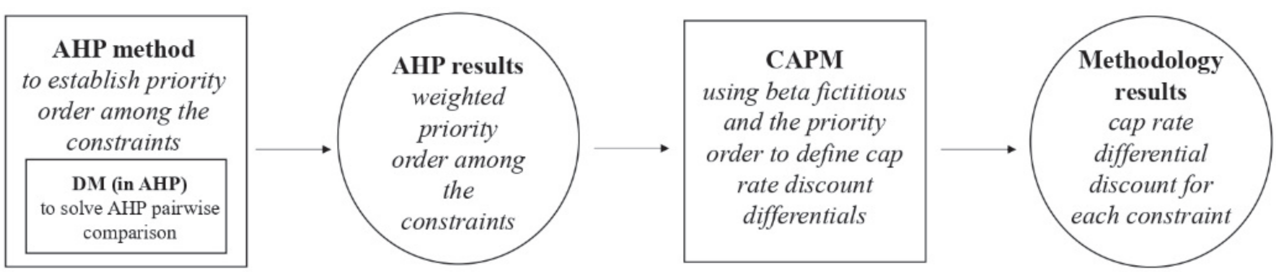

Figure 1. Synthetic diagram on the integration of the methods used.

while the Consistency Index (CI) is:

$$CI = \frac{\lambda max - n}{n - 1} \quad (2)$$

where:
λmax represents the maximum eigenvector of the A matrix of criteria, while n is its dimension.
RI is the Random Index, a tabulated value associated with the size of the A matrix of criteria. The A matrix is considered to be consistent if CR <0,1 (10%);

– after verifying the Consistency Ratio, the final step is the hierarchization of alternatives (and the resolution of the evaluation problem). n B matrices with m x m size are defined, assigning a preference degree between alternatives with respect to the selected criteria. In this case, a priority vector is also calculated for each of the n matrices. At the end of this process, obtaining the hierarchy between alternatives is always possible.

As mentioned above, within AHP, attributing a degree of preference between the criteria is fundamental for correctly resolving the evaluation problem. For this purpose, experts are consulted: this refers to subjects with a recognized experience and knowledge in the field of investigation/object of the problem. In the literature, the process of expert individuation is not methodologically standardized, but there are some best practices to follow:

– definition of the scope of the investigation in which the judgment is required;
– definition of the skills to seek in the experts: the expert must have proven knowledge in the field of investigation/object of the problem;
– choice of the criteria for the verification of their knowledge, such as *i*) criterion 1: publications in the subjects in which the experience is required (monographs, contributions to collective volumes, articles in national and international journals, etc.); *ii*) criterion 2: degrees (PhD, specialization courses, masters concerning the subjects under evaluation); *iii*) criterion 3: professional skills and experiences.

After individuating the experts, defining the most suitable consultation technique is fundamental. Consultation techniques refer to critical listening to the subjects' (experts') opinions to expand the knowledge base on the problem under evaluation.

There are several techniques to achieve consensus which have a specific role and are applied to support the decision-making process if a lack of scientific evidence characterizes the research context, or if they are not demonstrated or fully shared, or even in the case of contradictions between the pieces of evidence or the sources that generated them, resulting in a misaligned picture, within which a reference point or shared guidelines must be sought. These techniques can include experts, stakeholders, or both of them. Can be mentioned:

– The Delphi Method is a typical methodology of social research whereby a selected group (also known as a panel) of experts are interviewed anonymously to express their views and opinions on a given topic, to validate some of them through mutual comparison and progressive sharing (Gordon, 1994; Linstone and Turoff, 1975; Pretty and Hine, 1999);
– Focus Group: a discussion among a limited number of experts with the presence of the decision-maker, often supported by a tutor, to describe the nature and the main characteristics of a problem (Mattia, 2008);
– Interviews: qualitative interviews are "extended" conversations between the researcher and interviewed people, during which the researcher tries to obtain as detailed and in-depth information as possible on the research theme (Mattia, 2008);
– Questionnaire: an observation tool to quantify and compare the data collected on a population sample chosen according to the characteristics of the evaluation (Mattia, 2008).

The CAPM is a model that explains the capital market price formation mechanism. It allows for determining the suitable expected return or discount rate considering the characteristics of the (generally financial) activity under evaluation (discounted cash flows generated by the activity) in relation to its risk (Faiteh and Aasri, 2022; Mattia, 2008; Pretty and Hine, 1999).

The most common formula of the CAPM is (Sharpe, 1964):

$$r_a = r_f + \beta_a * (r_m - r_f) \quad (3)$$

where:
r_a = expected return on investment (in this case, asset);
r_m = expected return of the market or its segment (in this case, real estate market);
r_f = risk-free rate;
β_a = Beta coefficient of the investment (in this case, asset), that is, the sensitivity coefficient of the stock to the market (Battisti and Campo, 2021).

In the CAPM, a particularly interesting element is the Beta coefficient, which synthesizes the relationship between the average market return rate and a specific return rate through the risk associated with an asset (Tang and Way, 2003).

In this sense, by expressing the covariance between a single stock and the whole market, it provides the simplest measurement of systematic risk and, hence, information on the volatility and liquidity of the market. It is a simple risk index of a coefficient with practical use. Within the use of the CAPM in finance, there is comprehensive literature on estimating the Beta coefficient. The following proposal of a multi-step method starts with considering a fictitious Beta to estimate the discount rate in real estate development actions; AHP and DM are conjunctly used for estimation.

3. METHODOLOGICAL PROPOSAL

The proposed multi-step method's structure is based on AHP, DM, and CAPM and aims to determine a discount rate that takes into account constraints and the regulatory framework that can affect urban transformation; the discount rate can hence be used to appraise the Market Value of buildings that can be subjected to real estate development (pre-transformation or Transformation Value).

In detail, the proposed method aims to evaluate the so-called "regulatory/administrative risk" within the specific discount rate of an asset subject to a transformation intervention (that is, it will be transformed only at the end of a complex administrative authorization process). This discount rate component is a key element for estimating the pre-transformation Market Value. It also provides a parameter for the profitability of the initial capital that will be immobilized for the acquisition of the asset to transform.

Determining the discount rate in relation to real estate development risk can help define the real estate players' basket of investments.

The proposed method is articulated into 2 macro-phases:

1) the first, general, phase is aimed at the transformation of the constraints of a given context into a range of discount rate differentials depending on the same framework of constraints that affect the "regulatory/administrative risk" component;
2) the second (specific) phase aims to define a specific discount rate for the building in relation to the regulatory/administrative risk that can be envisaged in the valorization action.

Phase 1 is divided into the following actions:

1) recognition of the constraints within a specific territorial context, affecting territorial transformations (excluding not-buildability constraints);
2) application of the AHP, conjunctly with the DM, for the hierarchization of constraints (according to their importance) to attribute an importance index to (national) constraints. The AHP, carried out using Delphi Method results obtained with the support of experts in regulatory/administrative subjects (public officials of Regional Direction of the Urban Planning sector), will perform the pairwise comparison of each territorial constraint within the area, based on the elements that characterize the constraint itself, inferred from regulations (Acampa et al., 2021). Two criteria are used: i) capacity to inhibit the transformation and ii) administrative-procedural time to verify the compatibility/conformity with the constraint. The capacity to inhibit the transformation is intended as the complexity of the constraint (so-called "vesting") and the verification process to which it is subjected (compatibility/conformity, or both). The administrative-procedural times for verifying compatibility/conformity with the constraint are related to the average time needed by the competent authorities of the given constraint to elaborate on the authorization/nihil obstat request and issue the related provision. The objective of this phase is to obtain weights/coefficients (as a result of the AHP) that, after suitable elaboration, can provide valuable indications on the specific discount rate of a real estate development initiative in a constrained area. Each potential constraint in a given territorial area is associated with a score resulting from the AHP; these scores represent the "base" dataset to elaborate or normalize to proceed to the estimation of the fictitious Beta of the CAPM.

Phase 2 is articulated into the following actions:

1) identification of the fringe parameters related to the financial Beta coefficient of the CAPM. The proposed procedure considers numerical fringe values that, in the market, express the beta coefficient, which can be regarded as related to a riskless investment (minimum parameter) or a high-risk investment (maximum acceptability by an investor). Fringe values are related to the context where an asset has to be transformed or built, hence expressing the risk components connected to the context, thus the market, inflation, etc.;
2) conversion of AHP results (scores representing hierarchical ratios) into coefficients between the minimum and maximum Beta. In brief, the point is to interpolate AHP results within a value scale between the minimum and the maximum Beta. The interpolation leads to transforming "real Beta" coefficients related to the financial market into fictitious Beta coefficients associated with the real estate market and in the specific segment of real estate development. In

particular, each constraint (within the taxonomy of a specific territorial context) is associated with a variation of the fictitious Beta. To implement the AHP, a DM has to be carried out considering the Experts' points of view regarding the relation between constraints (environmental and landscape); in other words, Experts solve the AHP pairwise comparison;

3) the obtained fictitious Beta coefficients can be used in the Capital Asset Pricing Model (CAPM); in particular, they contribute to the determination of the "overall fictitious Beta" coefficient referred to a given asset to be transformed. Beta values above 1 imply a higher risk than the average market (constraint condition above the average, associated with an expected lower "reactivity" in the conclusion of the authorization procedure, which remains under risk); instead, Beta values below 1 correspond to a lower risk. It is evident that the overall fictitious Beta, whose estimation is based on the increase in the risk of the transformation of the asset due to the constraints, embeds the risk that is generally defined in the scientific literature as "regulatory/administrative" but it does not include all the multiple variables underlying the return rate, which also depend from other factors (generally: sector, location, typology, technical and financial aspects); in this case, these additional elements can be overlooked if the considered market return r_m has no time and location inhomogeneity (with respect to the asset under evaluation). Considering the above, considering results from AHP implementation (phase 2.2), this phase is implemented through the summation of the variables of fictitious Beta associated with constraints, only in relation to the constraints that are present on the asset to transform, according to the formula:

$$\beta_a = f(v_1 + v_2 + v_3 + \cdots + v_n) \quad (4)$$

4) Implementation of the CAPM in its traditional formulation: the result of the implementation of the CAPM is a discount rate that is calibrated on the specific constraint condition of the asset (deriving from the elaboration of the regulatory/administrative risk in one coefficient through AHP and DM), but also related to its historical-temporal-geographic context (deriving from the adoption of fringe parameters related to specific contexts and periods). After determining the expected return through the CAPM, the future cash flows of the analysed financial activity can be discounted, determining their current value. The discount operation allows for determining the correct price for the financial activity. Hence, a riskier real estate development will have a higher Beta value and will be discounted at a higher rate; less risky financial activities will have lower Beta values and will be discounted at lower rates.

4. EXPERIMENTATION AND RESULTS

The proposed methodological approach has been tested using the Lazio Region as a reference. The experimentation considered the main types of constraints present within the regional territory (phase 1.1) that affect settlement transformations of a landscape and environmental nature.

The experimentation is conducted with a basic assumption: each of the constraints considered acts as a limitation to the right to build but not as an inhibition: the constraints considered are not of absolute unbuildability since they would, in such a case, be configured within the evaluation process as "barring criteria," in that they inhibit any possible transformation of the asset to which the constraint discipline applies. In the present case, it must be assumed that what is being tested is valid within the areas that have the following landscape classification from the Regional Territorial Landscape Plan: Landscape of Urban Settlements, Landscape of Evolving Settlements.

With reference to the literary review conducted in Sec. 2, 6 types of constraint summarized in Table 1 were considered. It should be noted that the experimentation is performed on the types of constraint, that is, on the categories of constraint that encompass, within them, different constraint cases. It is methodologically correct to proceed by focalizing the assessment on the constraint categories since, within each category, only one constraint is usually evident. Even where special (and rare) circumstances produce the coexistence of a double constraint of the same categories, with specific reference to the case of the Lazio Region, it is found that the constraint discipline remains the same with one or more constraints of the same category. For example, in the case of a double constraint under Art. 134 c. 1 lett. b) of Legislative Decree No. 42/2004, due to the mouth of a river (coastal territory and river), the level of protection appears to be the same compared to the case of single constraints due to either the coastal territory or the river.

Having defined the list of constraint categories being tested, both the prodromal hierarchy for AHP implementation and the DM (step 2.2) were structured.

The pairwise comparison of the 6 constraints considered was done through a DM implemented by involving a panel of no. 25 experts structured as follows:

Table 1. Constraint categories considered in the experiment.

	Types of constraints being tested
Properties and areas of significant public interest (Article 134, paragraph 1 (a), Legislative Decree No. 42/2004)	(a) immovable things having conspicuous features of natural beauty, geological singularity, or historical memory, including monumental trees; (b) villas, gardens, and parks not protected by the provisions of Part Two of this Code, which are distinguished by their uncommon beauty; (c) complexes of immovable things that make up a characteristic appearance having aesthetic and traditional value, including historic centers and cores; (d) scenic beauties, and so are those viewpoints or belvederes accessible to the public, from which the spectacle of those beauties is enjoyed.
Areas protected by Law (Article 134, paragraph 1 (b), Legislative Decree No. 42/2004)	(a) coastal territories included in a belt of a depth of 300 meters from the shoreline, including for land elevated on the sea; (b) the territories conterminous to lakes included in a strip of a depth of 300 meters from the shoreline, including for elevated lands on lakes; (c) rivers, streams, and watercourses included in the lists provided for in the Consolidated Text of the legal provisions on water and electrical installations, approved by Royal Decree No. 1775 of December 11, 1933, and their banks or foot of the banks for a strip of 150 meters each (d) mountains for the portion exceeding 1,600 meters above sea level for the Alpine chain and 1,200 meters above sea level for the Apennine chain and islands; (e) glaciers and glacial cirques; (f) national or regional parks and reserves, as well as the external protection territories of parks; (g) territories covered by forests and woodlands, even if they have been traversed or damaged by fire, and those subject to reforestation constraints, as defined by Article 2, paragraphs 2 and 6, of Legislative Decree No. 227 of May 18, 2001 (repealed provision, now the reference is to Articles 3 and 4 of Legislative Decree No. 34 of 2018) (h) areas assigned to agricultural universities and areas encumbered by civic uses; (i) wetlands included in the list provided for in Presidential Decree No. 448 of March 13, 1976; (l) volcanoes; (m) areas of archaeological interest.
Properties and areas protected by landscape plans (Article 134, paragraph 1, letter c), Legislative Decree No. 42/2004)	Identification, if any, of additional properties or areas of considerable public interest in terms of Article 134, paragraph 1, letter c), their delimitation and representation on a scale suitable for identification, as well as determination of the specific use prescriptions, in terms of Article 138, paragraph 1; identification of any, additional contexts, other than those indicated in Article 134, to be subject to specific safeguard and use measures.
Areas subject to hydrogeological constraints	Lands of any nature and use which, as a result of forms of use that conflict with the regulations in Articles 7, 8, and 9 (clearing, changes of cultivation, and grazing), may, to the public detriment, be denuded, lose stability or disturb the water regime.
Areas placed under protection by the Hydrogeological Structure Plan.	Areas under flood hazard protection, areas under landslide hazard protection, and areas under flood and landslide hazard protection.
Rete Natura 2000	Zone: SCI; SPA; IBA.

- no. 6 officials with organizational positions in landscape matters serving in the Lazio Region;
- no. 7 officials with organizational positions in environmental matters in service at the Lazio Region;
- no. 12 among managers and officials with urban planning competencies at Local Authorities.

The pairwise comparison is carried out considering the incidence of the constraint with respect to the criticality and the consequent risk of failure of the initiative, as well as the completeness/absence of normative and/or regulatory references capable of governing the constraint. Each of the DM participants was asked to perform the 15 pairwise comparisons by responding to the question: *"Which of the two types of constraint involves more criticality in settlement transformation processes? The expert considers the vulnerability of the constrained asset type, any mitigation measures and associated costs, and their track record. There remains the possibility of not answering where adequate knowledge is not available".*

Phase 1 of the DM involved aggregating the experts' judgments. The judgments were aggregated by means of a simple average. Therefore, the figure to be used for the AHP, indicative of the criticality ratio for each of the 15 pairwise comparisons, was derived from the averages of

Table 2. Pairwise comparisons.

	Pairwise comparisons					
	1	2	3	4	5	6
1	1	0.33	4.00	7.00	0.20	3.00
2	3.00	1	6.00	6.00	1.00	5.00
3	0.25	0.17	1	4.00	0.17	1.00
4	0.14	0.17	0.25	1	0.12	0.33
5	5.00	1.00	6.00	8.00	1	8.00
6	0.33	0.20	1.00	3.00	0.12	1

the DM results. The outcomes of the pairwise comparisons are reported below in Table 2.

Thus, it was possible to implement the AHP using the open-access software BPMSG. The results of the implementation are as follows:

- number of comparisons = 15;
- Consistency Ratio (CR) = 6.1%;
- Consistency Index (CI) = 1,24;
- Principal eigen value = 6,38;
- Eigenvector solution: 6 iterations, delta = 6,7E-9.

These data give the experimental results good robustness and thus denote them as acceptable. The AHP results are shown below in Fig. 2.

The AHP results, consisting of a preference scale, need to be interpolated to be used in CAPM; preliminarily, it proved necessary to find data on maximum and minimum Betas (step 2.1) obtainable in the market. In this regard, the information source was https://www.infrontanalytics.com/, from which the following were obtained for the real estate sector:

- maximum Beta: 7.12;
- minimum Beta: 0.78.

Based on these values, it was thus possible to convert the AHP results into beta coefficients (Tab. 3). Since, as can be inferred in the scientific literature, urban planning risk affects a portion of the real estate risk premium, the fictitious Beta coefficients are reduced by a percentage, conventionally established (and in any case considered congruous) in the present experiment of 40 percent, corresponding to an assumed incidence of the constraint component in urban planning risk, on the entire real estate risk premium (step 2.2).

To test the veracity of the results, the simulation of 3 sample cases, with the obtained values, is proposed.

The simulation considers the following:

- r_m = industry average return equal to 12%, deduced from the scientific literature (Forte and De Rossi, 1974; Ibbotson and Siegel, 1984);
- r_f = risk-free return equal to 3%, taken as a function of the net yield on government bonds (Italian BTPs).

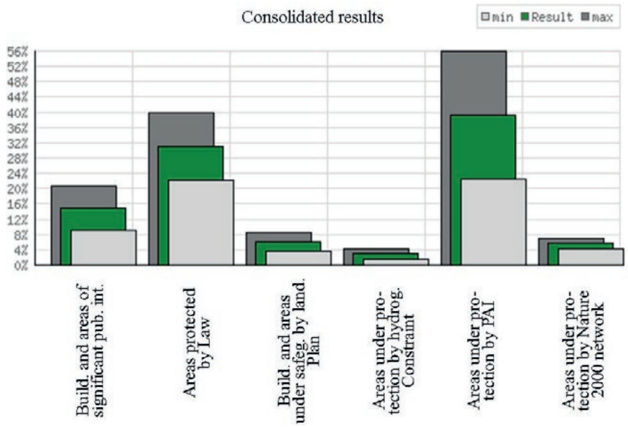

Figure 2. AHP results.

Simulations should be done considering 3 different risk situations that would flow into the Beta (step 2.3):

i) maximum risk hypothesis, with the co-presence of multiple constraints of different nature and, in detail of constraints 1, 2, 3, 4, 5, 6;
ii) medium risk hypothesis, with the co-presence of constraint 1, 4, 5;
iii) low-risk hypothesis, without the presence of constraints.

From the implementation of the CAPM we will have (step 2.4):

$$r_a = r_f + \beta_a * (r_m - r_f) \quad (5)$$

$$r_a = 0{,}03 + \beta_a * (0{,}12 - 0{,}03) \quad (6)$$

It is thus possible to identify the discount rate in the three simulations (step 2.4).

In the case of hypothesis 1, r_a will be:

$$r_a = 0{,}03 + 2{,}068 * (0{,}12 - 0{,}03) = 0{,}216 \quad (7)$$

In the case of hypothesis 2, r_a will be:

$$r_a = 0{,}03 + 1{,}241 * (0{,}12 - 0{,}03) = 0{,}142 \quad (8)$$

In the case of hypothesis 3, r_a will be:

$$r_a = 0{,}03 + 0{,}78 * (0{,}12 - 0{,}03) = 0{,}1 \quad (9)$$

Thus, the expected returns under the three assumptions considered – assuming that the additional conditions that characterize real estate-related investments are ordinary – 21.6%, 14.2 %, and 10%, respectively.

These percentages, derive from a comparative approach: the international financial market sees real

Table 3. AHP results and fictitious Beta appraisal.

AHP results and fictitious Beta appraisal						
	Constraints	Priority	Rank	(+)	(-)	Fictitious Beta incidence
1	Build. and areas of significant pub. int.	14.90%	3	5.8%	5.8%	0.424
2	Areas protected by Law	31.00%	2	9.0%	9.0%	0.883
3	Build. and areas under safeg. by land. Plan	6.10%	4	2.5%	2.5%	0.174
4	Areas under protection by hydrog. Constraint	2.90%	6	1.5%	1.5%	0.083
5	Areas under protection by PAI	39.40%	1	16.7%	16.7%	1.122
6	Areas under protection by Nature 2000 network	5.70%	5	1.3%	1.3%	0.162

estate, as one of the possible sectors of investment and therefore the allocation of capital is made on the basis of risk. The proposed method in fact, using parameters inferred from the financial market, returns results that in fact allow a reading that is comparable between investments. Therefore, the investor who is in condition A must be able to have an IRR of 21.6 percent in order to allocate the resources available to him or her, the investor who is in condition B, on the other hand, must be able to have an IRR of 14.2 percent, while the investor who is in condition C must be able to have an IRR of 10 percent.

Even if the properties were similar or equivalent, the legal condition dictated by the restrictions on them substantially differentiates the financial transactions to be undertaken by implying different returns on investments.

5. DISCUSSION AND CONCLUSIONS

This article presents the first results of research aimed at investigating the relationship between constraining aspects and the Market Value of assets that lend themselves to real estate development initiatives but are not yet the subject of title, enabling their transformation.

The results obtained with the experimentation return discount rates appear credible compared with the returns expected by operators; a remuneration of 10% is found to be adequate for real estate investments with low urban planning risk, while a percentage of 21% appears congruous for situations characterized by greater procedural uncertainty, in this case connected to the constraining condition to which the asset is subject.

The financialization of the real estate market, which examines real estate development interventions on assets to be transformed into assets subject to investment, has made it plausible to use a method, the CAPM, typically used to determine the relationship between a security's yield and its riskiness, measured through a single risk factor called Beta.

The proposed CAPM provides expected return via a fictitious Beta, which is the object sought by the proposed method, configured as a discount rate appropriate to the characteristics of the financial asset underlying the real estate development intervention.

Based on the proposed methodology, the return depends on the "notional" Beta coefficient, which measures the responsiveness of the expected return in relation to the property's constraining condition, on which the allowability of the intervention depends.

Like in financial markets, the higher the Beta coefficient, the higher the expected return of asset n because it possesses a higher degree of non-diversifiable risk. An investor will, therefore, demand a higher expected return for holding a riskier financial asset (Baum, 2020; Jordà et al., 2019; Wong and Ka, 2017).

The proposed procedure implicitly associates a return with the chances of success (regardless of the industry sector in which it occurs), referencing the range of returns expressed by the financial market in a given geographical context and at a given historical moment.

Further development of this research is related to more experimental detail in which a fictitious Beta is defined in relation not only to the types of constraints but specifically to the constraints and their possible combinations.

Despite this, there must be considered limitations in the proposed method which, considering the financialization of the real estate market over the past two decades, places financial and real estate investments on very similar planes; in fact, these are two areas of investment that can move with different logics.In summary, the proposed method can be seen as a tool for investors who want to reduce error margins in estimates of properties with complex administrative and constraint conditions, increasing transparency about investment risks on which profitability depends.

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Alternative methods for measuring the influence of location in hedonic pricing models

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Abstract. The effects of location play a crucial role in the real estate market, encompassing aspects of accessibility and neighborhood. However, these are elements that are not directly measurable. There are traditional ways to consider location, usually through subjective measures based on professional experience, through proxy variables. Understanding these elements is vital for estimating real estate values, whether for legal, commercial, or tax purposes. Furthermore, seeking more objective options is a relevant issue to broaden the justification of estimated values and to enable the development of mass appraisal models. This article proposes and evaluates alternative solutions based on statistics, machine learning, and geostatistics to estimate location. A study was conducted using market data from Novo Hamburgo, southern Brazil, verifying the feasibility of the options presented. Satisfactory statistical results demonstrate the viability of the proposed approach.

Keywords: location quality, hedonic modeling, Machine Learning, fuzzy logic, kriging.
JEL codes: O18, R33.

1. INTRODUCTION

Location is a crucial element in real estate market analysis. Its impact on property prices could be dissected into aspects related to accessibility and neighborhood quality. Accessibility is often considered in terms of the distance or travel time from the property to commercial areas and amenities. Typically, distances to the city center, shopping malls, supermarkets, as well as parks and other recreational areas are used. The challenge arises by considering simultaneously multiple points of interest. On the other hand, neighborhood effects are related to the quality of the surroundings, evaluated on different scales, either at a macro level (neighborhood or city part) or micro level (immediate surroundings within a neighborhood). However, in both cases, the effects are not directly observable (unlike built area or number of bedrooms, for example, which are elements of direct identification), and indirect measures (known as proxy variables) must be created for these effects (Anselin, 1998; Din et al., 2001; Dubin, 1988; Dubin, 1992; Dubin and Sung, 1987; Li et al., 2015; Li and Brown, 1980; Malpezzi, 2002; Smith et al., 1988).

There is no consensus on the most suitable measures for assessing accessibility and neighborhood quality. However, it seems clear that properties with similar characteristics located close to each other tend to share a similar location effect. It is reasonable to assume that the price of a property is influenced by the quality of its location, which is expected to vary continuously within urban areas. This "location value", resulting from the immobility of the product, decreases with the increase in distance between properties. These variations form almost continuous patterns rather than random fluctuations. Using appropriate tools such as mathematical surfaces or geostatistics, these patterns can be mapped from market data, generating a set of objective location variables (Ball, 1973; Can, 1990, 1998; Dubin, 1992; Gallimore et al., 1996; González et al., 2002; Li and Brown, 1980; McCluskey et al., 2000; Wyatt, 1996a).

A more objective approach is demanded by contemporary appraisal context conditions. On the one hand, there are facilities for obtaining larger market samples, considering the digital availability of data, web scraping, and big data. However, with larger samples, there is an increased need for objective criteria in defining variables to reduce the professionals' effort and enable teamwork. Furthermore, some applications require reducing the subjectivity of measures, such as judicial expertise and taxation, which generally need justification for the adopted solutions due to existing or potential disputes, respectively. Another crucial point is that it has become common for value schedules to be developed by hired professionals who may not have a deep knowledge of the city under study. Virtually, a consulting company in this area can develop value schedules in any city in Brazil or even abroad. The option to obtain location through market-driven mechanisms (data-driven) is relevant in this case.

The issue of objectively measuring location value does not present direct or trivial solutions, identifying a space for proposing alternatives to contribute to the understanding and development of pricing models with applications in individual appraisal, legal actions, and taxation. Following this approach, the main objective of this work is to present alternative solutions and compare them with traditional measures of location, such as distances to relevant points and location variables based on professional experience. More advanced alternatives for measuring location effects based on objective criteria are explored, using statistical techniques, machine learning, and geostatistics. A case study was developed in Novo Hamburgo, a southern Brazilian city, proposing and analyzing various hedonic price models, demonstrating the construction and use of alternative variables.

The paper is structured as follows. The literature review explores studies on real estate valuation, emphasizing methodologies, key variables, and advances in performance evaluation. The research method describes the steps for defining variables, assessing their effectiveness, and collecting data to examine value determinants. The results section details the generated variables, models at various complexity levels, and their significance in predicting real estate values. The discussion analyzes the findings, evaluates model performance, compares them with existing studies, and identifies limitations. Finally, the conclusions provide key insights, underscore contributions, and suggest future research directions in real estate valuation.

2. LITERATURE REVIEW

The importance of location in the real estate market is a well-known factor in literature. Although it is a highly relevant element, there are challenges in measuring the effects of location in the appraisal practice. Since accessibility and neighborhood do not have standardized and ready-to-use measures, proxy variables are employed. However, there are some limitations. Proxy variables for location, measuring accessibility and neighborhood quality, sometimes rely on subjective judgments and may not fully capture a property's location attributes. The lack of standardized metrics for these factors makes comparison and replication difficult across studies or appraisal practices. Limited availability of reliable data on factors such as traffic patterns, public services, and socio-economic conditions affects the accuracy of appraisal models. Dynamic changes in location due to urban development, infrastructure projects, or socio-economic shifts further challenge the relevance of location-based measures. These challenges call for improved methods to better quantify and integrate location effects in real estate valuation (Balchin and Kieve, 1986; Balchin et al., 1995; Derycke, 1971; Harvey, 1996, 2006; Lavender, 1990; Lefebvre, 1991; Muth, 1975; Robinson, 1979).

Accessibility is sometimes explored by considering distances or travel times to key points in the city. It's common to verify the effects of distances to city' commercial and historical center (Allen et al., 2015; Ball, 1973; Can, 1990; Can, 1998; D'Acci, 2019; Gallimore et al., 1996; McCluskey et al., 2000; Smith et al., 1988; Straszheim, 1987), public transport (Allen et al., 2015; Li et al., 2016; Swoboda et al., 2015; Welch et al., 2016; Wyatt, 1996a, 1996b), schools (Ball, 1973; Bartik and Smith, 1987; Boyle and Kiel 2001; Can, 1990; Can, 1998; Gallimore et al., 1996; González et al., 2002; Li et al., 2016), leisure centers (Bartik and Smith, 1987; Boyle and Kiel 2001; Can, 1990; Can, 1998), parks (Boyle and Kiel 2001; Din et al., 2001; Li et al., 2016), distances to main avenues or highways (Allen et al., 2015; Bartik and Smith, 1987; Straszheim, 1987; Swoboda et al., 2015), and other elements are also used.

Traditional models often consider the Central Business District (CBD) as a general attraction center. These models are based on the premise that the CBD concentrates trade, essential urban functions, and most jobs (Derycke, 1971; Muth, 1975). While this projection is generally suitable for small cities or studying parts of larger cities, this simplification can be exaggerated for other situations, as city growth tends to generate more complex structures with multiple attraction centers, resulting in a polycentric city. In fact, some empirical studies using the distance to the CBD as an accessibility measure find little statistical importance for this variable, suggesting alternative measures or considering multiple centers, such as the location of shopping malls (Allen et al., 2015; Ball, 1973; Bartik and Smith, 1987; Can, 1990; Dubin, 1992; Dubin and Sung, 1987; Smith et al., 1988; Straszheim, 1987; Wyatt, 1996a, 1996b).

There is a similar challenge in measuring neighborhood characteristics. The effects are equally important and difficult to measure. More specifically, some studies demonstrate the effects of various factors, such as the pattern of neighboring properties (built environment), land use intensity, education and income levels of local residents, air quality, noise level, availability of schools and public transportation, access to exclusive bike lanes, and ease and safety for pedestrians walking in the neighborhood, or negative externalities, such as proximity to factories, landfills, or even nuclear power plants (Ball, 1973; Boyle and Kiel, 2001; D'Acci, 2019; Din et al., 2001; Ding et al., 2000; Jud and Watts, 1981; Kain and Quigley, 1970; Lang and Jones, 1975; Li et al., 2015; Li et al., 2016; Swoboda et al., 2015; Welch et al., 2016). Some authors also addressed sustainability aspects, such as the value of ecosystems, the effect of green areas, or the distance of properties to water (Cohen et al., 2015; Sander and Haight, 2012; Saphores and Li, 2012).

In traditional practice, professionals often assess measures for each neighborhood based on experience and knowledge of the local market, which can be useful in some cases. However, this method faces limitations, such as the lack of systematic analysis and justification of results, dependence on personal assessment, and difficulties in periodic reassessment, which can result in duplicated efforts and lack of accuracy. For individual appraisals, this is a viable task since information is collected by seeking comparable properties in terms of quality and location, and differences are generally not significant. On the other hand, large-scale appraisals (mass appraisal), such as models for property taxation and market studies, present greater difficulties and are a complex task, given the large variations in building types and spatial price variations (Ball, 1973; Bartik and Smith, 1987; Boyle and Kiel, 2001; D'Amato and Kauko, 2017; Kauko and D'Amato, 2008; Smith et al., 1998; Vargas-Calderón and Camargo, 2022).

3. RESEARCH METHOD

It is observed that literature presents a set of options traditionally applied in pricing models, considering distances to commerce, schools, amenities, presence of noise or pollution sources, among others. In general, daily commerce (represented by CBD, supermarkets, and shopping malls) and free leisure elements such as parks receive more emphasis. The distance to the nearest element is considered.

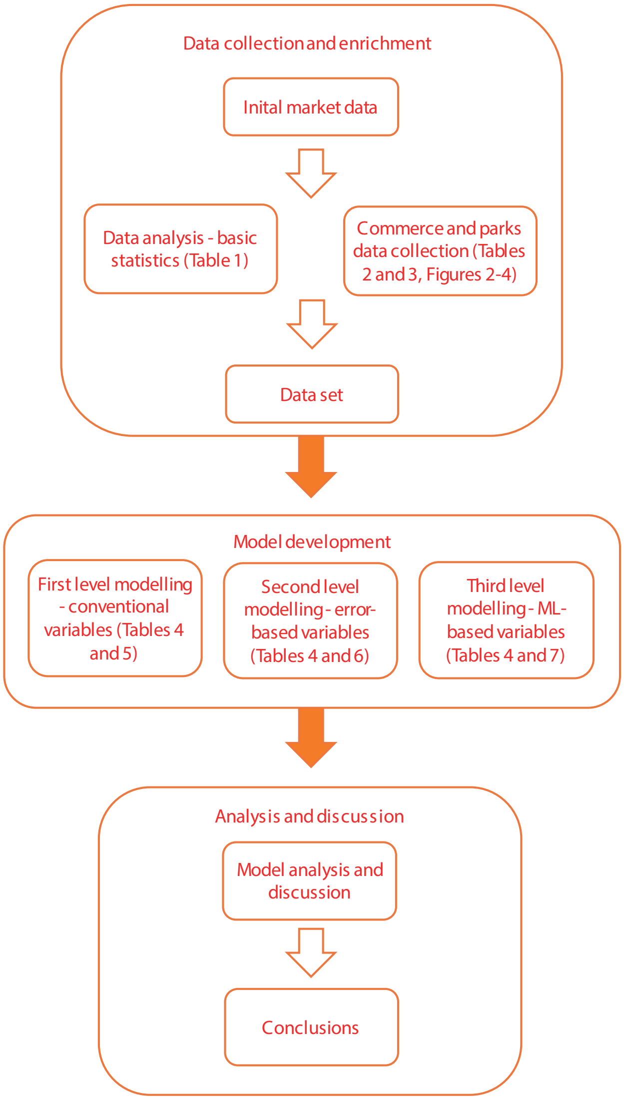
In a polycentric city, multiple attractions, such as commerce and leisure areas, influence property values through varying accessibility. These amenities and disamenities affect properties differently, depending on their proximity to these points. Distances and the mix of factors in different locations create unique impacts on real estate values. The traditional approach considers these effects through a set of variables, which complicates the analysis and reduces the degree of freedom of estimation. Statistical significance will probably not be achieved with this individualized analysis.

The assessment of location quality is often performed through a score for the neighborhood or part of it, based on the professional's experience, the average income of the region, and other parameters. However, this generates an aggregated measure with a low level of detail and requires frequent repetition of the process. In this case, the difficulty of justifying the assigned score is increased, and it is convenient to find ways to weigh the effects together.

This research employs a systematic methodology to address the research objectives. The process includes several key steps. Flowchart 1 represents visually the research methodology, highlighting each step and the interconnections between them to provide a clear outline of the approach.

3.1. Proposal of variables

The developed study is designed in three levels of complexity concerning the variables employed in the



Flowchart 1. Stages of the research methodology. Source: Authors.

models. Through a case study conducted in the city of Novo Hamburgo, southern Brazil, information was collected, and analyses were developed to examine the proposed measures.

a) Initial Level – Traditional Approach

The first level considers the most traditional analysis process, where conventional location measures are employed, with the neighborhood level being subjectively evaluated. It adopts straight-line distances to the nearest points of commerce and urban parks for each property in the sample. The Distance to CBD is related to the city's shopping mall, and the distances to commerce and parks indicate the distance from the nearest element to each property in the sample. The variables generated at this level are Neighborhood-A, Dist.CBD, Dist.Commerce, Dist.Park. Neighborhood-A represents the location variable determined based on the author's experience.

b) Intermediate Level – Statistics and kNN

The second level proposes a linear weighting model to coordinate accessibility measures and an error modeling mechanism (data-driven) to generate neighborhood measures. For accessibility, it is considered that there are multiple points of interest, such as various supermarkets or leisure points at similar distances, given the convenience of weighing the effects together. Therefore, it analyzes the simultaneous influence of these alternatives on the population. It proposes the analysis of a set of measures, generating a variable for commerce and another for parks, considering a weighting mechanism for the relative size of each option and the distances to the sample data. The linear weighting model is basically an equation. A relative weight (pre-determined) is adopted for each point of interest. As amenities, the variables Commerce and Parks were calculated, representing the weighted averages of the distances from supermarkets and parks to each property in the sample, respectively. The general scheme is presented in Equation (1):

$$Amenity(I_i) = \Sigma^a \left[\frac{Distance(I_i, a)}{weight\_a}\right] / A \quad (1)$$

where $Amenity(I)$ is the weighted average measure of the attribute (in this case, supermarket or park) for property I_i; $Distance(I_i,a)$ is the Euclidean distance from property i to reference a, which has coordinates (x_i, y_i) and (x_a, y_a); $weight\_a$ is the relative weight of each alternative a, with $a = (1,\ldots, A)$, and A indicating the total number of points of interest. With the application of $weight\_a$, larger elements have a smaller distance, representing increased attractiveness.

For the neighborhood issue, the measurement variable at the neighborhood level was constructed from the residuals generated in a model that does not contain location-related variables, in a data-driven approach. Error modeling starts from a hedonic model without the inclusion of location-related variables. Consequently, location effects will be mixed with random errors, however, location effects should be spatially distributed, unlike random errors. In a second step, spatial analysis of errors should be developed, through trend surfaces or kriging, techniques that identify the trends of the studied attribute, isolating the effects of location into a new variable (D'Amato, 2017; Gallimore et al., 1996; Helbich et al., 2014; McCluskey et al., 2000; Ward et al., 1999).

The assumption is that location effects, as they were not explicitly considered, will be contained in the errors and can be isolated, filtering out random variations. At this intermediate level of complexity, the measure for the neighborhood was obtained by summing the standardized errors of the data for that neighborhood, followed by normalization to a scale (1-10), generating the variable Neighborhood-E.

A second neighborhood variable was determined at a micro level, defined pointwise for each property in the sample. A hedonic model was generated with basic variables, also including the neighborhood variable (Neighborhood-E). Following the same reasoning, the premise is adopted that internal neighborhood differences will be contained in the residuals (internal variability). Point estimates – neighborhood value for each property in the sample – were obtained by linear kNN (unweighted).

The k-Nearest Neighbors (kNN) algorithm is a robust and intuitive machine learning method used to solve classification and regression problems. It is a supervised learning method. By incorporating the concept of similarity, kNN calculates values for a new point considering its k nearest neighbors in the training data set. As it works with the average, random differences are filtered, obtaining the trend of neighborhood quality. The calculated variable was called Local-kNN, adopting the arithmetic mean of the 20 nearest neighbors.

c) Advanced Level – Machine Learning and Geostatistics

The third level follows the basic idea of the proposals of the second level but uses more complex techniques, introducing machine learning (fuzzy logic) and geostatistics (kriging). The weighting of commerce and parks distances was performed by fuzzy sets, with membership functions proportional to distances. The participation of each commerce or park element is calculated by the membership function, with the respective weight identified for each source.

A fuzzy system consists of a sum of the partial estimates of each considered effect, which are weighted according to a membership function. Unlike sets that follow classical logic, which have a binary membership definition, such as {0,1}, the membership functions of fuzzy sets assign fractional memberships, in a continuous interval [0,1]. In this approach, each element can belong to several sets with different participation, identified as any value in this interval. The sum of memberships of all elements in the set must reach 1, and at the same time, the sum of the participation of an element in different sets of the system also reaches 1 (Dubois and Prade, 1980; González, 2017; Nguyen and Walker, 2019).

In the case of location, the relationship of properties with neighboring properties occurs in all directions (360°), requiring an adaptation of the membership functions of fuzzy sets, normalizing values to achieve a unitary sum. The general influence is the weighted sum of effects in all directions. The participation of neighboring cases in the final values depends on the weighting scheme defined for fuzzy sets. Participation is more significant for closer units. A format based on the inverse of the distance to weigh cases is an interesting option, using 1/dk, usually k=1 (inverse function, 1/d), or k=2 (square of the distance, $1/d^2$). If adopted with k=0 (no weighting), the result is the unweighted kNN adopted at the intermediate level. Increasing k reinforces the membership values to neighboring points (weighing more strongly closer cases). Therefore, the importance of neighboring cases in the final value increases proportionally to the increase in k. In the studied case, the effects of the exponent were verified, obtaining better results with k=2 (González, 2017). More formally, a fuzzy system composed of D fuzzy sets (one for each attraction point) can be described as in Equation (2):

$$Distance(I_i) = \Sigma^d[\mu_d(I_i)] * Distance_d(I_i) \quad (2)$$

where $Distance(I_i)$ is the adjusted measure for property i; $\mu_d(I_i)$ is the function that calculates the membership of property i to each fuzzy set d; $Distance(I_i)$ is the calculated value for i using rule d. In the case of a function involving urban space, $\mu_d(I_i) = Distance(I_i,d)^{-k}/w$ is adopted, with $w = \Sigma^d[Distance(I_i,d)^{-k}]$, and w calculated to reach $\Sigma^{d,i}\mu_d(I_i) = 1$; $Distance(I_i,d)$ is the Euclidean (linear) distance from property i to the reference (supermarket or park) of rule d, which have coordinates (x_i, y_i) and (x_d, y_d); k is the exponent that gives the weight of the distance influence; and d=(1,…, D), with D representing the total number of reference points. The set of participations was normalized to reach 100% in all cases, using w. This scheme generated the variables Fuzzy-Commerce and Fuzzy-Parks.

For the neighborhood variable, a continuous surface was generated using kriging, from the residuals of an equation using only Neighborhood-E as a location measure. This technique allows smoothing the surface, to some extent, filtering out random errors and concentrating the result on the trends of the studied effect. A mean of the 20 nearest neighbors was also adopted, but now weighed by the inverse of the square distance. The calculation process using kriging is like weighted kNN, but kriging always uses the distance of each nearby information as a weight to consider spatial similarity. The weights were normalized by a mechanism similar to fuzzy sets (*w*), determining the variable Local-Kriging.

Kriging is a spatial weighting technique originally developed by Daniel Krige for use in mining and since then widely expanded for the study of any spatially distributed phenomenon. The basic premise is related to the so-called "first law of geography", introduced by Waldo Tobler, which essentially says, "everything is related to everything else, but things close are more related than things far away" (Tobler, 1970). This proposition is the basis of fundamental concepts of spatial dependence and spatial autocorrelation and is specifically used for the inverse distance weighting method for spatial interpolation and to support the theory of regionalized variables for kriging (Matheron, 1963; Miller and Kahn, 1962; Tobler, 1970).

3.2. Performance evaluation of studied measures

The work focuses on the proposition and testing of some alternative measures for location, with testing and comparison of the results with traditional measures. Each proposed variable must undergo an evaluation of its statistical performance to validate the obtained measure. For this purpose, hedonic price models can be used.

In the real estate market domain, it is essential to simultaneously consider the effects of various elements on prices. In this context, a real estate property is considered a "composite good", characterized by a set of attributes, each assuming different weights in explaining price variations. Hedonic price models involve the proposition and testing of a relationship between prices and the main attributes of properties (Goodman, 1978; Griliches, 1971; Lancaster, 1966; Lucena, 1985; Malpezzi, 2002; Rosen, 1974).

Given the complexities of the real estate market, specific conditions need to be met for price modeling. Hedonic models are constructed using a data set from the analyzed segment, resulting in equations suitable for property valuation or market condition analysis, usually using regression analysis. Regression analysis is a technique that associates independent variables with a dependent variable - in this case, the market price - generating a model. The goal is to establish a numerical model (in this case, an equation) (Gujarati, 2000). A general form for a hedonic price function is expressed in Equation (3):

$$Price = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k + \varepsilon \qquad (3)$$

where *Price* is the variable under study (response variable or dependent variable); $x_1,\ldots, x_k$ are the explanatory variables (for *k* independent attributes); $\beta_1,\ldots, \beta_k$ are the coefficients of the equation representing the relative importance of each of the attributes in explaining the dependent variable; β_0 is the constant or intercept of the equation; and ε is the error term.

The coefficients of the equation are interpreted as the contribution of one unit of each variable to the property price. In other words, βi is the weight or implicit price of that feature, measured in the same currency as the price when the equation is linear. The model's format is not clearly known beforehand, as it is determined through statistical analysis of the data, however, there are guides on literature about often-important attributes, such as size, age, location and other aspects. This data-driven approach allows for flexibility, enabling the identification of the most relevant variables and their relationships with property prices. The format evolves based on the data structure and the underlying patterns observed during the analysis.

The evaluation of regression models initially includes fundamental statistical parameters, including the coefficient of determination (R^2) and the model's significance level through an F-distribution-based variance test (Fisher-Snedecor F). The individual significance of variables is assessed through hypothesis tests based on the Student's t-distribution (Gujarati, 2000).

The value of each sample case is estimated through the adjusted model, and the differences between the collected market value and the estimated value generate residuals or errors. Error analysis is a crucial part of model evaluation. In addition to outlier analysis (individual case view), model residuals can be assessed using root mean square error (RMSE) and mean absolute error (MAE), common metrics used to evaluate predictive model accuracy (a collective, holistic view), particularly in the field of mass appraisal.

The analysis indicates the variables that should remain in the model under a certain significance level and their importance in explaining the price. Some conditions must be checked to ensure the quality of the generated model. Among the regression assumptions, the presence of homoscedasticity (constant variance of errors), normality of errors, and linearity of the relationship in Equation (3) should be analyzed (Gujarati, 2000).

Furthermore, considering the spatial nature of the market, addressing the issue of spatial correlation is crucial. The presence of spatial correlation may indicate trends in the model and reduce the accuracy of estimated values. Spatial correlation can be assessed using the Moran's I index (Anselin, 1998; Can, 1990; Can, 1998; Dubin, 1988; Dubin, 1992).

Finally, to avoid overfitting, it is common to develop the modeling stage with a cross-validation mechanism, typically using 80% of the sample data for training (model generation), reserving 20% for testing and model verification. The data are chosen through simple random sampling. The test verifies whether the model has the ability to generalize (in other words, if it can provide good estimates for cases not seen in the modeling stage).

3.3. Collected data

The study was conducted in Novo Hamburgo, southern Brazil (29°40'4'' S; 51°07'5'' W), a city located along the federal highway BR-116, about 45 km from the state capital. The research involved acquiring market data for apartments and reference information to assess accessibility on an urban scale. The city is 94 years old, and its urban space is distributed over an area of 223.6 km². It has approximately 247,000 inhabitants (1,105 inhabitants/km²), with a per capita GDP of R$ 37,500.00 (according to 2020 data).

The initial data was obtained from the Brazilian real estate website Viva Real, which is the country's real estate portal with one of the largest property listing databases, focusing on information including prices and precise locations. In some situations, the address was not disclosed in the advertisements, but it was possible to identify the building from photos of the facade or by the name of the condominium (a local peculiarity of referring to buildings by name instead of address). Information collection took place from January 2020 to December 2022, collecting all currently available properties. Since the data collected consists of listings and not sales data, one possible bias is the presence of some exorbitant pricing, but in a large sample this could be detected in conventional outlier analysis. Indeed, an initial analysis allowed the removal of data with discrepancies or lack of information, resulting in obtaining 963 apartment data, which were divided into a training sample with 80% for model generation (771 data) and a test sample with 20% for model evaluation (193 data).

The position of each data point was verified by identifying its coordinates (x_i, y_i). The classification into neighborhoods followed the legal definition of their boundaries (see Figure 1).

The information provided for each property includes traditional options such as private area, number of bedrooms, parking spaces, bathrooms, among others (Table 1). In cases of conflicting information between different advertisements, the latest information was adopted. The correlation of attributes with the price is an essential element, anticipating the expected relationship, although

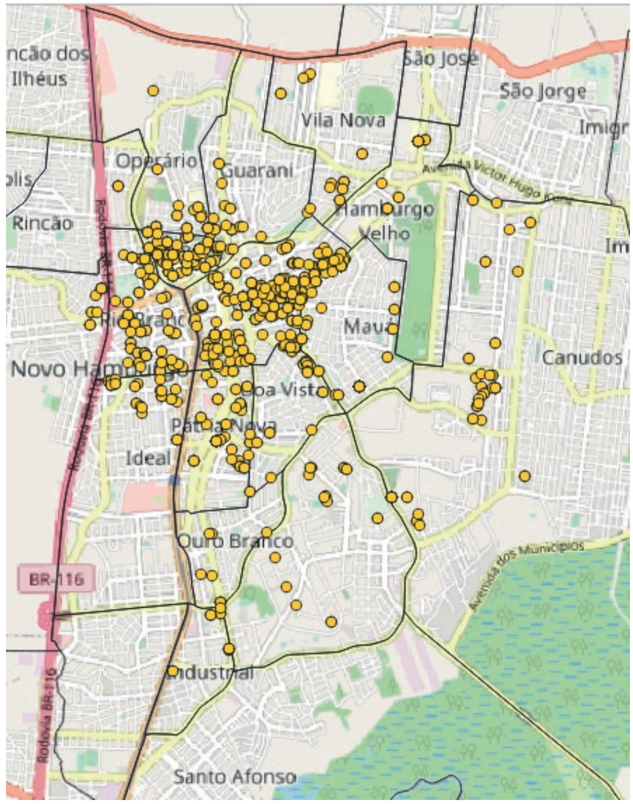


Figure 1. Collected market data and delimitation of city neighborhoods. Source: Data collection by the Authors; Neighborhood limits: Municipal Government of Novo Hamburgo.

the actual contribution is better assessed in hedonic models with multivariate analysis.

While some attributes are conventional and indicate in an objective way their contents, the number of elevators serves as a proxy variable for the construction standard. In this city, a building with two elevators tends to be of a higher standard, accompanied by amenities such as a party hall, swimming pool, or other common-use facilities. On the other hand, a building without an elevator tends to be older or of a lower standard, with a smaller shared area, and so forth.

For the evaluation of accessibility in this region, some reference points were considered. Regarding commerce, distances to the main shopping mall in the city were measured, representing the traditional center of the city (CBD). The central metro station is opposite the shopping mall, serving as an accessibility element and a representation of a relevant and recognized shopping space in the city. Notably, this part of the city does not have other significant points of interest. The major supermarkets were identified, assigning a relative weight based on their size (selling space). Table 2 presents the considered commercial elements.

Table 1. Characterization of Initial Variables.

Attribute	Description	Unity	Range	Average	Correlation with Price
Price	Price	BR Reals	115,000.00 – 3,800,000.00	567,777.21	-
Area	Private area	m^2	30.0-459.0	111.94	0.829
Bedroom	Number of bedrooms	-	1-4	2.44	0.568
Bathroom	Number of bathrooms	-	0-5	2.10	0.825
Parking	Number of parking spaces	-	1-5	1.43	0.796
Penthouse	Penthouse (1) regular (0)	-	0-1	0.082	0.234
Elevators	Number of elevators	-	0-2	0.856	0.309
Month	Information time, on a continuous scale: Month=1: Jan 2020; Month=36: Dec 2022	Month	1-36	18.81	-0.011

Source: Data collection by the Authors; the main source is https://www.vivareal.com.br/.

Table 2. Commerce elements.

#	Identification	Weight	Longitude	Latitude
-	Bourbon Shopping mall/CBD	4	487036.326	6716018.285
1	Hipermarket Bourbon	3	487264.408	6715143.973
2	Supermarket Carrefour	2	487255.919	6716323.870
3	Supermarket Atacadão	2	486800.125	6713588.738
4	Supermarket Rissul – Ave. Nações Unidas	2	486693.097	6717370.535
5	Supermarket Rissul –Bartolomeu Gusmão Str.	1	490319.794	6714939.050
6	Supermarket Rissul – Jamaica Str.	1	491141.607	6716357.547
7	Nacional supermarket – Hamburgo Velho	1	489205.314	6717119.572

Source: Data collection by the Authors.

Table 3. Urban Parks.

#	Identification	Weight	Longitude	Latitude
1	Parque do Trabalhador (Worker's park)	1	485206.205	6716795.575
2	Parque Floresta Imperial (Imperial Forest park)	1	487783.091	6713154.146
3	Parque Municipal Henrique Luis Roessler – "Parcão" ("Big park")	10	489410.252	6716359.260

Source: Data collection by the Authors.

The shopping mall was not included in the supermarket group because it does not offer this service; instead, it is composed of clothing stores, jewelry and accessories shops, musical instruments, electronic equipment, toys, among others.

The city's urban parks were identified, shown in Table 3.

Following findings from various published studies, it can be assumed that small-scale elements such as fruit stands, mini-markets, or squares are not decisive factors in the purchasing process and do not influence the prices charged, with more significant impact from supermarkets and urban parks.

Figure 2 indicates the position of the parks and supermarkets considered, as well as the shopping mall, to check the distribution of the elements.

4. RESULTS

The initial models assessed variables related to the property itself (size, characteristics, number of bedrooms) and upon this foundation, location variables were tested. After the initial exploration of the data and considering the spatially extensive sample with properties exhibiting significant variations, a semi-logarithmic

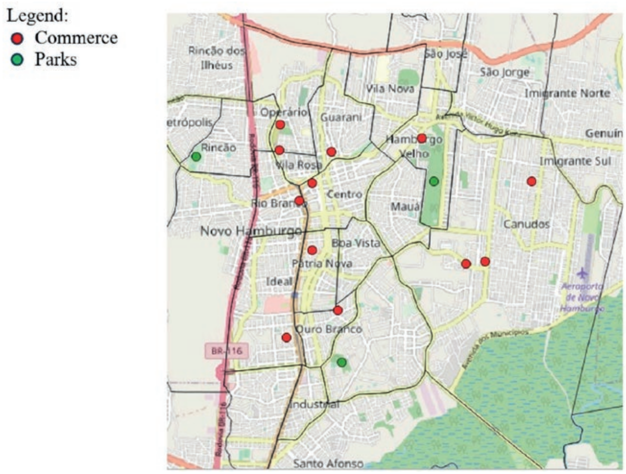


Figure 2. Position of the city's commerce and parks. Source: Data collection by the Authors.

model was adopted, presented in the Equation (4):

$$Price = exp(a_0 + a_1\text{Area} + a_2Bedrooms + a_3Parking + \cdots + a_k\{Location\}_k) + \varepsilon \quad (4)$$

where the basic variables are described in Table 1, and $\{Location\}$ represents one or more variables related to measuring the location effects, as per the level of analysis, presented in Table 4. Various models were examined, exploring different compositions of location variables. It was selected models with the best statistical performance, avoiding unnecessary repetition and proliferation of results.

4.1. Presentation of generated variables

Broad neighborhood variables (macro-location), at the urban scale of the neighborhood, were generated traditionally, based on the professional and research experience of the authors (Neighborhood-A). The second variable is based on the residuals of a model estimated without location variables. The sum of standardized residuals in each neighborhood was normalized, generating Neighborhood-E, representing a less subjective option for this attribute.

Figure 3 shows the distribution of neighborhood valuation for the sample data points. Although similar, there are differences between them. The values are the same for all data in the same neighborhood, in each case.

Local neighborhood variables, assessing intra-neighborhood variations, were based on the errors of the model including the objective neighborhood measure (Neighborhood-E). Two options were adopted. At the intermediate level, Local-kNN adopts the kNN option without weighting, and for the advanced level, a surface

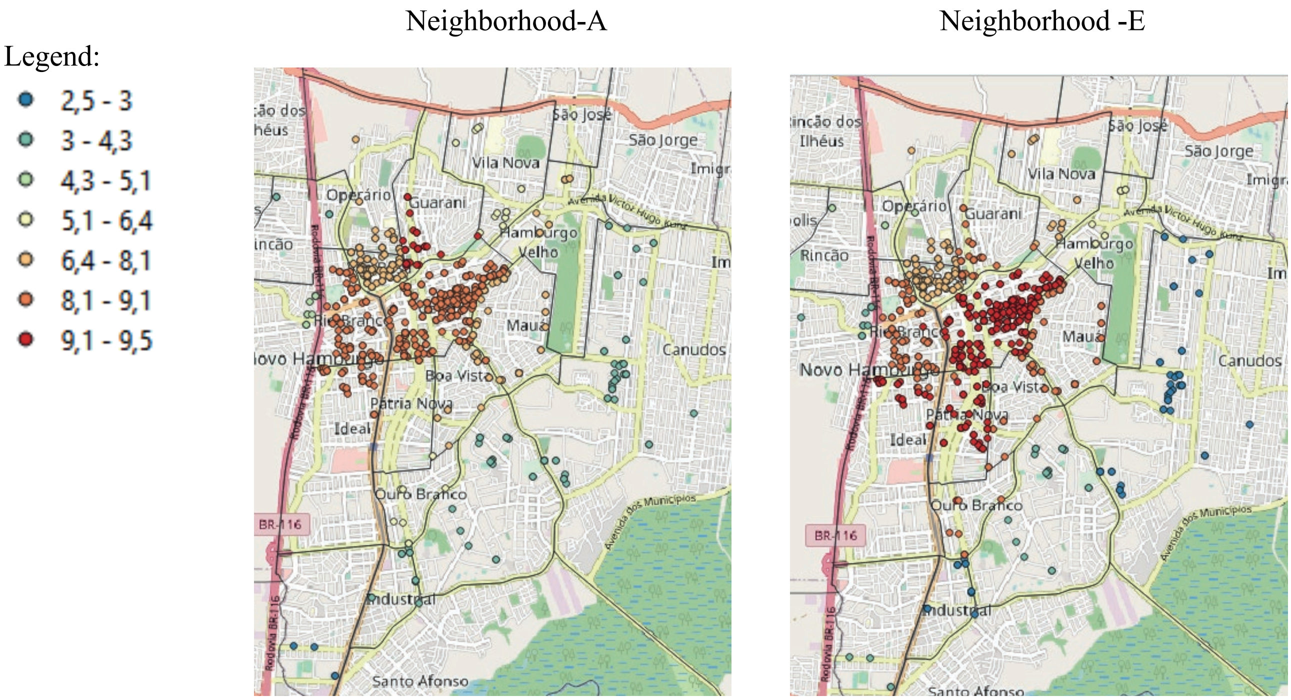


Figure 3. Distribution of neighborhood variables on the neighborhood scale. Source: Authors.

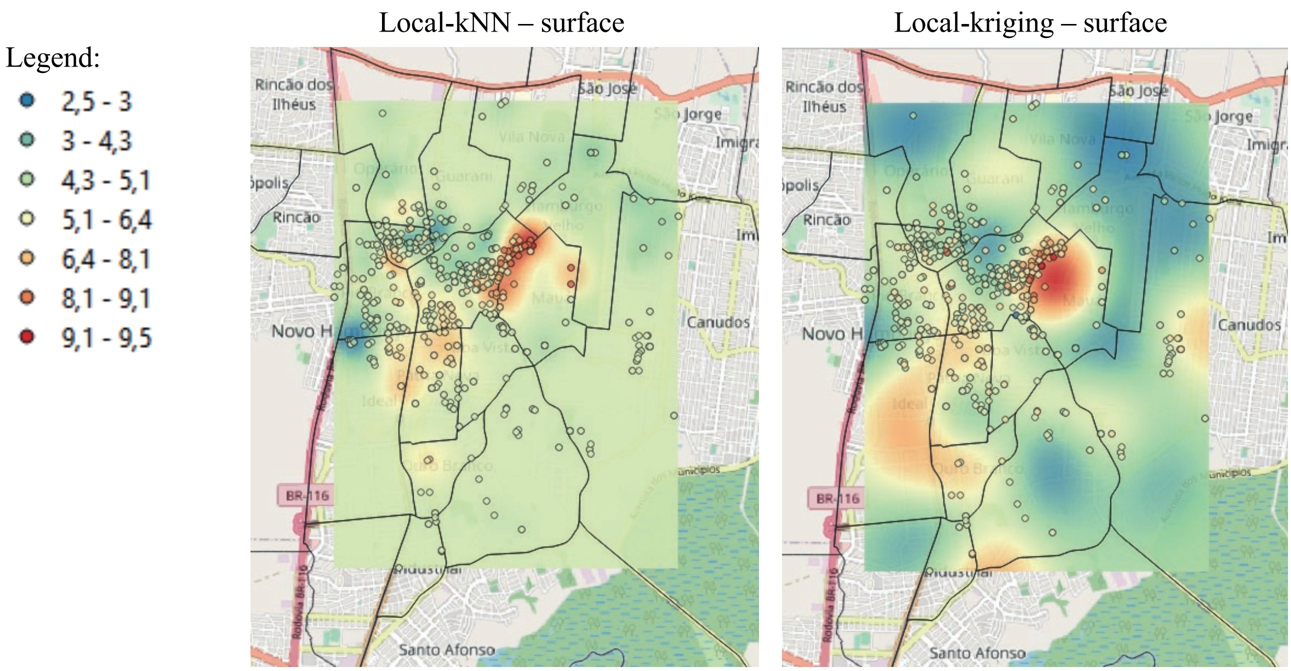


Figure 4. Distribution of intra-neighborhood variables. Source: Authors, using QGIS and Smart-Map plugin.

was calculated with kriging weighted by the inverse of the squared distance ($1/d^2$), subsequently interpolating the point values for each data point in the sample. The generated variable is Local-kriging. For both, the 20 nearest cases were used.

Figure 4 presents the spatial distribution of these variables. Point values and corresponding surfaces are indicated. There are natural differences between the distributions, considering the existence or absence of distance weighting. In the more peripheral areas, which also have less data availability, there is a prevalence of lower values which, in the case with kriging, are characterized by the dark blue color. On the other hand, the more valued region is in the same city area in both alternatives.

Regarding the variables that aim to measure the effects of accessibility, at the first level, distances to the CBD, for commerce and parks were calculated using the distances to all properties and choosing the nearest element (only one in this case).

For the second level, the weighting of the effects of supermarkets and parks was carried out considering the Euclidean distance (linear distance from each data point in the sample to the considered reference point) and the relative weight assigned to the element, whether it be a supermarket or park. For commerce, following the Equation (1) scheme, the function takes a form as in Equation (5):

$$Commerce = \Sigma^c \left[\frac{Distance_d(I_{i,c})}{weight_c}\right] / C \qquad (5)$$

where $c = (1, \ldots, C)$; $Distance_d(I_{i,c})$ is the Euclidean distance between property i and supermarket c; $weight_c$ is the relative size of supermarket c, and C=7 (see Table 2).

At the third level, Fuzzy variables for commerce and parks were calculated. For the fuzzy commerce model, Equations (2) and (5) transform into (Equation 6):

$$Fuzzy\text{-}commerce = \Sigma^c[weight_c * Distance_d(I_{i,c})^{-2}/\mathrm{w}] \qquad (6)$$

With $w = \Sigma^c[Distance_d(I_{i,c})^{-2}]$. The parameter w is the normalization element of the results. The other elements have the same meaning as in Equation (5). The calculation scheme considers the inverse of the square distance, a situation that provides better results than with the inverse of the distance.

In the case of Parks, the proposal follows the same format as Equations (5) and (6), but now considering the elements from Table 3.

In summary, the variables generated to measure the location effects are described in Table 4. The correlation of each variable with the price indicates the potential relationship, to be more precisely verified in the multivariate analysis.

Table 4. Description and averages for location variables in training and testing.

Level	Attribute	Description	Unity	Range	Average	Correlation with Price
Initial	Neighborhood-A	Defined as based on Author's experience	-	3.0-10	7.95	0.312
	Dist.CBD	Distance to shopping mall	km	0.2-6.2	1.182	-0.094
	Dist.Commerce	Shortest distance to supermarkets (Table 2)	km	0.1-1.85	0.690	-0.111
	Dist.Park	Shortest distance to urban parks (Table 3)	km	0.25-2.4	1.572	-0.201
Intermediate	Neighborhood -E	Defined as based on errors of a model with no location attributes	-	2.5-10	8.30	0.289
	Commerce	Weighted average of supermarket distances	km	1.3-3.0	1.721	-0.354
	Park	Weighted average of park distances	km	1.5-3.4	1.981	-0.069
	Local-kNN	Neighborhood calculated by kNN, 20 cases, no weighting	-	4.0-6.8	4.909	0.179
Advanced	Fuzzy-Commerce	Fuzzy weighting of supermarket distances	km	1.0-3.0	2.072	-0.187
	Fuzzy-Park	Fuzzy weighting of park distances	km	1.0-9.8	5.283	-0.354
	Local-kriging	Neighborhood calculated by kriging, 20 cases, with inverse squared distance	-	3.4-6.8	4.895	0.186

Source: Authors.

4.2. Models for the first level of complexity

The initial models adopted conventional attributes. Three models were generated. One uses only the Neighborhood-A variable (Model 1), another includes the three distance measures (Model 2), and the third includes the entire set (Model 3). Similarities between them are observed. The initially evaluated parameters are R^2 and F, which showed no restrictions. The determination coefficient of the models is suitable for a model with spatial coverage and significant variations in characteristics among the data, representing about 87 to 89% explanation for price variations. The calculated F-statistic indicates significance and is extremely low, close to zero (Table 5).

Variables were analyzed for significance with t' statistics. Generally, they were significant at the $\alpha = 0.01$ level. In cases where the achieved level was $\alpha = 0.05$, the coefficient was identified in the table (using an *). No variable exceeded this limit. The signs and coefficients of the variables are as expected, according to each one's contribution. They can be considered good results.

Being a semi-log model, the coefficients of continuous variables can be interpreted by their participation in price relative to a unit of the variable (this is the partial derivative of the equation). For example, in the case of the private area of the models presented in Table 5, a one-square-meter variation represents an increase of about 0.25% in price, considering a range near the variable's average.

The subjective neighborhood variable showed significance in both models in which it appears, with and without the distance' attributes. The coefficients are similar (0.0647 and 0.0722), indicating, respectively, that a 1-point increase in the variable represents about a 7% increase in the average price.

Location variables based on distance were significant, showing a negative coefficient, as expected. Without the Neighborhood-A variable, the coefficients of the distances indicate stronger effects, which is coherent, as in this case, these three variables represent all location effects. In Models 2 and 3, the weight of the proximity to the shopping mall is slightly higher than for the nearest supermarket, while the distance to parks has a much higher coefficient than these two (Table 5). Considering that the effort required to generate distance variables is reduced, it can be considered a positive result.

The verification with the test sample (20% of the data) indicated a slight increase in RMSE (1.7 to 3%), with a more significant effect on MAE (increase of 7 to 8%). There is no evidence of overfitting in this case. Considering the exploratory nature of the analysis, the results can be considered good.

Spatial correlation was assessed through the Moran's I coefficient (Table 5). The three models show similar results, not indicating the presence of spatial autocorrelation, with Moran's I values between 0.083 and 0.160. The second model indicates larger differences between the training and test samples, but both can be considered adequate.

Overall, the model with the four variables (Model 3) presents the best results, although with a slight difference from the others. All four variables are significant at the α=0.05 level. RMSE and MAE measures are lower for both training and test samples. There are no indications of spatial correlation, and the determination coef-

Table 5. Result of models with traditional location variables (dependent variable: Ln(Price)).

Attributes		*Model 1*	*Model 2*	*Model 3*
Intersection		11.001020	11.495044	11.090280
Area		0.002438	0.002688	0.002395
Bedroom		0.141338	0.136166	0.147499
Bathroom		0.111389	0.131407	0.105304
Parking		0.254705	0.244094	0.247395
Penthouse		0.090689	0.055278*	0.099039
Elevators		0.237026	0.304255	0.253368
$Month^2$		$7.26*10^{-5}$*	$9.05*10^{-5}$	$7.69*10^{-5}$*
Neighborhood-A		0.064739	-	0.072231
Dist.CBD		-	-0.032437*	-0.012125*
Dist.Commerce		-	-0.029988*	-0.007198*
Dist.Park		-	-0.064838*	-0.084296
Training sample	R^2	0.873097	0.866564	0.895426
	F	~0	~0	~0
	RMSE	262,687.11	299,799.88	250,809.30
	MAE	349.66	361.96	345.83
	Moran's I	0.0857352	0.0752964	0.0827976
	N	770	770	770
Test sample	RMSE	270,632.17 (+3.0%)	303,811.29 (+1.3%)	254,972.07 (+1.7%)
	MAE	377.97 (+8.1%)	386.97 (+6.9%)	372.97 (+7.9%)
	Moran's I	0.1175520	0.1605040	0.0895514
	N	193	193	193

Source: Authors. Note: Variables significant at α = 0.01, except *: α = 0.05.

ficient indicates that almost 90% of price variations can be explained by the variables included in the model.

4.3. Models at the second level of complexity

Next, alternative models using weighted distances and neighborhood determined with error modeling are presented at two scales (Neighborhood-E and Local-kNN). Three models were generated, progressively incorporating location variables (Table 6). The first includes Neighborhood-E (Model 4), the second incorporates weighted distance variables (Model 5), while the third adds to these three the Local-kNN variable (Model 6).

The coefficients of the variables are similar from one model to another, and the overall results are also similar. The initial model evaluation parameters, R^2 and F, indicate that the models are suitable. The signs and values of the coefficients are consistent with expectations and the first-level models. Although the error level measured by RMSE and MAE, is slightly higher in the test models, it can be concluded that the models do not have problems in this issue.

The location variables show coefficients and signs consistent with expectations (positive for Neighborhood-E and Local-kNN, and negative for weighted distances). There is stability in the coefficients from one model to another. Based on these results, the models can be considered satisfactory.

The coefficients for Commerce in models 5 and 6 are higher than those of the initial models (2 and 3). Conversely, for Park, the coefficients are similar. However, a direct comparison cannot be made since weighted distances are involved here (Table 4 shows the differences in the means of these variables). If a direct comparison is desired, an alternative is to normalize the three measures to a common interval, such as [1-10], transforming them into indices but losing the physical reference of distance.

The results for the training and test samples are similar, ruling out the possibility of overfitting. For the second-level models, Moran's I do not indicate spatial correlation, but there are reasonably higher values for the test data.

Table 6. Result of models with alternative location variables (dependent variable: Ln(Price)).

Attributes		*Model 4*	*Model 5*	*Model 6*
Intersection		11.042742	11.508040	11.148211
Area		0.002385	0.002372	0.002384
Bedroom		0.142306	0.143130	0.144285
Bathroom		0.112631	0.108601	0.105705
Parking		0.257036	0.256736	0.256645
Penthouse		0.100017	0.108687	0.108715
Elevators		0.240248	0.239672	0.248087
Month²		$8.41*10^{-5}$	$8.21*10^{-5}$	$8.01*10^{-5}$
Neighborhood-E		0.055720	0.046151	0.045845
Commerce		-	-0.137610	-0.109840*
Park		-	-0.070760*	-0.067070*
Local-kNN		-	-	0.061709
Training sample	R^2	0.875252	0.876354	0.897412
	F	~0	~0	~0
	RMSE	261,157.49	261,750.97	257,747.22
	MAE	348.48	349.46	347.52
	Moran's I	0.0702365	0.0730797	0.0563623
	N	770	770	770
Test sample	RMSE	267,494.19 (+2.4%)	266,214.52 (+1.7%)	271,084.02 (+5.2%)
	MAE	376.14 (+7.9%)	376.98 (+8.2%)	378.02 (+8.8%)
	Moran's I	0.1121580	0.1223300	0.0839717
	N	193	193	193

Source: Authors. Note: Variables significant at α = 0.01, except *: α = 0.05.

4.4. Models for the third level of complexity

Subsequently, alternative models were developed with machine learning (distances with fuzzy logic) and geostatistics (neighborhood calculated with kriging). The resulting models are presented in Table 7 (models 7 and 8).

The basic parameters used for model evaluation (R^2, F, RMSE, MAE), as well as Moran's I analysis, indicate good results. The coefficients of the variables show signs and values consistent with the previous models. Additionally, the results for the training and test samples are similar, with a slight increase in error levels (3 to 4% for RMSE and about 7% for MAE). It can be concluded that the models are suitable by these criteria.

In general, models 7 and 8 show slightly better results than the initial and intermediate level models. For example, the determination coefficients exceeded 90% for these models.

5. DISCUSSION

The data sample is relatively diverse and poses challenges for generating a single model. It cannot be precisely classified as a mass appraisal, but the sample size is significant and allows for some insights for use with big data. In this context, the presented results can be deemed appropriate.

The produced hedonic models include a stable set of common variables with quite similar results among the models in terms of coefficient values and statistical significance. All variables are significant at levels often adopted in the cited literature (α = 0.01 or α = 0.05). This surpasses the requirements of the Brazilian property appraisal standard, which stipulates α = 0.10 as the minimum threshold for classifying evaluations in the highest quality grade of this standard. Thus, the presented models could even be used in professional activities in this sector (ABNT, 2011; Dantas, 2012; González, 2003).

In general, the presented models were similar in determination coefficient and error parameters (RMSE, MAE). Homoscedasticity, normality, and other conditioning analyses were not presented but were conducted, with results approving the models. Spatial correlation tests also indicate the good performance and suitability of the models. Results from the reserved sample test offer a relative assurance of no overfitting, meaning there is potential for generalization in the models. One

Table 7. Results of the models with advanced (macro and micro) location variables (dependent variable: Ln(Price)).

	Attributes	*Model 7*	*Model 8*
	Intersection	11.348717	11.019981
	Area	0.002357	0.002378
	Bedroom	0.142816	0.144896
	Bathroom	0.256539	0.256448
	Parking	0.112713	0.106633
	Penthouse	0.100957	0.100897
	Elevators	0.238955	0.250131
	$Month^2$	$8.00*10^{-5}$	$7.19*10^{-5}$
	Neighborhood-E	0.053517	0.051674
	Fuzzy-Commerce	-0.073901*	-0.080903*
	Fuzzy-Park	-0.065351*	-0.071380*
	Local-kriging	-	0.075482
Training sample	R^2	0.902623	0.918551
	F	~0	~0
	RMSE	247,809.61	243,331.33
	MAE	318.02	316.54
	Moran’s I	0.074836	0.0592868
	N	770	770
Test sample	RMSE	255,694.07 (3.2%)	253,286.94 (4.1%)
	MAE	340.92 (7.2%)	338.46 (6.9%)
	Moran’s I	0.105896	0.0665885
	N	193	193

Source: Authors. Note: Variables significant at $\alpha = 0.01$, except *: $\alpha = 0.05$.

could say there is a statistical balance. Naturally, there is a dependence on the employed data, and the results are connected to a specific case, delimited in time and space.

The goal of the work was to demonstrate the use of techniques with an objective character and compare them with the traditional option, which is subjective. In this sense, the balance of results between models is promising, as unconventional techniques require fewer human resources and offer more reproducibility, ease of updating, and teamwork facilitation, besides expanding the possibility of justifying calculation parameters for taxation and other applications.

For example, comparing models containing the variable Neighborhood-A (models 1 and 3) and the variable Neighborhood-E (models 4 to 8) reveals minor differences. One can consider an advantage of the objective variable, which can be obtained and updated more quickly (actually within a few minutes of analysis) and independent of deep personal technical knowledge about the market context under study.

Although they require some processing time, the advantage of Local-kNN and Local-kriging variables is measuring neighborhood effects in more detail, considering existing variations within neighborhoods. These variables are generated for a broad space and can be used in different situations, with only periodic updating. In other words, the processing time is diluted by the reuse of generated numerical surfaces.

The variables used to measure accessibility, considering distances to trade elements and urban parks, were significant, with balanced coefficients and contributions to the models. In the presented case, weighted variables did not reveal significant contributions compared to the traditional option. Since they must be generated for each study sample, considering the processing time, their use should be evaluated case by case.

Looking ahead, the proposed methodology holds significant potential for adaptation and application in diverse real estate markets or geographical contexts. Its capacity to incorporate various layers of location variables, including those derived from machine learning and geostatistics, makes it flexible for different urban environments and market conditions. The use of objective and easily generated variables, such as accessibility and neighborhood quality, can facilitate the mass appraisal process in other regions, especially in areas where traditional data may be sparse or challenging to obtain. Furthermore, the methodology’s robustness, demonstrated through solid statistical performance, suggests it could be applied to evaluate emerging real estate markets, offering industry professionals valuable insights into property pricing dynamics in evolving urban landscapes.

A sensitivity analysis could be developed aimed at checking the robustness of the data obtained by varying key input variables, model assumptions, and data sampling methods. By examining how price predictions change with these variations, the analysis ensures consistency and reliability across different techniques, confirming the methodology's applicability and generalization to real estate valuation.

There are some possible limitations on presented research. While the research demonstrates the effectiveness of the proposed methodology, its limitations include potential data constraints and the challenge of integrating diverse variables across different regions. Future developments could focus on testing it in different contexts (other cities or countries.

6. CONCLUSIONS

The location of a property is a crucial factor in the real estate market. In simple terms, the quality of location can be divided into two parts: accessibility (as a "macro" location, at the city or neighborhood level) and local neighborhood (a "micro" level, related to the quality of the immediate surroundings of each property).

Traditional measures have some limitations, and this study proposes alternatives. In summary, three sets of location variables were compared. At an initial level, traditional variables were employed. At the intermediate level, variables based on statistics and kNN were adopted, while the advanced level employed machine learning and geostatistics.

The comparison was based on a sample of over 960 cases, with good statistical performance for all presented models, from various perspectives. The balance of models with traditional variables with models developed with other techniques is considered an advantage for the more objective ones, which provide more detailed information for accessibility measured through distances and require less time to generate neighborhood variables. This suggests that the methodology not only produces consistent results but also yields well-qualified models that can be relevant for industry professionals.

Additionally, the statistical analysis revealed that models based on near-neighborhood variables (Local-kNN and Local-kriging), which have a higher degree of innovation, showed strong qualifications for statistical performance. These variables have a continuous spatial variation surface, a detail that is hardly obtainable without an objective data analysis.

Objectivity is important for promoting mass appraisal models, considering the effort required to generate variables that are not directly observed, such as location. In summary, the results indicate the viability of the methodology in using objective variables to measure accessibility and evaluate neighborhood quality, while emphasizing the ease of creating price models.

Ultimately, the methodology shows potential for adaptation to various real estate markets. Its flexibility, incorporating machine learning and geostatistics, allows it to be applied in different urban contexts with limited traditional data. The robust statistical performance suggests that it can assess emerging markets, offering valuable insights into price dynamics and supporting mass assessment efforts.

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Filling the old with new life. Application of original indicators for evaluating ecovillages as village repopulation initiatives

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Abstract. The recently intensified trend of centripetal movements from small to bigger centres has multiplied the number of inhabitants of large cities. In Italy, this has resulted in worrying figures: more than 70% of Italian Municipalities have less than 5,000 inhabitants. Despite several regional and national policies dedicating programs and funds to counteract this progressive phenomenon fostering the repopulation of abandoned villages, this trend is far from being halted. Though the functional gap between cities and villages is evident, this study and previous research on this theme aim to change the perspective on the possible uses and repopulation processes of villages, pivoting on their potential as places where to enjoy different lifestyles. The focus is on the ecovillage model, developing a set of specific indicators to individuate them through their peculiar aspects and assess their benefits and vulnerabilities. An experimental application is also proposed on 7 ecovillages. This set of indicators is not conceived as completely substitutive of those used in current policies, but rather as a suggestion of possible integrations to avoid demoting this category of villages in policy-related evaluations for funding allocation.

Keywords: indicators, inner areas, ecovillage.
JEL codes: I31, P25.

1. INTRODUCTION

In Europe, Italy has the most significant percentage of "small towns" or villages, also known as *borghi*. Italian Law 158/2017 defines a small town (*piccolo comune* in Italian legislation) as any municipality with less than 5,000 residents. These villages make up a remarkable 69.85% of all Italian municipalities, housing 17% of the population, that is, nearly 10 million residents. One more inhomogeneity is associated with the relevant presence of cultural heritage and museums within them: despite their small size, 31.1% of cultural artifacts and 32.8% of museums are located there (Rossitti and Torrieri, 2022a). This is naturally related to the stratified and articulated history of Italian regions and areas, with each of these villages having much more relevance in the overall context in the past.

Since the early 1900s, a large-scale migration has occurred from these villages to larger cities. Many villages are at risk of abandonment, with a growing average age and only 15.7% of residents under 40 (Rossitti and Torrieri, 2022b).

This depopulation puts a strain on both the villages and the larger cities struggling with overcrowding. For these reasons, these issues have placed an accent on the need to reverse this trend, by allocating funds and triggering individual and collective actions (Acampa and Parisi, 2021). However, impacting on these dynamics can be inspired by different goals and thus be structured in different ways. On the one hand, focusing on the material aspects of a village, that is, its architectural and cultural heritage, and its reconstruction may end up prioritizing tourism (Acampa et al., 2020) rather than the recovery of a collective identity, which follows different and more articulate processes.

Most of the initiatives launched by local and national administrations are noticeably more oriented in this direction:

- The 1 Euro Houses Project, a program that allows people to buy houses in some villages, most of them at risk of abandonment and in a poor economic state, for just 1 euro, provided they renovate the property and potentially start a local business. While initially popular, unofficial reports suggest it may not be as successful as hoped;
- The National Strategy for Inner Areas (NSIA), a wide program that aims to support development in rural areas in the overall Italian territory, was launched in 2013 by the Agency for Territorial Cohesion and focuses on the so-called Inner Areas, marked by higher levels of depopulation and lower economic levels (Rossitti et al., 2021);
- The National Recovery and Resilience Plan (NRRP), launched in 2021, consists of a wider set of actions and structural interventions to support Italy's post-pandemic relaunch. One of its sections, the National Plan for Villages (*Piano Nazionale Borghi*), is specifically dedicated to funding small villages (Germano and Lizzi, 2024).

On the other hand, some initiatives are driven by different principles, that is, to reconstruct a new identity beyond or regardless of the initial material heritage of the villages. These are often started by residents, former residents, or stakeholders who want to preserve their villages' identity and way of life. In some cases, a different and recurring typology of initiatives emerges. This alternative kind of initiative is based on the discovery and valorisation of new lifestyles in villages, rooted in the values that they can realize and are more difficult to find in cities. Spirituality and community cohesion play a bigger role in this: smaller, isolated places immersed in nature are an advantageous opportunity to rediscover a new paradigm of life, which can complement the typical values of urban contexts. In particular, this refers to ecovillages, a recurring repopulation model that is now spread in Europe in and beyond historical villages. In previous stages of this research, this model has been defined and codified, and indicators were developed to identify them among village repopulation initiatives through a score-based methodology and assess their benefits for residents and for the wider regional territory where they are located as well as their vulnerabilities. In this paper, the set of indicators is integrated with additional categories rooted in the concepts of social generativity and psychological well-being, which can help understand the manifold dimensions to be encompassed to perform a correct evaluation of these contexts.

Finally, the indicators are applied to 7 ecovillages to demonstrate their use and assess the procedural difficulties within their implementation.

2. MATERIALS AND METHODS

2.1. Literature review on ecovillages and village regeneration

An ecovillage can be defined as "an intentional community with a manifold approach to economic, environmental, and social sustainability" (Losardo, 2016). They are small settlements pursuing several dimensions of sustainability, attempting a more "human" lifestyle, thus often encompassing transversal values, such as spirituality, above all. When newly founded, their establishment and development follow a typical and characteristic process: after the acquisition and purchase of an uninhabited or scarcely habited location by an intentional community, which settles there, self-construction and self-production are employed to achieve self-sufficiency and self-sustainability; together with the autonomous reconstruction of uninhabitable households, this new lifestyle produces new attractiveness, which leads to forms of one-day tourism and small-scale hospitality, enhanced by the organization of cultural, spiritual, and educational activities.

The literature review on ecovillages focused on:

- determining the state of the art regarding the awareness of their diffusion in the national and international scene;
- exploring the formulation of indicators for the regeneration of villages and the employed methodologies;

– verifying the presence of specific indicators for ecovillages and their purposes.

For this reason, the following search queries have been performed on the Scopus platform:

– Search 1 – “ecovillage,” 143 results;
– Search 2 – “village” AND “regeneration” AND “indicators,” 22 results (11 excluded);
– Search 3 – “village repopulation,” 19 results (4 excluded);
– Search 4 – “ecovillage” AND “indicators,” 9 results (1 excluded).

Analysing the keywords employed in the 143 results from the first search provided an overview of the most discussed themes regarding ecovillages. In particular, except for “ecovillages” (used 54 times), “ecovillage” (used 26 times), and “ecovillage” (used 10 times), the top 5 keywords by the number of uses are “sustainability” (35 times), “sustainable development” (24 times), “intentional communities” (13 times), “ethnography” (9 times), and “social movements” (8 times). The first two keywords show a strong emphasis on the opportunity for sustainability arising from these contexts. Some recent articles (Nogueira et al., 2024) describe them as laboratories for social innovation, leading to sustainable development (Sherry, 2019), proving their contribution to the fulfilment of Sustainable Development Goals (de Souza et al., 2023). Socio-pedagogical aspects also appear in other works (Cisek and Jaglarz, 2021; Papenfuss et al., 2019), along with a focus on the benefits of these contexts for several other aspects, such as experiencing nature (Brombin, 2019) and the development of collective identity (Ulug et al., 2021). Ecovillages have been more frequently discussed in the scientific literature in the last few years – a peak of 8 articles was recorded in 2018 (Grinde et al., 2018; Henfrey and Ford, 2018; Ilieva and Hernandez, 2018; Moravčíková and Furjeszova, 2018; Sala and Casazza, 2018; Schafer et al., 2018; Ucok Hughes, 2018). Ecovillages are generally perceived as a chance to experiment with new and more sustainable lifestyles, which can allow mankind to better adapt to contemporary needs for sustainability, starting from the small scale and possibly expanding beyond the borders of episodic initiatives.

One of the most pertinent contributions that have emerged from the analysis is a 2018 work from Iran (Barani et al., 2018), which explored existing ecovillages throughout several countries to determine the extrinsic and intrinsic characteristics leading to the successful implementation of their settlement model and its associated sustainability. This led to the formulation of 10 criteria and 119 indicators; one more interesting aspect is the characterization of each criterion as a transferable (saving energy and resource mechanisms and effective transportation systems; self-reliance and support of the local economy; water and wastewater management; waste and scrap management; human development and capacity building; foresight) or non-transferable strategy (protection and conservation of the environment; provision of appropriate and sustainable habitats; social, individual, and spiritual capital; healthy physical and spiritual lifestyle). Non-transferable criteria encompass both the aspects related to the environmental capital in the place where ecovillages are set and aspects representing the effects and consequences of the settlement model; for example, this latter sub-group includes physical and mental health, whose high levels are observed in ecovillages as a consequence of specific choices and virtuous practices. Instead, transferable criteria refer to the management choices, the systems adopted for energy saving, and the ways through which self-sustainability and self-sufficiency can be achieved.

In Italy, research has been conducted on heterogeneous aspects: one of the most recent works (Pignatelli et al., 2023) outlines indicators to distinguish between different typologies of villages in inland areas to support optimal decisions for regeneration interventions, with a subdivision into “peripheral mountain municipalities”, “peripheral mountain municipalities in significant shrinkage”, and “belt municipalities in growth”. Some articles explicitly address the issue of “repopulation” (Bascherini, 2021; Amodio, 2022), with criticism of stylistic restoration interventions that do not produce changes and improvements in a hamlet’s social fabric, thus without altering the dynamics behind its depopulation.

Additional Italian research works are particularly pertinent to the reflection developed in this article: the case of Ingurtosu, in South Sardinia (Fiorino et al., 2020), an abandoned town where two historic buildings were reconstructed, yet no repopulation was triggered; the tourist attractiveness of cultural festivals in Vernazza, Liguria (Napoleone, 2020), showing that the valorisation of the immaterial heritage produces higher effects than for the material heritage; the TripAdvisor-based analysis of the artistic redevelopment in the towns of Satriano, Braccano, Cibiana, Orgosolo, Dozza, and others (Manuele, 2020), which reveals that the practice of murals mostly produces short visits, unable to revitalise the hospitality sector.

Finally, a particularly interesting work (Lauria and La Face, 2018) attempts to identify resilience indicators for small towns. This set of indicators assesses the characteristics of their fragility and evaluates the effects of regeneration interventions by introducing scales to monitor their results.

As one last note, the presence of ecovillages across Italian regions has been surveyed, detecting the promi-

Table 1. List of Italian ecovillages in abandoned villages in Emilia Romagna, Liguria, Tuscany, and Umbria, indicating region, village, and year of establishment.

Region	Village	Year
Emilia Romagna	Montefreddo di Tredozio	2015
Emilia Romagna	San Pietro in Cerro	1992
Emilia Romagna	Castel Merlino	2010
Emilia Romagna	Mogliazze	1970
Emilia Romagna	Coli	2004
Liguria	Torri Superiore	1989
Liguria	Cascina San Michele	2017
Liguria	Erli	1980
Tuscany	Campanara	1985
Tuscany	Sambuca Pistoiese	1980
Tuscany	Upacchi	1990
Tuscany	Buonconvento	2018
Tuscany	Tresana	2021
Tuscany	Sommo Ripola	2015
Tuscany	Ancaiano	1979
Tuscany	Tertulia	2012
Tuscany	Mezzana	2020

nence of this settlement typology in three main Regions: Emilia-Romagna, Liguria, and Tuscany. A list is reported in Table 1.

2.2. Typologies of village regeneration interventions

The literature analysis, in addition to the measures reported in the National Plan for Villages and the National Strategy for Inner Areas, has led to the drafting of a comprehensive table of the most frequent interventions adopted by local policies and national plans for the regeneration of small villages. Table 2 below reports on this.

Most regeneration interventions aim to fill a functional gap between towns and cities, create new elements for attractiveness, enhance services for citizens, restore the past history of the settlement and its traces, and provide amenities for tourists to increase interest and visit time.

2.3. Indicators in national Italian policies for village regeneration

The Italian government has initiated two major programs aimed at revitalizing small towns across the country: the National Strategy for Inner Areas (NSIA) and the National Plan for Villages. The NSIA, launched by the Agency for Territorial Cohesion in 2013, is an ongoing strategy that aims to promote and protect the assets and local communities of "Inner Areas." It encompasses a wide range of initiatives aimed at enhancing natural and cultural resources, creating new employment opportunities, and improving essential services such as education, healthcare, and mobility in 72 designated "Inner Areas" throughout Italian regions. The National Plan for Villages includes two distinct intervention lines. The first line, Line A, focuses on funding regeneration strategies in 21 villages, each selected by one of the Italian Regions and Autonomous Provinces. The second line, Line B, provides funding for 229 villages selected through a national tender. The two lines differ in their selection criteria, the types of villages they target, and the amount of funding allocated to each village. Line A targets "villages at risk of abandonment or already abandoned," with each village receiving €20,000,000 in funding. In contrast, Line B targets "historical villages with a population below 5,000 inhabitants," providing them with €1,600,000 in funding. The distinction in targeting and funding amounts suggests that Line A focuses on comprehensive regeneration efforts, including infrastructure and community revitalization, while Line B mainly emphasizes restoration interventions on buildings with historical significance, additional service implementation, and support for commercial activities to mitigate the lack of services and maintenance in small villages. Overall, these initiatives represent a concerted effort by the Italian government to address the challenges faced by small towns and villages and to support their sustainable development.

In the NSIA, indicators are utilized to determine the specific areas that require intervention. This process involves an initial desk phase followed by a more detailed on-field phase. The indicators consist of 161 elements classified into nine sections: Main characteristics, Demographics, Agriculture and sectoral specialization, Digital divide, Cultural heritage and tourism, Health, Accessibility, School, and Cooperation among municipalities. A recent study (Rossitti et al., 2021) has pointed out some limitations in this approach, including challenges related to data collection and quantitative comparisons. Furthermore, the approach towards evaluating cultural heritage primarily based on its potential for tourist attraction disregards its intrinsic and intangible values.

In the context of the National Plan for Villages, the fulfilment of the priorities in the NRRP is appraised using 14 common indicators as specified by delegated Regulation 2021/2106. These indicators are applied to assess proposals in each of the Plan's Measures and Tasks according to a detailed methodology. The indicators used for the National Plan for Villages include "1—

Table 2. List of interventions for village regeneration with description and most frequent outcomes in the centres where they have been carried out.

Intervention name	Description	Effects
Conservative restoration	Restoration of historic buildings with core functions in the original settlement to preserve heritage and restore the sense of identity within the population that has left the village.	When performed alone, it does not produce significant changes; however, it serves as the precondition for restoring a generally acceptable state of conservation in the villages and is combined with other strategies, such as functionalisation.
Diffused Hotel	Restored households and former public buildings are used for hospitality, and a central administration manages the houses throughout the town.	When established, it often represents a driving force for the local economy, primarily commercial and food businesses. Accessibility is a crucial factor.
Artistic redevelopment	Open-air artworks are realised in the town, often by volunteering artists or through local funding. The most frequently chosen medium is murals.	Tourism within the town is generally triggered, primarily through good communication strategies. However, due to the short visit time, local businesses scarcely benefit from it.
Musealisation	Realisation of punctual or diffuse museums, often monographic and related to major aspects of the town's history and art.	Preservation needs mostly trigger these interventions, but the results are hardly successful and economically detrimental due to the management costs.
Services to citizens and tourists	Refunctionalization of historic buildings to realise punctual services for the village's community, increasing local equipment.	This is the most frequent intervention in the NSIA. Most transformations have only been planned; when co-designed with the community, the new spaces are generally well-accepted.
Support to local businesses	Fund allocation for the start of new businesses in villages, hiring local professionals and workers.	This strategy has proven successful, especially for primary-sector businesses, recalling the original vocation of most villages. Instead, its inclusion in the buying conditions of the 1 Euro Houses Projects has yet to produce results.

Savings in annual primary energy consumption" and "9—Number of enterprises supported". However, this priority structure presents challenges.

Indicator 1 assesses the total energy savings achieved, which depends on the number of inhabited households and buildings where energy efficiency interventions are implemented. This may disadvantage villages experiencing depopulation, as the number of inhabited buildings suitable for intervention is lower. Hence, villages with a population closer to the threshold of 5,000 inhabitants may receive an advantage compared to those with lower population numbers, despite facing a higher risk of abandonment.

Similarly, Indicator 9 is subject to the same challenge as Indicator 1 due to the correlation between a village's population and the number of enterprises. Additionally, the generic nature of the NRRP's common indicators results in the exclusion of non-profit enterprises, a key driving force in village regeneration, which is explicitly not accounted for in the total number of supported enterprises.

The criticalities of these indicators are not strictly supposed to directly affect the decision-making processes behind the choice of the villages within Line A: this selection is performed by each Region and Autonomous Province without any approval by the central administration and according to internal selection processes. Even so, Indicators 1 and 9 have been proposed as criteria for choice; thus, it can be deemed that regional and provincial administrations have considered them when selecting the villages for funding. Moreover, this is confirmed by the distribution of the intervention modalities throughout the 21 local projects, as shown in the following. Instead, they directly affect the selection of projects in Line B; as shown in Table 3, the distribution of their allocation is heavily unbalanced with respect to the number of "small towns" in each Italian Region.

3. CASE STUDY EXPERIMENTATION

The traditional approach to selecting indicators for assessing a context or phenomenon for funding allocation or simple monitoring involves identifying common aspects to standardize different realities. The previous discussion aimed to emphasize the distinctive characteristics of ecovillages compared to other settlements and their incompatibility with the approach that is implicitly embodied in traditional indicators of national and local policies. For this reason, the apparent "transversality" of those indicators alters the perception of these contexts, turning their autonomous and self-sufficient economy into a flaw due to the lack of economic profit and the non-standard entrepreneurial form. Though indicators

Table 3. Funding allocation (A), number of small towns (<5,000 inhabitants) (B), and funding/number of small towns ratio for each Italian region in Line B of the National Plan for Villages (C).

Region	A (€)	B	C (€)
Abruzzo	5,469,692.84	253	21,619.34
Aosta Valley	2,708,640.22	73	37,104.66
Apulia	47,681,122.69	88	541,830.90
Basilicata	8,651,427.42	107	80,854.46
Calabria	27,925,095.53	325	85,923.37
Campania	61,637,928.16	344	179.180,00
Emilia-Romagna	31,878,591.92	135	236.137,70
Friuli Venezia Giulia	11,494,886.58	153	75.129,98
Latium	53,221,031.32	255	208.709,90
Liguria	16,924,652.18	185	91.484,61
Lombard	54,583,091.06	1,039	52.534,26
Marche	17,153,940.94	160	107.212,10
Molise	3,542,153.20	128	27.673,07
Piedmont	43,768,364.10	1,045	41.883,60
Sardinia	20,461,967.79	316	64.753,06
Sicily	64,900,612.37	212	306.135,00
Tuscany	35,987,678.55	119	302.417,50
Umbria	12,657,812.98	63	200.917,70
Veneto	48,148,148.14	291	165.457,60

should be based on a neutral and standardized formulation to evaluate multiple alternatives, those proposed here stand as complementary to correctly take into account the peculiarities of ecovillages. The established logic, rooted in urban development and performance (Acampa and Pino, 2023), should be modified or partially rethought to accommodate their significantly different principles. Consequently, valid indicators should emerge from an understanding of the specific advantages of ecovillages and the aim to address their inherent and external weaknesses and requirements.

This line of thought has led to the development of the following indicators:

– Benefit indicators: assess the positive aspects of the subject under evaluation.
– Risk indicators: evaluate the extent of vulnerabilities and risks faced by the subject under evaluation.

It's important to note that this is not a risk-benefit analysis where risks and benefits are compared to determine the desirability of a choice or scenario. In this case, the objective is different: benefit indicators identify desirable qualities that need to be preserved and enhanced, acting as benchmarks to identify contexts where the described pattern generates such positive environments. Conversely, the risk indicators can be utilized to gauge the extent of funding required and could be beneficial for public administration in tailoring appropriate measures. As a result, the two sets of indicators are not intended to be interconnected or to imply a trade-off evaluation.

3.1. Benefit indicators

The categories of benefit indicators have been chosen based on the principle of identifying areas where urban contexts lack certain features. The first inspiration has derived from the analysis of the Italian Index of Equitable and Sustainable Well-Being (BES, *Benessere Equo e Sostenibile*), promoted by ISTAT (Bruni and Mazzantini, 2018). Its avant-garde peculiarity resides in the goal of estimating non-economic factors to determine the state of progress of a country, thus encompassing 12 categories: Health, Education and training, Work and life balance, Economic well-being, Social relationships, Politics and institutions, Safety, Subjective well-being, Landscape and cultural heritage, Environment, Innovation, research and creativity, Quality of services (Chelli et al., 2015). Generally, almost all indicators have been showing good results and have been increasing since 2010. However, the only category with poor values is Social relationships: out of 9 survey items, five report results below 33% (less than one-third of the population above 14 answered positively). In detail, these correspond to Satisfaction with family relations (32.6% in 2022), Satisfaction with friend relations (21.6% in 2022), Social participation (25.4% in 2022), Volunteering activity (8.3% in 2022), and Generalised trust (24.3% in 2022). Therefore, these topics, which point out a general criticality in traditional societies, can be used to evaluate the social satisfaction of the community within the proposed indicators. Indeed, social satisfaction serves as a precondition to ensure that values are shared within the community and are easily transmitted to visitors (Weijis-Perrée et al., 2017). Specifically, they are evaluated through the corresponding five items (later indicated as SR1, SR2, SR3, SR4, and SR5 respectively):

– "How do you consider your satisfaction toward family relationships?";
– "How do you consider your satisfaction toward friends' relationships?";
– "In the last 12 months, have you participated in social activities, such as meetings or initiatives promoted by religious or spiritual groups, meetings of cultural associations or similar organizations?";
– "In the last 12 months, have you carried out free activities for associations or volunteering groups?";
– "How much do you consider people trustworthy, in general?".

The second category of benefit indicators is associated with the principle of social generativity, defined as “a distinctive social phenomenon apt to enlighten the relation between personal development and social change” (Di Fabio and Svicher, 2023) as well as “concern for future generations and contribution to the future of their community” (Slater, 2003). This idea, rooted in behavioural psychology, expresses strong assonance with the ideological foundations of ecovillages: that is, places where the fulfilment of collective benefits is pursued within the community while keeping in mind large-scale goals and ideals to contribute to the whole global society in terms of sustainability and resource preservation (Syamsiyah et al., 2023). A questionnaire-based tool to evaluate social generativity (Morselli and Passini, 2018) was adopted to devise specific indicators in the form of six items (later indicated as SG1, SG2, SG3, SG4, SG5, and SG6 respectively):

– “I carry out activities to ensure a better world for future generations”;
– “I have a personal responsibility to improve the area in which I live”;
– “I give up part of my daily comforts to foster the development of next generations”;
– “I think that I am responsible for ensuring a state of well-being for future generations”;
– “I commit myself to do things that will survive even after I die”;
– “I help people to improve themselves.”

The third category of benefit indicators is associated with Psychological Well-Being. It is worth pointing out that this concept is already quite difficult to frame since it has been subjected to several definitions and oscillates between mental health (Eiroa-Orosa, 2020), “positive functioning” (Burns, 2017), and the presence of positive feelings (Stoll and Pollastri, 2023). However, it was selected as the third area of benefit indicators because it has been envisioned as a way to evaluate the positive influence of inhabiting and visiting ecovillages without explicitly specific purposes and goals and considering the individual’s psychological health as a useful, 360-degree benchmark instead. Moreover, the Ryff Scale (Ryff, 1989) seemed particularly suitable for this purpose. Ryff introduced a scale based on six factors: Autonomy, Environmental Mastery, Personal Growth, Positive Relations with others, Purpose in Life, and Self-Acceptance. Each represents a different dimension of psychological well-being and is evaluated through a distinct set of 3-to-7 items (specifically, the test can be administered in a longer 42-item version or in a shorter 18-item version).

3.2. Risk indicators

Risk indicators are, instead, associated with the vulnerability of the places where ecovillages are located. These places share all the typical characteristics of villages in a state of abandonment or at risk of abandonment: they are far from main centres and are often situated in non-convenient places, with morphological and orographic accessibility issues, such as being on a high mountain. These natural problems are compounded by those brought about by some intrinsic aspects of the lifestyle of ecovillages: for example, they tend to avoid employing electric systems or networks as well as sharing water networks with nearby cities and villages. In case of local problems with the obtainment of resources, this represents a weakness. Moreover, self-sufficiency lifestyles allow little redundance, thus hindering resilience: often, their connections with the outside are strongly limited or interrupted by phenomena such as floods or landfalls, requiring costly interventions to restore viability. This is generally solved through fundraising; however, the vulnerability within these dynamics is evident.

For this reason, it was chosen to introduce risk indicators as signals of the intrinsic issues within ecovillages, with a double function:

– on the one hand, as a tool to quantify the right to fund allocation of each place, based on their actual needs, which deeply differ from those in regular repopulated villages;
– on the other hand, to differentiate territorial contexts depending on the opportunities they provide for the successful and more resilient establishment of ecological villages. This can help driving settlers’ choices.

These risk indicators have been drawn from a wider research work on indicators for villages’ resilience that was individuated in the literature (Lauria and La Face, 2020), introduced in the previous paragraph. These indicators are subdivided into 8 categories (Natural/Environmental, Socio-Political, Financial, Human, Physical, Maintenance, Regeneration/Valorisation, and Development). They have several purposes and refer to heterogenous contexts and moments of their development. Moreover, many of them are not applicable to ecovillages, for the reasons that have been widely discussed in the previous paragraphs: for example, the Development category has indicators such as “Support to business creation” or “Adoption of network and emerging technologies for digital economy”, which would result non-coherent with what is analysed in the approach of the present work; moreover, the mentioned benefit indicators already allow a detailed survey of the positive aspects of these peculiar contexts. Instead, a complementary support to this set of indicators has been found in the "Natural/Environmental" and "Physical" categories, which respectively reflect the intrinsic natural risks in the place, due to the history of calamities, geology, morphology, and similar aspects, and the physical characteristics of the settlement typology, based on the state of networks with other cities. In detail, the following items were chosen:

- Existence of damage from (current or) expected flood (Natural/Environmental);
- Frequency of forest fire (Natural/Environmental);
- Quality of transport systems (Physical);
- Presence of water networks (Physical);
- Presence of electric networks (Physical).

3.3. Experimentation

A questionnaire comprising all the items of the benefit indicators has been sent to all ecovillages in the Italian RIVE (*Rete Italiana di Villaggi Ecologici*, Italian Network of Ecological Villages), requesting all inhabitants and visitors to answer to answer it. The request was sent by using the e-mail addresses reported in the profile pages of each ecovillage; thus, it was received by the administrators of ecovillage public relations services and presumably forwarded to all the involved individuals. The total number of ecovillages was 76; however, as was expected, a small number of them provided answers since ecovillages' lifestyle forces them to a very limited use of electronic devices and digital services and scarce familiarity with digital tools. However, a significant number of responses (32) came from an ecovillage with which a direct connection had been developed – Borgo Tutto è Vita, in Mezzano (PO) – and some responses came from other 6 ecovillages: 8 from Comunità rigenerative in Calasca-Castiglione (VCO), 4 from Eco-house in Noto (SR), 4 from Lacasarotta APS in Cherasco (CN), 28 from Lumen in San Pietro in Cerro (PC), 4 from Meraki in Monzuno (BO), and 4 from Shangri-là in Donnafugata (RG). This led to a total of 84 answers, which allowed the evaluation of the scores for the benefit

Table 4. Items of the questionnaire sent to the ecovillages of the Italian Network of Ecological Villages (RIVE).

Tab	Question	Options	Item
General Information	What is your gender?	Male/Female/Other/Unspecified	
	What is your age group?	0-14/15-24/25-34/35-50/51-64/65+	
	Which ecovillage do you visit/inhabit?	Text Input	
	Visit frequency/Residence	I live there/I go there more than weekly/I go there around weekly/I go there less than weekly/I rarely go there	
Social Relationships	How would you rate your satisfaction toward family relationships?	1-10 Scale	SR1
	How would you rate your satisfaction toward friend relationships?	1-10 Scale	SR2
	In the last 12 months, have you participated in social activities, such as meetings or initiatives promoted by religious or spiritual groups, meetings of cultural associations or similar?	Yes/No	SR3
	In the last 12 months, have you conducted volunteering activity?	Yes/No	SR4
	How much do you think people deserve trust?	1-10 Scale	SR5
Social Generativity	I carry out activities to ensure a better world for future generations.	1-7 Scale Agreement	SG1
	I have a personal responsibility to improve the area in which I live.	1-7 Scale Agreement	SG2
	I give up part of my daily comforts to foster the development of next generations.	1-7 Scale Agreement	SG3
	I think that I am responsible for ensuring a state of well-being for future generations.	1-7 Scale Agreement	SG4
	I commit myself to do things that will survive even after I die.	1-7 Scale Agreement	SG5
	I help people to improve themselves.	1-7 Scale Agreement	SG6

(Continued)

Table 4. (Continued).

Tab	Question	Options	Item
Psychological Well-Being	I like most parts of my personality.	1-7 Scale Agreement	SA1
	When I look at the story of my life, I am pleased with how things have turned out so far.	1-7 Scale Agreement	SA2
	Some people wander aimlessly through life, but I am not one of them.	1-7 Scale Agreement	PiL1
	The demands of everyday life often get me down.	1-7 Scale Agreement	EM1
	In many ways I feel disappointed about my achievements in life.	1-7 Scale Agreement	SA3
	Maintaining close relationships has been difficult and frustrating for me.	1-7 Scale Agreement	PR1
	I live life one day at a time and don't really think about the future.	1-7 Scale Agreement	PiL2
	In general, I feel I am in charge of the situation in which I live.	1-7 Scale Agreement	EM2
	I am good at managing the responsibilities of daily life.	1-7 Scale Agreement	EM3
	I sometimes feel as if I've done all there is to do in life.	1-7 Scale Agreement	PiL3
	For me, life has been a continuous process of learning, changing, and growth.	1-7 Scale Agreement	PG1
	I think it is important to have new experiences that challenge how I think about myself and the world.	1-7 Scale Agreement	PG2
	People would describe me as a giving person, willing to share my time with others.	1-7 Scale Agreement	PR2
	I gave up trying to make big improvements or changes in my life a long time ago.	1-7 Scale Agreement	PG3
	I tend to be influenced by people with strong opinions.	1-7 Scale Agreement	A1
	I have not experienced many warm and trusting relationships with others.	1-7 Scale Agreement	PR3
	I have confidence in my own opinions, even if they are different from the way most other people think.	1-7 Scale Agreement	A2
	I judge myself by what I think is important, not by the values of what others think is important.	1-7 Scale Agreement	A3

indicators through statistical analysis. The scores for the risk indicators were instead evaluated through technical data collection and synthesis.

The English translation of each questionnaire item (administered in Italian language) is presented in Table 4.

4. RESULTS AND DISCUSSION

4.1. Analysis of the questionnaire answers

Tables 5-6 report the analysis of the results of the questionnaire, aggregating the items for each of the benefit indicators: Social Relationships (SR), Social Generativity (SG), and the six dimensions of Psychological Wellbeing – Self-Acceptance (SA), Purpose in Life (PiL), Personal Relationships (PR), Personal Growth (PG), Autonomy (A), and Environmental Mastery (EM). A descriptive and a reliability analysis have been performed for each indicator and its items, evaluating the mean, median, and standard deviation (SD) for each item and the mean, standard deviation (SD), Chronbach-alpha, and McDonald-omega for each indicator. Reverse items are marked with an asterisk in Table 5.

4.2. Comparison with known data

Social Relationships items report particularly beneficial values: compared with the already-mentioned values from the 2022 BES Report, all 5 results are higher, converting percentage values into integer numbers on a 1-10 scale:

- SR1: 8.81 > 3.26;
- SR2: 8.87 > 2.16;

Table 5. Descriptive analysis of Social Relationship, Social Generativity, and Psychological Wellbeing items.

	Mean	Median	SD
SR1	8.81	8.75	1.45
SR2	8.87	8.75	1.18
SR3	9.05	10	3.01
SR4	8.10	10	4.02
SR5	7.35	7.14	1.71
SG1	6.48	7	0.98
SG2	6.57	7	0.87
SG3	5.57	6	1.80
SG4	6.24	7	0.99
SG5	5.90	7	1.41
SG6	5.63	5.60	1.36
SA1	5	5	1.38
SA2	5.30	5.60	1.76
PiL1	5.48	5.60	1.78
EM1*	4	4	1.95
SA3*	2.24	2	1.55
PR1*	2.10	1	1.58
PiL2*	2.62	2	1.77
EM2	6.05	7	1.47
EM3	5.53	5.60	1.27
PiL3*	3.29	4	1.95
PG1	6.30	7	1.21
PG2	6.57	7	0.75
PR2	5.80	5.60	1.13
PG3*	2.56	2.33	0.70
A1*	4	4.67	1.67
PR3*	2.62	2	1.80
A2	5.33	6	1.53
A3	5.67	6	1.43

- SR3: 9.05 > 2.54;
- SR4: 8.10 > 0.83;
- SR5: 7.35 > 2.43.

The Social Generativity items values have instead been compared with the values obtained in the experimentation conducted among university students in the city of Florence with the same items, which have been found in the literature (Morselli and Passini, 2015), leading to the following evidence:

- SG1: 6.48 > 4.43;
- SG2: 6.57 > 5.62;
- SG3: 5.57 > 4.31;
- SG4: 6.24 > 5.59;
- SG5: 5.90 > 5.12;
- SG6: 5.63 > 5.06.

In this case, too, all items proved better results than in urban contexts. In particular, the highest difference was found for SG1, over two points. This shows that, despite the general awareness of the need for sustainability-aimed actions, the opportunity of carrying out coherent actions, provided by ecovillages, is particularly rare outside.

Table 6. Reliability analysis of Social Relationship, Social Generativity, and Psychological Wellbeing indicators.

	Mean	SD	Chronbach	McDonald
Social Relationships	8.43	1.37	0.404	0.657
Social Generativity	6.03	0.861	0.753	0.780
Self-Acceptance	5.02	1.26	0.728	0.763
Purpose in Life	4.86	0.921	0.493	0.139
Environmental Mastery	3.83	1.03	0.304	0.389
Personal Relationships	5.36	1.13	0.584	0.665
Personal Growth	5.77	0.528	0.00798	0.344
Autonomy	5.44	1.34	0.831	0.842

The Ryff Scale's results are considered to show psychological well-being if single-indicator values are above sufficiency (4); in this case, this is applied to the mean of each dimension. Compared to others, this does not show remarkable results, instead, surprisingly, the Environmental Mastery indicator has a negative outcome. It can be speculated that the different perceptions of self in ecovillages' lifestyle do not suit the typology of questions in the Ryff Scale. For this reason, it will not be considered relevant to define the benefit ensured by ecovillages.

4.3. Definition of risk indicator values

The values for the five items of the risk indicators have been attributed by adopting the following criteria for each of them, using a 1-5 scale for items with a gradual variation (the first three), considering 1 as a low value of resilience and 5 as connoting a good resilience characteristic, and a 0-1 (absence-presence) scale for the last two, related to the existence or non-existence of networks:

- EN1, Flood damage (1-5 scale): values attributed based on the records of flood in the village or in the area surrounding the village. 1 was assigned if a flood was known to have caused liveability issues in the city, 2 if it had caused accessibility issues, 3 if it had hit the village but had not caused operational issues, 4 if floods were recorded but no effective damage, and 5 if no floods were recorded in the area;
- EN2, Frequency of forest fire (1-5 scale): values attributed to the frequency of news on forest fire in the area of the village, with 1 if over 3 fires per year were recorded, and 5 if none were found;

Table 7. Scores for the Environmental/Natural and Physical risk items.

Indicator	Item	Borgo Tutto è Vita	Comunità rigenerative	Eco-house	Lacasarotta	Lumen	Meraki	Shangri-là
Environmental/Natural	EN1	2	5	4	2	4	1	1
	EN2	2	2	2	4	2	2	4
Physical	P1	3	4	5	3	4	2	4
	P2	1	0	0	1	1	0	1
	P3	1	0	0	1	1	0	0

Table 8. Descriptive analysis for the Environmental/Natural and Physical risk items.

	Mean	Median	SD
EN1	2.71	2	1.600
EN2	2.57	2	0.976
P1	3.57	4	0.976
P2	0.57	1	0.535
P3	0.43	0	0.535

- P1, Transport system quality (1-5 scale): this evaluation was conducted based on the typology and length of road connections to reach relevant urban centres (>20,000 inhabitants). In particular, 1-2 scores have been attributed if a village requires using unpaved roads to reach the main road network, while 3-5 scores have been given if the village is directly connected to provincial/state roads, with higher scores corresponding to lower distances from main centres;
- P2, Presence of water networks (0-1) and P3, Presence of electric networks (0-1): based on direct knowledge from village inhabitants or websites regarding their history, it was determined whether the ecovillages were served by water and electric networks. It must be noted that this item is most often related to voluntaristic aspects of each ecovillage's lifestyle. 0 was attributed in case the networks were absent, while 1 was attributed if they were present.

Table 7 summarizes the results for each item.

Table 8 reports the results of the descriptive analysis of the five items carried out through the Jamovi software. In this case, it was not deemed correct to perform a reliability analysis through aggregation since the items of the same category refer to different natural conditions and settlement choices, not necessarily related to each other.

As expected, the results tend to be low for most items: the means for EN1 (2.71) and EN2 (2.57) are below the average (3), while P1 (3.57) is slightly above average. Finally, the two binary items, that is, P2 (0.57) and P3 (0.43), are around the average, showing that less than half of the tested ecovillages have the availability of electric networks, while almost half do not have water networks.

5. CONCLUSIONS

In the current age, contemporary urban settlements and lifestyles are experiencing a major crisis, which has been mostly interpreted in terms of sustainability, which represents the need to adjust our living standards and habits to suit a longer temporal perspective and a broader view of humanity and their needs as a whole. This is only one side of the problem: another one is represented by the increasing discomfort toward metropolitan, mostly artificial environments, where some vital aspects of people's lives cannot be thoroughly fulfilled. Villages in general, and ecovillages even more, are different players in this equation, leading to questioning the possible contaminations and diversification of contemporary living. However, as it has often been stressed in this paper, the role of villages can be valorised as long as they are considered places with different and complementary characteristics from a topological and morphological perspective: this change must be reflected in national and local policies, keen on capturing the aspects through which their opportunities can emerge the most.

This paper has attempted to perform a step in this direction, by outlining a proposal for possible integrative indicators to adopt in policies – where ecovillages are implicitly disadvantaged, as detailed and iterated – so that their distinctive features and opportunities can be evaluated in a fairer way. The work has pivoted on originality and innovation: on the one hand, focusing on the Italian context and discussing its existing policies provides new insight into this debate, highlighting the discrepancies between the vocation of places and the chosen approaches; on the other hand, the proposal of indicators articulated with a dual aim of proving the benefits of a context and assessing its degree of vulnerability is not common and particularly suitable to allow administrations to correctly ponder the entity of the funding to be allocated for the successful implementation of a specific initiative, for example.

Aside from this, it is worth emphasizing the expected yet non-negligible outcome of the analysis conducted in the seven ecovillages involved in the experimentation. It indeed resulted that those who live or frequently visit ecovillages are characterized by higher satisfaction with Social Relationships than average people. This reflects the most typical nature of ecovillages: they foster close-knit social bonds through shared responsibilities, collaborative projects, and communal decision-making, encouraging trust and cooperation among residents. By prioritizing mindfulness and intentional living, these communities create a supportive social fabric where meaningful relationships and emotional well-being thrive.

The same goes with Social Generativity, and this leads to reflecting on the large-scale effect that these places can produce regarding the global awareness and consciousness of the battles that have to be fought at this moment. In other words, valorising them can easily translate into investing in sustainability. Instead, Psychological Well-Being indicators did not report particularly promising results. Other authors (Temesgen, 2024) who have researched the analysis of psychological well-being in ecovillages highlight an inhomogeneous and discontinuous trend due to the many challenges present when getting used to the different lifestyles of ecovillages. With a wider sample, it might be interesting to analyse the relationship between the number of years spent in an ecovillage or intentional community and the evolution of one's psychological well-being; however, the figures considered here for this experimentation could not allow that. Alternatively, it can be considered that its evaluation through the Ryff scale is not entirely suitable, and different substitutive tools will be tested in future research, such as the PERMA model (Chisale and Phiri, 2022) or the Flourishing Scale (Diener et al., 2009).

Finally, it must be stated that, despite often stressing that the characteristics of these ecovillages cannot be evaluated through traditional economic-based approaches, values, and principles, they can still be regarded in a broader economic dimension – as in the formulation of the Total Economic Value (Plottu and Plottu, 2007), for example. Future research on this topic will cover the economic evaluation of the way in which ecovillages impact territorial dynamics, with their restored capability of actively producing resources and activating new stable processes, which ultimately result in economic benefits to be compared to other territorial and local regeneration models.

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Rassegna giurisprudenziale II semestre 2024

A CURA DI NICOLA LUCIFERO

AGRICOLTURA E PESCA

CGUE, 19/12/2024, C-392/23, *Rustrans SRL*

Rinvio pregiudiziale – Politica comune della pesca – Fondo europeo per gli affari marittimi e la pesca (FEAMP) – Regolamento (UE) n. 1303/2013 – Articolo 69 – Nozione di "spesa ammissibile" – Articoli 4 e 125 – Regolamento (UE) n. 508/2014 – Articolo 48, paragrafo 1, lettera c) – Ammodernamento di un'unità di acquacoltura – Regolamento (UE, Euratom) 2018/1046 – Articolo 33 – Principio della sana gestione finanziaria – Contributo in natura sotto forma di un terreno e di fabbricati presenti su tale terreno – Collegamento diretto tra il contributo in natura e l'operazione finanziata

L'articolo 65, paragrafi 1 e 2, l'articolo 67, paragrafo 1, lettera a), e l'articolo 69 del regolamento (UE) n. 1303/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, recante disposizioni comuni sul Fondo europeo di sviluppo regionale, sul Fondo sociale europeo, sul Fondo di coesione, sul Fondo europeo agricolo per lo sviluppo rurale e sul Fondo europeo per gli affari marittimi e la pesca e disposizioni generali sul Fondo europeo di sviluppo regionale, sul Fondo sociale europeo, sul Fondo di coesione e sul Fondo europeo per gli affari marittimi e la pesca, e che abroga il regolamento (CE) n. 1083/2006 del Consiglio, in combinato disposto con l'articolo 4 e l'articolo 125, paragrafo 1, di tale regolamento, nonché con l'articolo 33 del regolamento (UE, Euratom) 2018/1046 del Parlamento europeo e del Consiglio, del 18 luglio 2018, che stabilisce le regole finanziarie applicabili al bilancio generale dell'Unione, che modifica i regolamenti (UE) n. 1296/2013, (UE) n. 1301/2013, (UE) n. 1303/2013, (UE) n. 1304/2013, (UE) n. 1309/2013, (UE) n. 1316/2013, (UE) n. 223/2014, (UE) n. 283/2014 e la decisione n. 541/2014/UE e abroga il regolamento (UE, Euratom) n. 966/2012, devono essere interpretati nel senso che non rientra nella nozione di «spesa ammissibile», ai sensi di tali disposizioni, un contributo in natura apportato da un beneficiario sotto forma di fornitura di terreni e di fabbricati presenti su questi ultimi ai fini di un progetto di ammodernamento di un'unità di acquacoltura consistente unicamente nell'acquisto di attrezzature, macchinari tecnologici e dotazioni specifiche per un'azienda di allevamento ittico esistente.

CGUE, 17/10/2024, C-239/23, *Karl und Georg Anwander GbR Güterverwaltung*
Indennità a favore delle zone soggette a vincoli naturali o ad altri vincoli specifici – Zone montane – Indennità compensativa – Disposizioni amministrative nazionali che escludono il pagamento di tale indennità per zone ammissibili situate in una regione dello stesso Stato membro diversa da quella in cui ha sede l'azienda agricola – Disposizioni che utilizzano la sede dell'azienda agricola come condizione per la concessione dell'indennità compensativa
1) L'articolo 2, paragrafo 1, secondo comma, lettera b), l'articolo 31, paragrafo 1, primo comma, e paragrafo 2, nonché l'articolo 32, paragrafo 1, lettera a), paragrafo 2, primo comma, e paragrafo 3, secondo e terzo comma, del regolamento (UE) n. 1305/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, sul sostegno allo sviluppo rurale da parte del Fondo europeo agricolo per lo sviluppo rurale (FEASR) e che abroga il regolamento (CE) n. 1698/2005 del Consiglio, come modificato dal regolamento (UE) 2017/2393 del Parlamento europeo e del Consiglio, del 13 dicembre 2017,devono essere interpretati nel senso che essi non ostano a una normativa o a una prassi amministrativa di uno Stato membro e/o di una regione di uno Stato membro che escludono la concessione di un'indennità compensativa agli agricoltori situati in zone montane e in altre zone soggette a taluni vincoli naturali o ad altri vincoli specifici in quanto le zone ammissibili a tale indennità sono situate al di fuori del territorio della regione dello Stato membro il cui programma di sviluppo rurale prevede detta indennità. Per contro, tali stesse disposizioni ostano a che l'ubicazione della sede dell'azienda dell'agricoltore che gestisce la zona di cui trattasi sia utilizzata come criterio per l'assegnazione della medesima indennità.
2) L'articolo 31, paragrafo 1, primo comma, e paragrafo 2, del regolamento n. 1305/2013, come modificato dal regolamento 2017/2393, deve essere interpretato nel senso che da tali disposizioni discende direttamente, ai sensi del diritto dell'Unione, un diritto all'erogazione di un'indennità compensativa agli agricoltori situati in zone montane e in altre zone soggette a vincoli naturali o ad altri vincoli specifici qualora uno Stato membro o una regione di uno Stato membro preveda, nel suo programma di sviluppo rurale, di concedere siffatte indennità per tale tipo di zone.
3) L'articolo 2, paragrafo 1, secondo comma, lettera b), e l'articolo 31, paragrafo 1, del regolamento n. 1305/2013, come modificato dal regolamento 2017/2393, devono essere interpretati nel senso che il diritto all'erogazione di un'indennità compensativa agli agricoltori situati in zone montane e in altre zone soggette a vincoli naturali o ad altri vincoli specifici è esigibile nei confronti dello Stato membro o della regione dello Stato membro di cui trattasi qualora tale Stato o tale regione, quest'ultima indipendentemente da detto Stato membro, abbia deciso di concedere indennità compensative a favore delle zone ammissibili a queste ultime situate sul suo territorio.

CGUE, 04/10/2024, C-240/23, *Herbaria Kräuterparadies II*
Prodotti biologici – Regolamento (UE) 2018/848 – Norme di produzione biologica – Articolo 16 – Etichettatura – Articolo 30 – Termini riferiti alla produzione biologica – Articolo 33 – Logo di produzione biologica dell'Unione europea – Condizioni d'uso – Conformità del prodotto al regolamento 2018/848 – Articoli 45 e 48 – Importazione di prodotti provenienti da un paese terzo per essere immessi sul mercato dell'Unione come prodotti biologici – Equivalenza delle norme di produzione di tale paese terzo con le norme del regolamento 2018/848 – Uso del logo di produzione biologica del paese terzo
L'articolo 30, paragrafo 2, e l'articolo 33, paragrafo 1, del regolamento (UE) 2018/848 del Parlamento europeo e del Consiglio, del 30 maggio 2018, relativo alla produzione biologica e all'etichettatura dei prodotti biologici e che abroga il regolamento (CE) n. 834/2007 del Consiglio, devono essere interpretati nel senso che né il logo di produzione biologica dell'Unione europea né, in linea di principio, termini che fanno riferimento alla produzione biologica possono essere utilizzati per un alimento trasformato importato da un paese terzo alle condizioni previste all'articolo 45, paragrafo 1, lettera b), iii), e all'articolo 48, paragrafo 1, di tale regolamento per essere immesso sul mercato dell'Unione come prodotto biologico, se tale alimento, contenendo minerali e vitamine di origine non vegetale, non soddisfa i requisiti derivanti dal combinato disposto dell'articolo 16, paragrafo 1, e dell'allegato II, parte IV, punto 2.2.2, lettera f), di detto regolamento. Il logo di produzione biologica di tale paese terzo può tuttavia essere utilizzato nell'Unione per un alimento siffatto, anche qualora tale logo contenga termini riferiti alla produzione biologica ai sensi dell'articolo 30, paragrafo 1, del medesimo regolamento e del suo allegato IV.

CGUE, 04/10/2024, C-228/23, *Association AFAÏA*
Produzione biologica ed etichettatura dei prodotti biologici – Regolamento (UE) 2018/848 – Utilizzo di taluni prodotti e sostanze nella produzione biologica e relativi elenchi – Deroga – Regolamento di esecuzione (UE) 2021/1165 – Allegato II – Nozioni di "allevamento industriale" e di "allevamento senza terra"

– Fiducia dei consumatori – Benessere degli animali – Rispetto dell'ambiente e del clima – Criteri
1) L'allegato II, terzo comma, del regolamento di esecuzione (UE) 2021/1165 della Commissione, del 15 luglio 2021, che autorizza l'utilizzo di taluni prodotti e sostanze nella produzione biologica e stabilisce i relativi elenchi, adottato ai fini dell'applicazione del regolamento (UE) 2018/848 del Parlamento europeo e del Consiglio, del 30 maggio 2018, relativo alla produzione biologica e all'etichettatura dei prodotti biologici e che abroga il regolamento (CE) n. 834/2007 del Consiglio, deve essere interpretato nel senso che per quanto riguarda i preparati a base di microrganismi che possono essere utilizzati per migliorare le condizioni generali del suolo o per migliorare la disponibilità di elementi nutritivi nel suolo o nelle colture, l'espressione «proibito se proveniente da allevamenti industriali», utilizzata nella tabella contenuta in tale allegato, non equivale a un divieto dei soli preparati provenienti dagli allevamenti «senza terra», con la precisazione che, conformemente a tale disposizione, i concimi, gli ammendanti e i nutrienti di cui detto allegato vieta l'uso in agricoltura biologica sono quelli ottenuti dall'allevamento industriale e non unicamente quelli provenienti dall'allevamento senza terra.
2) L'allegato II, terzo comma, del regolamento di esecuzione 2021/1165 deve essere interpretato nel senso che esso non osta a una normativa nazionale in forza della quale il divieto di utilizzare, su terreni biologici, concimi e ammendanti di origine animale «provenient[i] da allevamenti industriali» riguarda anche gli effluenti di allevamenti in sistemi fessurati o a griglia integrale e che superano le soglie definite nell'allegato I della direttiva 2011/92/UE del Parlamento europeo e del Consiglio, del 13 dicembre 2011, concernente la valutazione dell'impatto ambientale di determinati progetti pubblici e privati, come modificata dalla direttiva 2014/52/UE del Parlamento europeo e del Consiglio, del 16 aprile 2014, nonché quelli di allevamento in gabbie e che superano le stesse soglie. Tuttavia, ai fini di tale qualificazione, occorre basarsi su un insieme di indizi attinenti, quanto meno, alla salvaguardia del benessere degli animali, al rispetto della biodiversità nonché alla tutela dell'ambiente e del clima.

CGUE, 04/10/2024, C-793/22
Politica Agricola Comune - Coltivazione della canapa (Cannabis sativa) – Rifiuto di autorizzare la coltivazione della canapa in sistemi idroponici in ambienti chiusi
Il diritto dell'Unione relativo alla politica agricola comune deve essere interpretato nel senso che non osta ad un divieto, in uno Stato membro, della coltivazione della canapa (Cannabis sativa) in sistemi idroponici in ambienti chiusi, purché tale divieto sia idoneo a garantire l'obiettivo di tutela della salute pubblica e che, alla luce degli obiettivi della politica agricola comune nonché del buon funzionamento dell'organizzazione comune dei mercati, non ecceda quanto necessario per raggiungere l'obiettivo di tutela della salute pubblica.

CGUE, 12/09/2024, C-557/23, *SPAR Magyarország Kft*
Rinvio pregiudiziale – Organizzazione comune dei mercati dei prodotti agricoli – Regolamento (UE) n. 1308/2013 – Normativa nazionale che prevede prezzi regolamentati per taluni prodotti agricoli nonché l'obbligo di mettere in vendita un quantitativo determinato di tali prodotti – Ammende
Il regolamento (UE) n. 1308/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, recante organizzazione comune dei mercati dei prodotti agricoli e che abroga i regolamenti (CEE) n. 922/72, (CEE) n. 234/79, (CE) n. 1037/2001 e (CE) n. 1234/2007 del Consiglio, come modificato dal regolamento (UE) 2021/2117 del Parlamento europeo e del Consiglio, del 2 dicembre 2021, deve essere interpretato nel senso che esso osta ad una misura nazionale che, a causa di una situazione di emergenza, da un lato, impone a un commerciante di mettere in vendita prodotti agricoli rientranti nell'ambito di applicazione di tale regolamento ad un prezzo regolamentato e in un quantitativo giornaliero medio registrato nelle scorte del commerciante nel corso di un anno di riferimento e, dall'altro, prevede l'imposizione obbligatoria di un'ammenda in caso di violazione degli obblighi previsti da tale misura nazionale.

CGUE, 29/07/2024, C-286/23, *Asociația Crescătorilor de Vaci «Bălțată Românească» Tip Simmental*
Politica agricola comune – Regolamento (UE) 2016/1012 – Riproduttori di razza pura – Procedura di riconoscimento degli enti selezionatori – Procedura di approvazione dei programmi genetici – Possibilità di rifiutare l'approvazione di un ulteriore programma genetico per la stessa razza, riguardante lo stesso territorio, se tale approvazione può pregiudicare un programma genetico già esistente – Diritto degli allevatori di animali di razza pura di scegliere tra i diversi programmi genetici esistenti
1) L'articolo 4, paragrafo 3, lettera b), del regolamento (UE) 2016/1012 del Parlamento europeo e del Consiglio, dell'8 giugno 2016, relativo alle condizioni zootecniche e genealogiche applicabili alla riproduzione, agli scambi commerciali e all'ingresso nell'Unione di animali riproduttori di razza pura, di suini ibridi riproduttori e del loro materiale germinale, che modifica il regolamento (UE) n. 652/2014, le direttive 89/608/CEE e 90/425/

CEE del Consiglio, e che abroga taluni atti in materia di riproduzione animale («regolamento sulla riproduzione degli animali»), in combinato disposto con l'allegato I, parte 1, di tale regolamento e alla luce del considerando 24 di detto regolamento, deve essere interpretato nel senso che esso non osta alla concessione di un riconoscimento come ente selezionatore a un richiedente che, al fine di dimostrare di disporre di una popolazione sufficientemente ampia di animali riproduttori e di un numero sufficiente di allevatori, faccia valere impegni di partecipazione sottoscritti da allevatori già iscritti in un programma genetico presso un altro ente selezionatore riconosciuto.
2) L'articolo 10 del regolamento 2016/1012, in combinato disposto con l'articolo 13 e con l'allegato I, parte 1, sezione B, punto 2, lettera a), di tale regolamento nonché alla luce dei considerando 21 e 24 di detto regolamento, deve essere interpretato nel senso che da un lato, qualora in uno Stato membro sia in corso un programma genetico avente come obiettivo principale il miglioramento di una determinata razza animale, l'autorità competente di tale Stato può approvare un nuovo programma genetico presentato da un altro ente selezionatore, relativo alla stessa razza di animali, che riguarda lo stesso territorio geografico, che persegue lo stesso obiettivo e nell'ambito del quale sono stati selezionati animali riproduttori tra la popolazione di riproduttori del programma genetico già in corso e, dall'altro, qualora tale approvazione possa compromettere uno o più elementi di cui alle lettere da a) a c) dell'articolo 10, paragrafo 1, del regolamento 2016/1012, questa stessa autorità ha la facoltà di rifiutare l'approvazione del nuovo programma genetico.

CGUE, 4 luglio 2024, C-708/22, *Asociación Española de Productores de Vacuno de Carne – Asoprovac*
Pagamenti diretti agli agricoltori nell'ambito dei regimi di sostegno previsti dalla politica agricola comune – Finanziamento, gestione e monitoraggio della politica agricola comune – Prati permanenti di proprietà pubblica – Condizioni di accesso al pagamento diretto agli agricoltori – Animali che devono appartenere all'azienda agricola propria degli agricoltori
1) L'articolo 4 e l'articolo 32, paragrafo 2, del regolamento (UE) n. 1307/2013, del Parlamento europeo e del Consiglio, del 17 dicembre 2013, recante norme sui pagamenti diretti agli agricoltori nell'ambito dei regimi di sostegno previsti dalla politica agricola comune e che abroga il regolamento (CE) n. 637/2008 del Consiglio e il regolamento (CE) n. 73/2009 del Consiglio, devono essere interpretati nel senso che non ostano a una normativa nazionale che, al fine di evitare che siano create artificialmente le condizioni richieste per l'ottenimento di un aiuto in occasione della concessione di prati permanenti di proprietà pubblica ad uso comune ad agricoltori che non li utilizzano, esige che l'attività di pascolo su tali prati sia esercitata con animali appartenenti all'azienda propria dell'agricoltore richiedente l'aiuto.
2) L'articolo 60 del regolamento (UE) n. 1306/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, sul finanziamento, sulla gestione e sul monitoraggio della politica agricola comune e che abroga i regolamenti del Consiglio (CEE) n. 352/78, (CE) n. 165/94, (CE) n. 2799/98, (CE) n. 814/2000, (CE) n. 1290/2005 e (CE) n. 485/2008, deve essere interpretato nel senso che non osta a una normativa nazionale che, al fine di evitare che siano create artificialmente le condizioni richieste per l'ottenimento di un aiuto in occasione della concessione di prati permanenti di proprietà pubblica ad uso comune ad agricoltori che non li utilizzano, esige che l'attività di pascolo su tali prati sia esercitata con animali appartenenti all'azienda propria dell'agricoltore richiedente l'aiuto.
3) L'articolo 4, paragrafo 1, lettera c), punto ii), del regolamento n. 1307/2013 deve essere interpretato nel senso che non osta a una normativa nazionale che esclude che l'attività di pascolo su un prato permanente di proprietà pubblica ad uso comune possa essere qualificata come attività di mantenimento di tali superfici in uno stato che le rende idonee al pascolo.
4) L'articolo 4, paragrafo 1, lettere b) e c), del regolamento n. 1307/2013 deve essere interpretato nel senso che non osta a una normativa nazionale in forza della quale una persona che è unicamente titolare di un diritto non esclusivo di pascolo su prati permanenti di proprietà pubblica ad uso comune e che cede tale diritto ad un allevatore terzo affinché quest'ultimo eserciti l'attività di pascolo con i propri animali, non esercita un'attività agricola ai sensi dell'articolo 4, paragrafo 1, lettera c), punto i), di tale regolamento, e non può essere considerata come gestore di tali prati ai fini dell'esercizio di un'attività di mantenimento di tale superficie in uno stato che la rende idonea al pascolo ai sensi dell'articolo 4, paragrafo 1, lettera c), punto ii), di detto regolamento.

Cass. civ., Sez. V, Ordinanza, 19/11/2024, n. 29754
Impianto fotovoltaico – fondo rustico – leasing energia prodotta utilizzata nell'attività agricola – qualificazione catastale – imposizione fiscale
L'impianto fotovoltaico situato su terreno agricolo utilizzato per attività agricola, anche se non di proprietà dell'imprenditore agricolo ma condotto tramite contratto di leasing, può essere classificato come "fabbricato rurale strumentale" nella categoria catastale D/10, a condizione che la produzione di energia fotovoltaica sia

imputabile all'imprenditore agricolo e venga utilizzata prevalentemente nell'attività agricola. Tale classificazione è possibile seguendo i requisiti soggettivi e oggettivi previsti dall'art. 9, comma 3-bis, del D.L. 30 dicembre 1993, n. 557, convertito con modificazioni dalla legge 26 febbraio 1994, n. 133.

ALIMENTI E BEVANDE

CGUE, 4 ottobre 2024, C-438/23, *Protéines Francia*

Rinvio pregiudiziale – Regolamento (UE) n. 1169/2011 – Informazioni ai consumatori sugli alimenti – Articolo 2, paragrafo 2, lettere n), o) e p), e articoli 7, 9 e 17 – Pratiche legittime concernenti la denominazione degli alimenti – Denominazioni legali, nomi usuali e nomi descrittivi – Sostituzione di componenti o di ingredienti di un alimento – Articolo 38, paragrafo 1 – Questioni espressamente armonizzate – Misure nazionali che vietano l'uso di denominazioni legate a prodotti animali per designare alimenti contenenti proteine vegetali

1) Gli articoli 7 e 17 del regolamento (UE) n. 1169/2011 del Parlamento europeo e del Consiglio, del 25 ottobre 2011, relativo alla fornitura di informazioni sugli alimenti ai consumatori, che modifica i regolamenti (CE) n. 1924/2006 e (CE) n. 1925/2006 del Parlamento europeo e del Consiglio e abroga la direttiva 87/250/CEE della Commissione, la direttiva 90/496/CEE del Consiglio, la direttiva 1999/10/CE della Commissione, la direttiva 2000/13/CE del Parlamento europeo e del Consiglio, le direttive 2002/67/CE e 2008/5/CE della Commissione e il regolamento (CE) n. 608/2004 della Commissione, nonché l'allegato VI, parte A, punto 4, del regolamento n. 1169/2011, letti alla luce dell'articolo 2, paragrafo 2, lettere o) e p), e dell'articolo 9, paragrafo 1, lettera a), dello stesso regolamento, devono essere interpretati nel senso che armonizzano espressamente, ai sensi dell'articolo 38, paragrafo 1, di tale regolamento, la protezione dei consumatori dal rischio di essere indotti in errore dall'uso delle denominazioni, diverse da quelle legali, costituite da termini dei settori della macelleria, della salumeria e della pescheria per descrivere, commercializzare o promuovere alimenti contenenti proteine vegetali anziché proteine di origine animale, anche nella loro interezza, e quindi ostano a che uno Stato membro adotti misure nazionali che disciplinino o vietino l'uso di tali denominazioni.

2) L'articolo 38, paragrafo 1, del regolamento n. 1169/2011 deve essere interpretato nel senso che l'armonizzazione espressa dichiarata al punto 1 del dispositivo non osta a che uno Stato membro emetta sanzioni amministrative nel caso di mancato rispetto delle prescrizioni e dei divieti risultanti dalle disposizioni di tale regolamento e dalle misure nazionali conformi ad esso. Per contro, tale armonizzazione espressa osta a che uno Stato membro adotti una misura nazionale che stabilisca tenori di proteine vegetali al di sotto dei quali resterebbe consentito l'uso di denominazioni, diverse da quelle legali, costituite da termini provenienti dai settori della macelleria e della salumeria per descrivere, commercializzare o promuovere alimenti contenenti proteine vegetali.

CGUE, 4 ottobre 2024, C-329/22, *Confédération paysanne*

Accordi internazionali – Accordo euromediterraneo che istituisce un'associazione tra le Comunità europee e i loro Stati membri, da una parte, e il Regno del Marocco, dall'altra – Modifica dei protocolli n. 1 e n. 4 dell'accordo euromediterraneo – Regolamento (UE) n. 1169/2011 – Articolo 9 – Articolo 26, paragrafo 2 – Regolamento di esecuzione (UE) n. 543/2011 – Articolo 3, paragrafi 1 e 2 – Articolo 5, paragrafi 1 e 2 – Articolo 8 – Articolo 15, paragrafi 1 e 4 – Allegato I – Allegato IV – Regolamento (UE) n. 1308/2013 – Articolo 76 – Fornitura di informazioni sugli alimenti ai consumatori – Indicazione obbligatoria del paese d'origine o del luogo di provenienza di un alimento – Ortofrutticoli raccolti nel Sahara occidentale – Richiesta indirizzata a uno Stato membro di vietare unilateralmente le importazioni di tali prodotti nel suo territorio – Indicazione obbligatoria del Sahara occidentale come luogo di provenienza dei pomodori e dei meloni raccolti in tale territorio

1) L'articolo 207 TFUE, il regolamento (UE) 2015/478 del Parlamento europeo e del Consiglio, dell'11 marzo 2015, relativo al regime comune applicabile alle importazioni, e il regolamento (UE) n. 1308/2013 del Parlamento europeo e del Consiglio, del 17 dicembre 2013, recante organizzazione comune dei mercati dei prodotti agricoli e che abroga i regolamenti (CEE) n. 922/72, (CEE) n. 234/79, (CE) n. 1037/2001 e (CE) n. 1234/2007 del Consiglio, devono essere interpretati nel senso che non consentono a uno Stato membro di adottare unilateralmente una misura che vieti l'importazione di prodotti agricoli la cui etichettatura sia sistematicamente non conforme alla normativa dell'Unione in materia di indicazione del paese o del territorio di origine.

2) L'articolo 76 del regolamento n. 1308/2013, letto in combinato disposto con l'articolo 3, paragrafo 1, del regolamento di esecuzione (UE) n. 543/2011 della Commissione, del 7 giugno 2011, recante modalità di applicazione del regolamento (CE) n. 1234/2007 nei settori degli ortofrutticoli freschi e degli ortofrutticoli trasformati,

come modificato dal regolamento di esecuzione (UE) n. 594/2013 della Commissione, del 21 giugno 2013, deve essere interpretato nel senso che nelle fasi di importazione e di vendita al consumatore, l'etichettatura dei meloni «charentais» e dei pomodori ciliegia raccolti nel territorio del Sahara occidentale deve indicare come loro paese di origine unicamente il Sahara occidentale.

AMBIENTE

Cass. pen., Sez. III, 05/04/2024, n. 29351

Inquinamento idrico – liquami – acque di scarico – qualificazione - rifiuti

In tema di inquinamento idrico, i liquami prodotti da un'impresa (nella specie zootecnica) costituiscono acque di scarico se il collegamento fra ciclo di produzione e recapito finale sia diretto ed attuato mediante una condotta o altro sistema stabile di collettamento, costituito da un sistema di deflusso, oggettivo e duraturo, che canalizza, senza soluzione di continuità, i reflui fino al corpo ricettore; in mancanza, si verte nell'ambito della disciplina sui rifiuti (nella specie, le acque reflue confluivano all'interno di una vasca soggetta a svuotamento periodico; all'interno della vasca era tuttavia presente una tubatura di "troppo pieno" che consentiva di far tracimare i liquami, quando essi superavano un certo livello; la Cassazione ha ritenuto che i reflui convogliati nella vasca fossero destinati a permanere nella stessa fino ad essere allontanati tramite cisterna e perciò mancava il requisito dello "stabile collettamento", necessario per applicare la disciplina degli scarichi idrici).

ANIMALI

Cass. pen., Sez. III, 14/10/2024, n. 42474

Animali – ibridi – divieto di detenzione

Gli ibridi tra specie selvatiche e domestiche, come ad esempio tra lupo selvatico e cane domestico, rientrano nella categoria di animali la cui detenzione è vietata ai sensi dell'art. 4 comma 1 del D.Lgs. n. 135 del 2022, qualora uno dei genitori sia di provenienza selvatica, in conformità con quanto previsto dal DM Ambiente 19/4/1996.

Cass. pen., Sez. III, 23/04/2024, n. 30369

Animali – abbandono – detenzione - presupposti

Ai fini della configurabilità del reato di cui all'art. 727, cod. pen., la detenzione di animali in condizioni produttive di gravi sofferenze non richiede necessariamente la presenza di malattie o malnutrizione, ma può consistere anche in situazioni di patimento psico-fisico dovuto a condizioni di abbandono o incuria.

CACCIA E PESCA

Cass. civ., Sez. III, Ordinanza, 09/07/2024, n. 18817

Caccia - Ordinamento amministrativo - Regioni - In genere - Fauna selvatica - Ente responsabile dei danni ex art. 2043 c.c. - Individuazione - Affidamento di poteri di amministrazione del territorio e di gestione della fauna - Accertamento in concreto - Necessità - Art. 15 l.r. marche n. 25 del 2008 - Rilevanza sintomatica di allocazione dei poteri - Sussistenza - Fattispecie - responsabilità civile - Proprietà di animali

L'ente responsabile per i danni cagionati da fauna selvatica, nel caso in cui tale responsabilità sia sussunta nella previsione normativa di cui all'art. 2043 c.c., va individuato nel soggetto che, in base ad un accertamento in concreto, risulti affidatario dei poteri di amministrazione del territorio e di gestione della fauna; al fine di detto accertamento, l'art. 15 l.r. Marche n. 25 del 2008 - istitutivo di un apposito "fondo per l'indennizzo da parte della Regione dei danni causati alla circolazione stradale dalla fauna selvatica" nel bilancio regionale - assume rilevanza sintomatica della scelta di allocare in capo alla Regione la "neutralizzazione" di tale pregiudizio mediante attribuzione dei poteri funzionali alla sua prevenzione. (La S.C. ha affermato tale principio in una fattispecie in cui si era formato il giudicato interno sulla qualificazione giuridica della responsabilità ai sensi dell'art. 2043 c.c.).

CONTRATTI AGRARI

Cassazione civile sez. III, 08/11/2024, n.28876

Contratti agrari - Morte di una delle parti - Del proprietario coltivatore diretto - Diritti degli eredi --- Del proprietario coltivatore diretto - Diritti degli eredi - Disciplina dell'art. 49 della l. n. 203 del 1982 - Nullità del contratto di affitto stipulato dal "de cuius" - Esercizio abusivo dell'attività agricola da parte dell'erede - Applicabilità dell'art. 49 citato - Esclusione.

L'art. 49 della l. n. 203 del 1982 - il quale, in caso di morte del proprietario di fondo rustico, prevede, in capo all'erede che esercita al momento dell'apertura della successione attività agricola sul fondo condotto e di proprietà del "de cuius", il diritto alla continuazione della coltivazione con un contratto di affitto con gli altri coeredi - non trova applicazione qualora l'erede prosegua l'attività agricola già esercitata dal "de cuius" abusivamente e senza alcun titolo, per essere stato il contratto di affitto stipulato con quest'ultimo dichiarato nullo per violazione degli artt. 4 e 8 della l. n. 379 del 1967.

Cassazione civile sez. III, 16/10/2024, n.26921
Contratti agrari (procedimento in materia di) - Competenza e giurisdizione - Sezioni specializzate - Competenza - Opposizione al precetto di rilascio di fondo rustico - Competenza della sezione specializzata agraria - Opposizione all'esecuzione - Sussistenza - Opposizione agli atti esecutivi - Esclusione - Fondamento.
La competenza a decidere l'opposizione a precetto per il rilascio di un fondo rustico spetta alla sezione specializzata agraria se, in relazione ai motivi, è qualificabile come opposizione all'esecuzione; spetta invece al giudice dell'esecuzione se investe il quomodo dell'azione esecutiva, ed è quindi qualificabile come opposizione agli atti esecutivi, materia estranea a quella agraria, per cui non vi è ragione di attribuirla al giudice specializzato.

Cassazione civile sez. III, 20/09/2024, n.25286
Competenza civile - Regolamento di competenza - --- Azione di accertamento negativo di un rapporto agrario - Sentenza di accoglimento - Mezzi di impugnazione - Regolamento necessario di competenza - Esclusione - Appello - Necessità - Fondamento.
La sentenza della sezione specializzata agraria che accoglie la domanda di accertamento negativo della natura agraria del rapporto e declina, conseguentemente, la propria competenza per materia sulle altre domande proposte dall'attore, in quanto relative alla cessazione di efficacia di un contratto di locazione, non è impugnabile col regolamento necessario di competenza, ma solo con l'appello, non trattandosi di statuizione sulla competenza, bensì di pronuncia nel merito.

Cassazione civile sez. III, 02/09/2024, n.23487
Contratti agrari – natura del rapporto - competenza – sezioni specializzate – accertamento
Qualora nel giudizio instaurato dall'attore con domanda di rilascio di un bene immobile il convenuto eccepisca l'incompetenza del giudice adito, deducendo la competenza della Sezione Specializzata Agraria, il giudice deve rimettere a questa la decisione della causa, rientrando nella competenza della medesima anche l'accertamento della natura del rapporto, tranne che, sulla base delle deduzioni delle parti e senza necessità di attività istruttoria, risulti prima facie che la materia del contendere è diversa da quella devoluta alla cognizione del giudice specializzato, evenienza che ricorre, tra l'altro, allorché l'eccezione sollevata manchi del supporto argomentativo minimo indispensabile per chiarire i dati essenziali del rapporto agrario dedotto ovvero la specifica natura, la data di inizio, il corrispettivo, l'oggetto. (Tale, ha osservato la Suprema Corte, è stato ritenuto, nella sostanza, il caso di specie, se è vero che già il Tribunale - secondo quanto emerge proprio dal contenuto del ricorso - aveva dato atto che le odierne ricorrenti non avevano neppure dedotto l'attualità del rapporto agrario, non formulando istanze istruttorie volte a dimostrare una legittima ragione di possesso. Né senza rilievo, nella stessa prospettiva dell'esclusione prima facie dell'esistenza di un rapporto agrario, è la circostanza che il primo giudice avesse escluso l'avvenuta conclusione in forma verbale del contratto di affitto, in ragione della ritenuta insussistenza dei requisiti essenziali ex articolo 1325 del Cc).

Cass. civ., Sez. III, 15/07/2024, n. 19340
Contratti agrari – Morte di una delle parti - Del proprietario coltivatore diretto - Diritti degli eredi - Esclusione dell'erede legittimario dal testamento - Impossibilità di impugnare il testamento con l'azione di riduzione - Esercizio dell'azione di cui all'art. 49 della l. n. 203 del 1982 - Sussistenza - Condizioni
In materia di contratti agrari, l'erede legittimario che sia stato escluso dal testamento del genitore per aver ricevuto in vita un quantitativo di beni idonei a soddisfare la sua quota di legittima e si trovi, per tale ragione, nell'impossibilità di impugnare il testamento con l'azione di riduzione, ha titolo per esercitare l'azione di cui all'art. 49 della L. 3 maggio 1982, n. 203 e, ricorrendo le condizioni indicate da tale norma, può ottenere di continuare nella conduzione o coltivazione dei fondi agricoli anche per le porzioni ricomprese nelle quote degli altri coeredi e di essere considerato affittuario delle stesse.

IMPRESA E LAVORO

Cass. civ., Sez. lavoro, Ordinanza, 29/07/2024, n. 21156
Imprenditore agricolo – qualificazione – ente pubblico non economico - esclusione
L'Ente Sviluppo Agricolo (ESA) è un ente pubblico non economico e non può essere qualificato come imprenditore agricolo ai sensi dell'art. 2135 c.c.; pertanto, ai contratti di lavoro a tempo determinato conclusi da tale ente non è applicabile la disciplina delle deroghe prevista per i datori di lavoro agricolo dagli artt. 10, comma 2, del D.Lgs. n. 368 del 2001 e 29, comma 1, lett. b), del D.Lgs. n. 81 del 2015.

Cassazione civile sez. lav., 07/10/2024, n.26196
Lavoro – tempo determinato – attività agricola stagionale – interpretazione restrittiva – esclusione attività

idonee a perpetuarsi nel tempo – onere della prova - datore
Nell'ambito del diritto del lavoro, la nozione di attività agricola stagionale, ai fini dell'applicabilità della disciplina dei contratti a tempo determinato, deve essere interpretata in maniera restrittiva, riferendosi esclusivamente a situazioni aziendali caratterizzate da attività preordinate e organizzate per un espletamento temporaneo limitato ad una stagione agricola. Tale definizione esclude le attività idonee a perpetuarsi nel tempo e che non dipendono dall'ordinaria scansione temporale delle incombenze tipiche dell'attività agricola stagionale. Il datore di lavoro ha l'onere di dimostrare che l'attività svolta dal lavoratore costituisca effettivamente un'attività aggiuntiva e stagionale rispetto a quella ordinariamente svolta, con divieto di adibire il lavoratore a mansioni che esulino dal contesto stagionale. La eventuali deroghe regionali devono operare all'interno dei limiti fissati dalle norme nazionali, escludendo interpretazioni analogiche e garantendo la specificità nell'individuazione delle attività stagionali sia a livello legislativo che contrattuale.

PROPRIETÀ E PRELAZIONE

Corte cost., 26/07/2024, n. 152
Domini collettivi - In genere - Natura privatistica dei loro enti esponenziali - Finalità della gestione - Preservazione collettiva dell'ambiente, anche nell'interesse delle generazioni future - Possibili controlli dell'autorità pubblica - Riconduzione alla competenza legislativa esclusiva dello Stato in materia di ordinamento civile - Esclusione della competenza residuale regionale nella materia «agricoltura e foreste»
Non compete alla Regione estendere alle partecipanze agrarie la disciplina prescritta dalle fonti statali per le fondazioni. La peculiare gestione di una proprietà collettiva dedita alla coltivazione della terra e alla protezione dell'ambiente, anche nell'interesse delle generazioni future, non fa venire meno nelle partecipanze agrarie i tratti associativi. È, pertanto, costituzionalmente illegittimo l'art. 49, comma 1, lettera b), della L.R. Emilia-Romagna n. 6 del 2004, limitatamente alle parole ", ferma restando l'eventuale applicazione del titolo III, capo II, della L.R. n. 24 del 1994".

Cassazione civile sez. III, 28/11/2024, n.30615
Prelazione – riscatto – interessi e rivalutazione - esclusione
In ipotesi di retratto agrario, il retraente è tenuto a versare esattamente lo stesso prezzo indicato nel contratto di vendita che abbia violato il diritto di prelazione, senza interessi o rivalutazione monetaria, anche se la sentenza di accoglimento della domanda di riscatto è intervenuta successivamente alla vendita e se il retraente è rimasto nella detenzione del fondo senza pagare alcun corrispettivo.

Cassazione civile sez. III, 10/10/2024, n.26401
Prelazione e riscatto - Prelazione --- Prelazione - Retratto - Presupposti - Contiguità dei fondi - Assenza - Rilevabilità d'ufficio.
Il giudice del merito è tenuto alla verifica della sussistenza di tutte le condizioni prescritte dalla legge per l'accoglimento della domanda di prelazione e riscatto agrario, sicché rientra nei suoi doveri il rilievo d'ufficio dell'assenza del requisito della contiguità fisica dei fondi.

Cass. civ., Sez. III, Ordinanza, 07/10/2024, n. 26156
Prelazione – esercizio strumentale - vendita di quote di proprietà indivisa
La condizione negativa della mancata vendita di fondi rustici, prevista dall'art. 7 della legge n. 817/1971 e dall'art. 8 della legge n. 590/1965, mira a evitare l'esercizio strumentale e speculativo della prelazione agraria, promuovendo l'accorpamento dei terreni per migliorare la redditività agricola. Tale condizione si applica anche alla vendita di quote in proprietà indivisa, indipendentemente dalla percentuale.

Cass. civ., Sez. III, Ordinanza, 23/09/2024, n. 25443
Vendita di quota di eredità avente ad oggetto anche fondo agricolo - Prevalenza del diritto di prelazione del coerede su quello del coltivatore diretto, mezzadro, colono o compartecipante - Sussistenza.
In caso di acquisto di una quota di eredità comprendente un fondo agricolo, il diritto di prelazione spettante al coerede, ai sensi dell'art. 732 cod. civ., prevale sul diritto di prelazione del coltivatore diretto, mezzadro, colono o compartecipante previsto dall'art. 8 della legge 26 maggio 1965, n. 590.

Cassazione civile sez. III, 23/09/2024, n.25412
Prelazione - Frazionamento artificioso del fondo - Configurabilità - Condizioni - Limiti.
In tema di prelazione agraria, perché possa affermarsi che il frazionamento di un fondo agricolo - e la vendita solo di alcune sue partizioni - sia stato posto in essere dal venditore allo scopo di creare un "artificioso diaframma" rispetto al fondo di proprietà del coltivatore confinante, non è sufficiente che una porzione di fondo sia stata riservata alla parte alienante esclusivamente al fine di evitare il sorgere del diritto di prelazione o che lo sfruttamento dei fondi, risultanti dalla divisione, sia

meno razionale che non la conduzione dell'intero, originario, complesso, ma è indispensabile che la porzione costituente la fascia confinaria, per le sue caratteristiche, sia destinata a rimanere sterile e incolta o sia, comunque, inidonea a qualsiasi sfruttamento coltivo autonomo, sì che possa concludersi che la porzione non ceduta è priva di qualsiasi utilità per l'alienante.

Cass. civ., Sez. Unite, Ordinanza, 22/07/2024, n. 20084
Terreni agricoli – danno – innalzamento acque – gestione di ente pubblico – responsabilità – 2051 c.c. – solidarietà - Regione
Se il danno a terreni agricoli derivato dall'innalzamento del livello delle acque di un torrente è causato da corsi d'acqua o opere idrauliche la cui custodia e manutenzione sono affidate a un ente pubblico o un consorzio di bonifica, tali entità sono responsabili ex art. 2051 c.c. per i danni causati dalla mancata manutenzione. Tale responsabilità può coinvolgere sia la Regione che il consorzio di bonifica, soprattutto se le leggi regionali attribuiscono ai consorzi compiti di manutenzione.

Cass. civ., Sez. III, Ordinanza, 09/07/2024, n. 18786
Prelazione – retratto – coltivazione continuativa - onere della prova – sindacabilità – legittimità - esclusione
Il diritto di prelazione e di retratto agrario richiede la prova della coltivazione continuativa del fondo confinante da almeno due anni antecedenti alla vendita. La valutazione dei giudici di merito su tale requisito non può essere sindacata in sede di legittimità, salvo vizio radicale della motivazione.

Cass. civ., Sez. III, Ordinanza, 09/07/2024, n. 18786
Prelazione – riscatto - onere della prova – sindacabilità – legittimità - esclusione
L'accertamento della sussistenza dei requisiti per l'esercizio del riscatto agrario compiuto dal giudice di merito, se congruamente motivato e privo di vizi logici, non è rivisitabile in sede di legittimità. La valutazione del giudice di merito che si fondi su una ricostruzione globale e coerente del materiale probatorio a disposizione non può essere riconsiderata dalla Corte di Cassazione.

TRIBUTI, CONTRIBUTI E AGEVOLAZIONI

Cass. civ., Sez. V, Ordinanza, 24/07/2024, n. 20563
Imposte – ICI e IMU – esenzione – pensionati – mantenimento iscrizione nella gestione previdenziale
Il regime di esenzione dall'ICI e dall'IMU per i terreni agricoli richiede che il possessore del terreno sia un coltivatore diretto o un imprenditore agricolo a titolo principale. Tuttavia, con l'introduzione dell'art. 78-bis del D.L. 14 agosto 2020, n. 104, è stato stabilito che anche i pensionati che continuano a svolgere attività in agricoltura e mantengono l'iscrizione nella relativa gestione previdenziale e assistenziale agricola possono beneficiare dell'esenzione, ma solo con riferimento all'IMU e non all'ICI.

Cass. civ., Sez. Unite, Ordinanza, 16/07/2024, n. 19484
Sovvenzioni – revoca – giurisdizione – fase esecutiva – diritto soggettivo – giudice ordinario – revoca per vizi di legittimità – giudice amministrativo
In materia di controversie relative alla concessione e revoca di contributi e sovvenzioni pubbliche, la giurisdizione spetta al giudice ordinario quando la revoca si fonda sull'inadempimento del beneficiario rispetto agli obblighi previsti dal bando e dalle condizioni statuite in sede di erogazione del contributo. Tale controversia attiene alla fase esecutiva del rapporto di sovvenzione, dove la posizione soggettiva è di diritto soggettivo perfetto. Diversamente, la giurisdizione spetta al giudice amministrativo se il provvedimento di revoca è motivato da vizi di legittimità o dal contrasto originario con l'interesse pubblico.

Cass. civ., Sez. V, Ordinanza, 15/07/2024, n. 19432
Coltivazione – attività esclusiva – agevolazioni – esclusioni - pensionati
Il trattamento agevolato di cui all'art. 9 del D.Lgs. 30 dicembre 1992, n. 504, per i terreni agricoli è legittimamente escluso per i soggetti titolari di pensione, in quanto il beneficio è diretto a incentivare la coltivazione della terra e ad agevolare coloro che traggono dal lavoro agricolo la loro esclusiva fonte di reddito. Pertanto, il godimento di trattamenti pensionistici, già di per sé, impedisce il riconoscimento dell'agevolazione fiscale indipendentemente dall'iscrizione del soggetto negli appositi elenchi e dal versamento di contributi volontari.

Cons. Stato, Sez. VI, 10/09/2024, n. 7505
Quote latte – prelievi – restituzioni- solidarietà produttore e primo acquirente
Sussiste un vincolo di solidarietà che lega il produttore e il primo acquirente, per cui entrambi sono egualmente obbligati alle restituzioni di prelievi di quote latte dovute in esito alle compensazioni a livello nazionale. In virtù del predetto vincolo, l'interruzione della prescrizione nei confronti del condebitore solidale si estende anche agli altri a norma dell'art. 1310 c.c. e, quindi, gli elementi interruttivi per i produttori hanno effetto anche per gli acquirenti e viceversa.

Cons. Stato, Sez. VI, 10/09/2024, n. 750

Quote latte – prelievi – prescrizione – termine decennale

Gli importi dovuti a titolo di prelievo supplementare per le quote latte non sono debiti da pagarsi periodicamente, ma misure a carattere patrimoniale imposte per salvaguardare il sistema delle quote latte, e applicate sul presupposto dello sforamento delle quote individuali, talché la prescrizione rilevante è quella decennale. In sostanza, poiché il prelievo supplementare non costituisce una prestazione periodica, non è applicabile l'art. 2948 c.c. che disciplina la prescrizione di cinque anni, mentre, quanto al capitale, il termine di prescrizione decennale è previsto in via generale dall'art. 2946 c.c.

T.A.R. L'Aquila, (Abruzzo) sez. I, 04/09/2024, n.388

Agea – competenze – provvedimenti presa da un'altra amministrazione – esclusione

Nessuna disposizione dell'ordinamento interno, né di quello dell'Unione europea, conferisce all'Agea il potere di verificare incidentalmente la legittimità dei provvedimenti presi da un'altra amministrazione per interessi diversi da quelli finanziari dell'Unione europea, riguardanti relazioni amministrative in cui l'Agea non è coinvolta, né il potere di disapplicare gli effetti di tali provvedimenti.

Tribunale Forlì sez. lav., 09/07/2024, n.159

Contributi previdenziali – misura ridotta – consorzi e cooperative – zone svantaggiate – contributo dei soci

Il comma 5 dell'art. 9 della l. n. 67 del 1988 va interpretato nel senso che il pagamento dei contributi previdenziali ed assicurativi in misura ridotta è riconosciuto anche alle cooperative ed ai consorzi non operanti in zone svantaggiate o di montagna, in misura proporzionale alla quantità di prodotto coltivato od allevato dai propri soci, anche avvalendosi di contratti agrari di natura associativa, in zone di montagna o svantaggiate e successivamente conferito alla cooperativa. La "ratio" della norma è quella di incentivare l'allevamento e la coltivazione in zone svantaggiate o montane, laddove incombe sulla società che invoca l'applicazione dello sgravio provare la sussistenza dei relativi requisiti.

USI CIVICI

Cass. civ., Sez. Unite, Ordinanza, 27/08/2024, n. 23137

Giurisdizione ordinaria e amministrativa - Usi civici - Fondi riconosciuti di dominio collettivo in titolarità di un'università agraria - Delibere comunali di classificazione delle strade e di acquisizione dei fondi al patrimonio dell'ente - Giurisdizione del commissario agli usi civici - Esclusione - Giurisdizione del giudice amministrativo – Sussistenza

È devoluta alla giurisdizione del giudice amministrativo - e non del commissario agli usi civici - la controversia introdotta da un'università agraria, titolare di fondi già definitivamente riconosciuti di dominio collettivo, per contestare le delibere comunali di classificazione delle strade ed acquisizione dei fondi al patrimonio dell'ente.

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INDICE