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A COMPARISON OF IN SITU AND GIS LANDSCAPE METRICS FOR RESIDENTIAL SATISFACTION MODELING

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Introduction

Residential satisfaction is an important subject of research in varied domains such as environmental psychology (Hur, Nasar, & Chun, 2010; Amerigo, 1997), sociology (Kahana, Lovegreen, Kahana, & Kahana, 2003), and urban planning (Ellis, Lee, & Kweon, 2006; Kweon, Ellis, Leiva, & Rogers, 2010). Residential satisfaction may be thought of as the match between an individual's ideal residential environment and certain attributes of her actual environment, including its psychological, social, and spatial components. For Amerigo (1997) residential satisfaction arises from the evaluation of objective attributes of the residential environment through the filter of personal characteristics related to the individual's expectations, experiences, aspirations, or values. Each individual expresses a degree of residential satisfaction that is peculiar to her and that arises from the confrontation between a cognitive process and objective, physical, or social attributes of her environment (Weidemann & Anderson, 1985). However, some similarities exist in landscape preferences, explained by evolutionary theories such as *biophilia* (Wilson, 1984), *restorative environments* (Ulrich, 1979), *prospect-refuge theory* (Appleton, 1975) or by the *landscape preference matrix* proposed by Kaplan and Kaplan (1989). These theories hold that landscape preferences are formed by the common evolutionary history of humans who react positively to landscape features that supposedly ensure their survival and improve their well-being.

Of the various components of an individual's residential satisfaction, satisfaction with the landscape around her residence has been much studied (Hur & Morrow-Jones, 2008; Kweon et al., 2010; Lee, Ellis, Kweon, & Hong, 2008). Much work has been done on identifying the landscape criteria to which individuals are sensitive to varying degrees (Cavailhès et al., 2009; Cheshire & Sheppard, 1995; Cho, Kim, Roberts, & Jung, 2009; Kong, Yin, & Nakagoshi, 2007; Lee et al., 2008; Tyrväinen & Väänänen, 1998). Generally research can be split into two main bodies depending on the objective pursued. The first body of work endeavors to better understand individuals' landscape preferences by referring to the monetary value individuals are ready to attribute to landscape (Cavailhès et al., 2009; Cho, Poudyal, & Roberts, 2008; Gao & Asami, 2007; Jim & Chen, 2006; Tyrväinen, 1997) or by focusing on the various cognitive processes at work in the human–environment relationship (Kaplan,

Kaplan, & Brown, 1989; Sevenant & Antrop, 2009; Zube, Sell, & Taylor, 1982). The second body of studies addresses more operational issues by looking to include landscape in decisions about regional planning (Domingo-Santos, de Villarán, Rapp-Arrarás, & de Provens, 2011; Kaplan & Austin, 2004), environmental management (Bell, 2001) or urban planning (Lee et al., 2008). This involves evaluating landscape quality.

There are two main approaches to evaluating landscape quality (Daniel, 2001; Vouligny, Domon, & Ruiz, 2009). The first 'perceptive' approach is based on individual preferences and looks at landscape through the eye of the beholder (Lothian, 1999). The aim is usually to ask an individual what he thinks of a given landscape or a specific landscape criterion. These methods borrowed from the cognitive sciences can be used to explore the affective relationship between the individual and the landscape rather precisely by concentrating on the subject's different mental and psychological processes (Daniel & Vining, 1983; Zube et al., 1982). However, they are limited by the necessarily subjective character of the evaluation of the landscape by individuals and so cannot be readily applied in a context of regional planning decision-making.

The second approach brings together what are called expert methods (Daniel, 2001). They start from the postulate that a landscape can be evaluated objectively and that its intrinsic quality depends on various visual attributes. By this approach, landscape exhibits inherent qualities that can be evaluated as neutrally as possible, although a strict objectivity may be not totally reached. The approach generally entails making a descriptive inventory of the various components of the landscape and capturing them in the form of variables describing the landscape content, shapes, colors, diversity, texture, harmony, and coherence (Vouligny et al., 2009). This landscape description may be based on (1) a field approach whereby an expert attempts to describe the landscape as seen *in situ*, using a grid to evaluate the landscape (Arriaza, Cañas-Ortega, Cañas-Madueño, & Ruiz-Aviles, 2004; Otero Pastor, Casermeiro Martínez, Ezquerra Canalejoa, & Esparcia Mariño, 2007; Vouligny et al., 2009); (2) a cartographic or GIS approach using digital modeling whereby landscape information is based on spatial data describing altitude and land use (Bastian, McLeod, Germino, Reiners, & Blasko, 2002; Bishop, 2003; Cavailhès et al., 2009; Domingo-Santos et al., 2011; Horst, 2006). The *in situ* approach provides a wealth of information but that is limited to the survey sites; by contrast, digital modeling can be used to evaluate the landscape systematically and continuously in space, the quality of the evaluation being closely tied to the precision of the initial data. Otero Pastor et al. (2007) compare a cartographic and an *in situ* assessment method. They show that there are no significant differences between the two and that a cartographic method with accurate information can be used in landscape assessment to make savings compared with field observation.

Within the approaches based on spatial data, GIS visibility analyses are particularly relevant for landscape assessment (de la Fuente de Val, Atauri, & de Lucio, 2006; Sang, Ode, & Miller, 2008). Two main bodies of GIS computation methods exist for modeling the visible landscape: the sight-line method (Fisher, 1996; Joly, Brossard, Cavailhès, Hilal, Tourneux, Tritz, Wavresky, 2009) involves characterizing the visible landscape from a count of pixels seen from virtual viewpoints whereas the solid angles method (Domingo-Santos et al., 2011) uses trigonometric calculations to define the visual exposure of visible landscape elements

(Llobera, 2003). The latter method measures the visual salience of landscape characters on the retina of a potential observer.

There are currently no studies comparing approaches based on *in situ* metrics and GIS visibility metrics to explain residential satisfaction related to landscape. The purpose of this paper is to compare the capacity of each group of landscape metrics to explain residential satisfaction of individuals by: (1) a GIS-based approach that involves generating spatial visibility metrics; (2) an *in situ* approach based on collecting landscape information by means of a field audit. Our main hypothesis is that the field audit is expected to explain more about individuals' landscape satisfaction because its descriptors are qualitatively richer. If this hypothesis is confirmed, it shall call into question the value of GIS visibility metrics based on land cover data. Conversely, if GIS visibility metrics explain more about individuals' landscape satisfaction, they could be substituted with interest for *in situ* observations. If both approaches have similar explanatory powers, then we would need to examine whether the methods complement or duplicate one another. This study has been conducted in a suburban area near Besançon (eastern France). The choice of study area means we can re-examine the results of a residential survey reported in Youssoufi and Foltête (2013).

2. Material and methods

2.1. Study area

Besançon is a medium-sized city of about 120 000 inhabitants around which a suburban ring has developed since the 1970s and now counts some 60 000 inhabitants. The study area chosen lies to the north-west of Besançon (**Fig. 1**). It is made up of a group of 11 administrative districts (*communes*) where substantial suburbanization has occurred. The relief is characterized by low limestone hills separated by marl depressions. Land cover is mostly woodland (40%), farmland (34%), and villages (14.5%) with varying degrees of detached suburban housing.

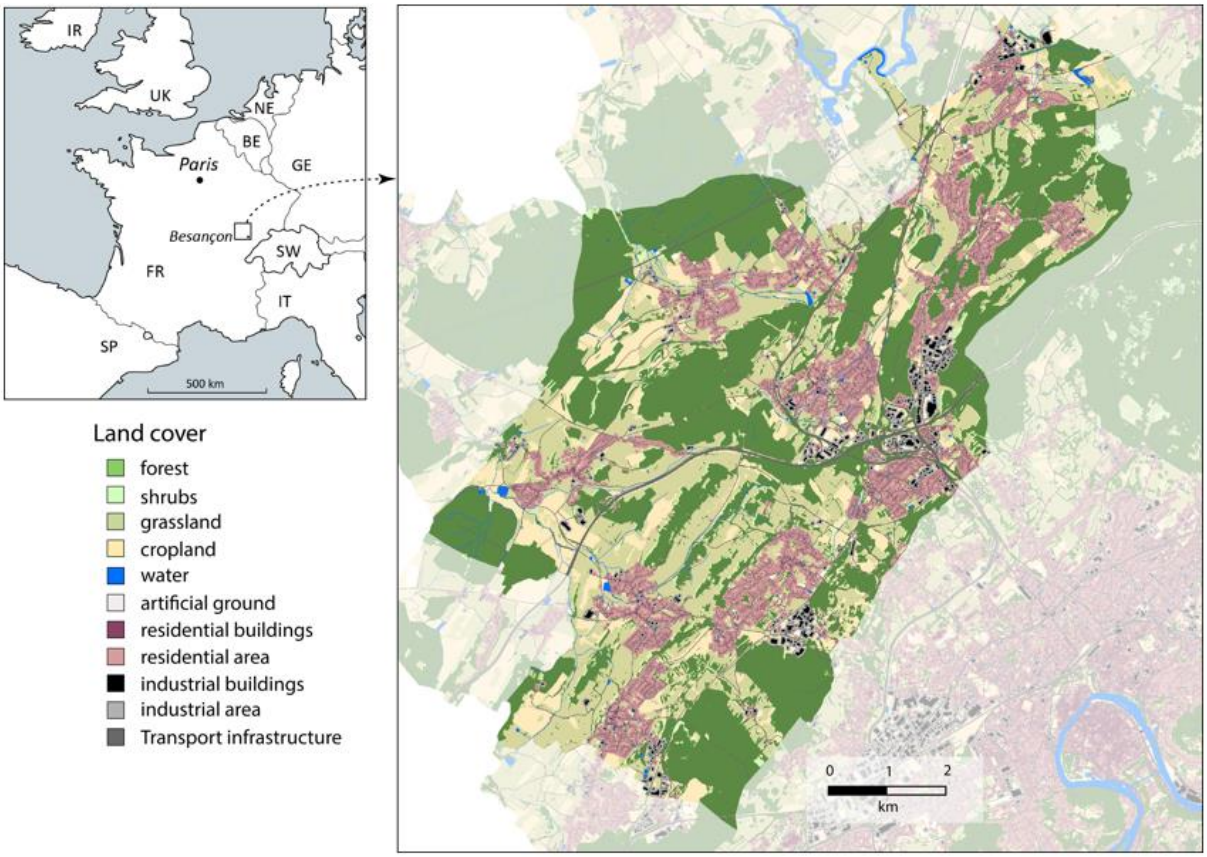


Fig. 1. Study area

2.2. Measuring the degree of landscape satisfaction

The degree of landscape satisfaction was evaluated by a survey in June 2009 and presented in Youssoufi and Foltête (2013). Here we set out the most important points of the survey. A sample of 1057 people was stratified by population of the administrative districts. Each respondent answered a series of questions about their residential environment and was GIS-referenced based on the postal address. Four main themes were covered by the survey: (1) evaluation of the surrounding landscape, (2) access to various urban amenities, (3) perception of the residential built environment in terms of aesthetics and density, and (4) evaluation of the individual and public transport conditions. Individuals were invited to respond to a series of assertions by saying whether they agreed with them.

A multiple correspondence analysis (MCA) was performed (Tenenhaus & Young, 1985) to synthesize the responses in the form of factorial axes (see Appendix A and B for details). The interpretation made it possible to identify the first factor (the only one considered in the present article) as the landscape satisfaction gradient. As in Youssoufi and Foltête (2013), the coordinate of individuals on this axis is the target variable of the analysis. The second factor concerns the level of satisfaction for accessibility to urban amenities.

In the present study, the constraints of the field survey for producing *in situ* metrics (see section 2.4.) mean that work has to be done on a subsample of individuals. A random draw of

60 individuals (5.7%) was made from the initial sample of 1057, maintaining the spatial stratification by administrative district. The **Fig. 2** shows the level of satisfaction and dissatisfaction for these 60 individuals.

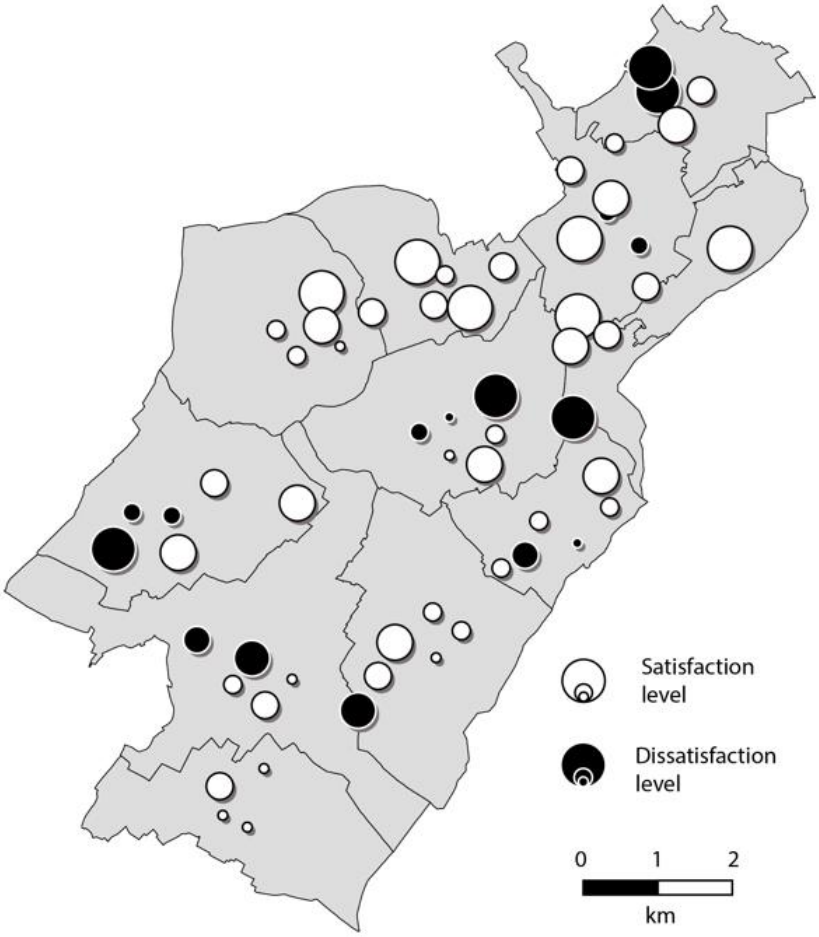


Fig. 2. Landscape neighborhood satisfaction level. The satisfaction and dissatisfaction levels correspond to the coordinates of individuals on the first factor of the MCA. The satisfaction level corresponds to the positive values and the dissatisfaction level to the negative values.

2.3. Field audit and in situ metrics

The field audit consisted in examining the landscape on the ground by a descriptive inventory of landscape scenes (Arthur, Daniel, & Boster, 1977). This involved focusing on landscape elements that could be seen from the residential location of each of the 60 individuals in the sample, by authorizing movements of a few tens of meters along streets in the neighborhood. This survey was used to capture the landscape elements of the relevant residential zone using systematic field audit rules.

The *in situ* evaluation was conducted with a landscape analysis grid (**Tab. 1**) defined from the literature (Otero Pastor et al., 2007; Vouligny et al., 2009) and some variables that are not present in the literature but seemed to us appropriate to add after a preliminary field audit. It is the case for example of the distinction between the different forested elements (forest, isolated

trees, copses, hedges, etc.) or to the composition of residential spaces such as walls and fences, advertising hoardings, etc. This field audit was conducted over five days in early autumn 2014 in identical weather conditions by two researchers together on all 60 individuals, to ensure inter-rater reliability by discussing the classifications and metrics for each case. The grid was composed of 32 metrics pertaining to landscape composition, configuration, and aesthetics and referring to the three themes set out below.

Natural elements and green areas (12 variables)

Previous studies noted the influence of natural elements and green areas on landscape satisfaction, such as for example agricultural areas (e.g. Hietala-Koivu, 1999; Howley et al., 2012; Lindemann-Matthies et al., 2010), vegetation (Ellis et al., 2006), water (Faggi et al., 2011) and gardens (Kendal et al., 2012). This description allowed for the features not included in the land-cover data presented such as copses or isolated trees, gardens, orchards, and kitchen gardens.

Residential spaces (11 variables)

These metrics were used to characterize the anthropic composition of landscapes by several elements such as the visual preponderance of built environments (Arriazza et al., 2004), the type of architecture characteristics, street and main roads, or the visual impact of more point-like features. Under this heading, we also took into account the upkeep of residential spaces, which is noted as an important element affecting neighborhood satisfaction by Hur and Nasar (2014). Most of the variables have been defined here in field audits so as to be adapted to the description of a suburban residential zone.

General configuration of the landscape (9 variables)

These metrics derived in part from theories of landscape aesthetics (Ode, Tveit, & Fry, 2008) provide the possibility of allowing for more general landscape atmospheres. The texture metric, for example, can be used to determine the diversity of depths of view of landscape scenery through the arrangement of landscape features. Coherence provides information in a complementary way about the level of harmony of landscape features composing the scenes. Metrics specifying the degree of openness of the landscape, the level of enclosure, and the general topography may also be important in establishing the overpowering or uplifting effects of landscape (Rogge et al., 2007, Appleton, 1975). Stamps (2002) also showed the importance of the shape of the skyline on preferences.

A modality was attributed to each variable of each observation site surveyed making it possible (1) to determine the level of visual presence of landscape elements or (2) to characterize certain elements of landscape scenes.

Tab. 1. *In situ* metrics considered by the landscape analysis grid

Metrics	**Categories**
Natural and green spaces	
Forest	absence, slight presence, marked presence
Copses	absence, slight presence, marked presence

Hedges	absence, slight presence, marked presence
Shrubs and tall grasses	absence, slight presence, marked presence
Isolated trees	absence, slight presence, marked presence
Gardens	absence, slight presence, marked presence
Kitchen gardens	absence, slight presence, marked presence
Grassland	absence, slight presence, marked presence
Cropland	absence, slight presence, marked presence
Orchards	absence, presence
Still water	absence, presence
Running water	absence, presence
Residential spaces	
Residential service	absence, presence
Street	absence, presence
Main road	absence, presence
Pylons or power lines	absence, presence
Advertising hoardings	absence, presence
Walls and fences	absence, presence
Car parking areas	absence, in street, car park
Industrial and commercial estates	absence, slight presence, marked presence
Visual preponderance of built environment	few visible buildings, built environment predominant, immersion in the built environment
Architectural characteristics	historical/vernacular, traditional, contemporary, housing estates
Quality of urban furniture	poor, moderate, good
Upkeep	poor, moderate, good
General configuration	
Openness (overall impression in middle ground)	closed, semi-open, open
Enclosure	hidden, private, visible
General topography	overlooking, overlooked, neutral
Horizon and shape of relief	flat, undulating, rough, imperceptible
Degree of naturalness	natural, intermediate, artificial
Coherence	harmony, intermediate, discordance
Color contrast	weak, moderate, stark
Texture	smooth, intermediate, rough

2.4. Land cover data and GIS visibility metrics

The land-cover data were defined mainly from a vector data base (BD Topo IGN, 2009) used for characterizing buildings, artificial areas, transport infrastructures, forests, and water bodies. The BD Agreste (2010) was used for characterizing agricultural areas, by distinguishing grassland and cropland These data were digitized at 5 m resolution. The resulting map was composed of 14 land cover categories (**Fig. 2**). Two other data layers at 5 m resolution were used to compute visibility metrics: a digital elevation model (DEM) and a digital surface model (DSM). A 50 m spatial resolution DEM was provided by the French National Geographic Institute (IGN). This DEM was re-sampled and interpolated by the regularized splines method to give the same resolution as on the land cover data. The DSM was defined by attributing a given height to land-cover categories corresponding to objects that might hide the view. Accurate information about the height of each building was obtained

from the BD Topo (IGN), while a random height between 15 m and 25 m was assigned to the forest pixels. A height of 0 was assigned to all other land-cover categories.

The visible landscape modeling was based on the solid angles method (Domingo-Santos et al., 2011) for quantifying the landscape visible on the retina of a potential observer. These analysis were performed with the PixScape software (see https://sourcesup.renater.fr/pixscape/en.html).

From each residential location, the landscape was characterized by 22 metrics.

Composition metrics quantified each visible element from the 14 land-cover categories to characterize the visual content of landscapes (Joly et al., 2009; Miller, 2001). For a landscape category *i*, *P(i)* is the proportion of angular surface given by:

$$P(i) = \frac{a_i}{\sum_{j=1}^{n} a_j}$$

where a_i is the number of pixels corresponding to the category *i* and *n* is the number of landscape categories.

In addition, configuration metrics allowed to measure the diversity of the visible landscape (S), its degree of aggregation or fragmentation (CONTAG and IJI), its openness (DISTave), its texture (SD and DL), and the shape of the skyline (SL), which can be more or less rough according to the relief or the presence of elevated elements (see appendix C for details).

From the residential location of each of the 60 individuals, we defined a reticular environment of 500 meters, corresponding to a walkable neighborhood around residential locations. Within this neighborhood, the GIS visibility metrics were computed every 10 m, at a height of 1.75 m. The resulting values were finally averaged by residential location to represent the day-to-day landscape around each of them. The appendix D presents the descriptive statistics of all the variables.

2.5. Statistical analysis

Several statistical analyses were conducted to evaluate the effect of landscape elements on individuals' satisfaction. As the satisfaction was dependent on the combination of several landscape characteristics, we used multivariate statistical models in which landscape satisfaction was the target variable and indicators describing landscape were the explanatory variables. Two different models were put in place by taking account of the statistical nature of the metrics: (1) OLS multiple regression to evaluate the influence of GIS visibility metrics which are quantitative, and (2) multiple analysis of variance (MANOVA) to estimate the role played by *in situ* metrics which are qualitative. Both models were applied with a variable-selection procedure based on minimizing the Akaike Information Criterion (AIC). This procedure was applied to all possible combinations including 1 to 10 explanatory variables.

2.6. Cross-classification analysis of metrics

The Moran index was calculated from a neighborhood of from 200m to 2000m every 200m for the residual variables derived from the two models, to check for any spatial autocorrelation, which would indicate a geographical gap in the explanatory variables.

To assess the shared contribution of each set of metrics, the common explained variance between the two models was quantified by calculating the r2 coefficient between the two series of predictions of individuals' satisfaction. Model residuals were then analyzed to identify locations where satisfaction is well explained by *in situ* metrics (weak MANOVA residuals) but less well explained by GIS visibility metrics (large residuals of OLS regression) or vice versa. To do this, each residual variable was discretized into three classes (strongly negative, around zero, and strongly positive) using the values $-0.5\,\sigma$ and $+0.5\,\sigma$ as class limits. The residual variables discretized in this way were then cross-classified so as to define nine cases. The more specific cases were subjected to a qualitative ground survey to find ways to better understand how the models deviated.

3. Results

Tab. 2 sets out the results of the statistical analyses. All the VIF values are less than 7 for each of the three models, proving the absence of collinearity among variables. The results are presented in two lots for each of the models.

Tab. 2. Results of the OLS regression and the MANOVA (* *p < 0.05; ** p < 0.01; *** p < 0.001)*

Model	***Variable***	***Coefficient***	***Normalized coefficient***	***Student's t***	**VIF**
OLS regression	*Constant*	4.363			
(GIS metrics)	*DEPTHLINE*	0.045	0.349	1.73	3.97
r2 = 0.466	*CONTAG*	-0.039	-0.304	-1.78	2.84
Adjusted R2 = 0.394	*Residential buildings*	-3.349	-1.015	-4***	6.28
p < 0.0001	*Retails buildings*	-5.586	-0.708	-4.88***	2.05
AIC = -156.56	*Grassland*	-7.484	-0.474	-2.65*	3.12
	Cropland	-9.870	-0.514	-2.89**	3.08
	Water	-77.425	-0.410	-3.76***	1.16
MANOVA	*Constant*	-0.560			
(in situ metrics)	*Cropland (absence)*	0.670	0.620	3.35**	1.06
r2 = 0.463	*Cropland (slight presence)*	0.750	0.580	3.14**	1.06
Adjusted R2 = 0.379	*Openness (closed)*	-0.320	-0.430	-3.30**	1.17
p < 0.0001	*Openness (semi-open)*	-0.170	-0.260	-2.00	1.14
AIC = -154.27	*Topography (overlooking)*	0.005	-0.010	-0.06	1.13
	Topography (overlooked)	-0.520	-0.350	-3.29**	1.04
	Color contrast (weak)	0.430	0.580	4.12***	1.29
	Color contrast (moderate)	0.110	0.170	1.26	1.17

3.1. Model based on GIS visibility *metrics*

The selection of the better model has led to the selection of seven explanatory variables among the 21 candidates. The explanatory power of the model is significant (r2 = 0.466; Adjusted R2 = 0.394; $p < 0.001$; AIC = -156.56). Two configuration metrics are selected: the texture (DL) which affects residential satisfaction positively and the contagion index which plays a negative role. Five composition metrics also selected are negative with respect to residential satisfaction: residential and retail buildings, agricultural areas (cropland and grassland), and water.

3.2. Model based on in situ metrics

Of the 32 *in situ* metrics, four have been selected from the MANOVA. They describe the presence of croplands, color contrasts, landscape openness, and general topography. The proportion of variance explained is lower overall than in the previous model (r2 = 0.463; Adjusted R2 = 0.379; $p < 0.0001$; AIC = -154.27). The absence or limited presence of croplands and landscapes with weak color contrasts influence individuals' satisfaction positively. Conversely, closed and overlooked landscapes affect satisfaction negatively.

3.3. Measuring spatial autocorrelations

The z-scores associated to the Moran index calculated at each step of distance are between -1.23 and 0.69 concerning the OLS regression, and between -0.36 and 0.38 concerning the MANOVA. The p-values calculated in each case are always higher than 0.1 concerning the OLS multiple regression, and always higher than 0.2 concerning the MANOVA. These values are not significant at the 5% level, which shows that no spatial autocorrelation of residuals occurs.

3.4. Cross-classification analysis

The common explained variance between the two models is low (10.4%) and leads us to explore the model residuals more closely.

The cross-classification analysis of residuals is dependent on the classification of residential locations in nine cases (**Fig. 3**).

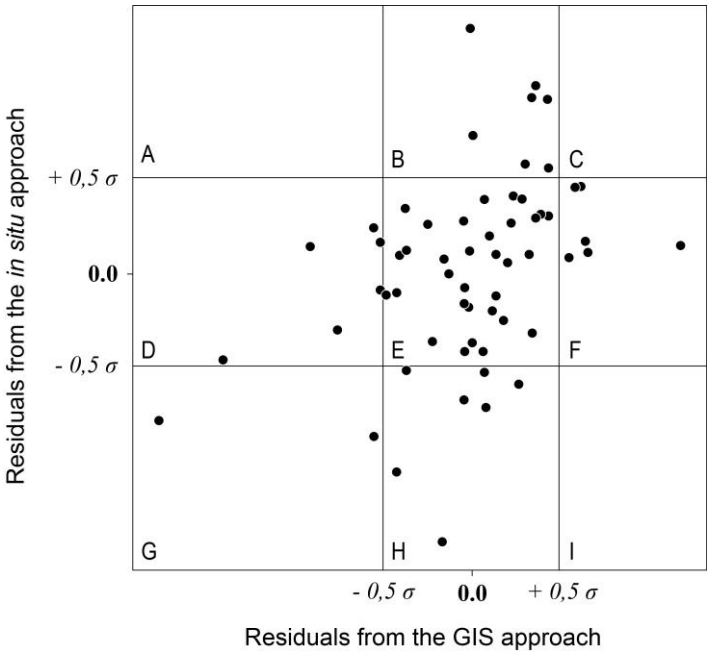


Fig. 3. Cross-classification analysis of residuals. Residential locations are positioned on the scatter-plot given the residual values of each statistical model.

Cases A, C, and I do not concern any residential location while case E corresponds to a good explanation by both models. Cases B and H respectively concern an overestimation and underestimation of the model based on *in situ* metrics. The last three cases particularly claim our attention:

- Case D: residuals around zero in the *in situ* model and strongly negative in the GIS-derived model. This case applies to situations where a favorable feature identified in *in situ* metrics is absent from GIS visibility metrics.

- Case F: residuals around zero in the *in situ* model and strongly positive in the GIS-derived model. This case suggests that a landscape element described by the *in situ* variables (but overlooked in the GIS visibility metrics) unfavorably influences satisfaction.

- Case G: residual strongly negative for both models. This case suggests that a feature perceived as a nuisance in the residential environment is ignored in both approaches.

To illustrate the value of the crossing analysis, one location meeting the criteria D and F and G were randomly defined and surveyed in the field.

The residence representing the criterion D is located on a site providing a degree of intimacy, overlooking the surrounding residential space. The opposite situation is observed for the criterion F. The residential location is located on a very visible site overlooked by the surrounding residential space. These elements, not characterized by GIS visibility metrics, are well revealed by *in situ* metrics and appears to have an effect on landscape satisfaction. For the criterion G, residential location concerns a more built-up pattern, with the presence of an apartment building adjacent to an unused semi-public residential space lending an impersonal feel to this location. We also observed significant road traffic in the neighborhood.

4. Discussion

The purpose of this article was to compare two approaches of landscape evaluation for residential satisfaction modeling: (1) an approach based on landscape metrics collected *in situ* and (2) an approach based on the use of GIS visibility metrics constructed from spatial data. To achieve this objective, the analysis consisted in explaining the residential satisfaction of a sample of 60 individuals by using the metrics provided by the two approaches as explanatory variables. Comparison of the explanatory powers of the models reveals a slight difference that GIS visibility metrics explain slightly better individual satisfaction (r2 = 0.466; Adjusted R2 = 0.394; AIC = -156.56) than *in situ* metrics (r2 = 0.463; Adjusted R2 = 0.379; AIC = -154.27). This result suggests that some of the information contained in the landscape and to which individuals are sensitive can be captured equally well by a GIS evaluation as by a field audit, thus infirming our first initial hypothesis. We can note that the sample of 60 individuals could contribute to reduce the reliability of the models compared to the initial number of 1057 individuals. However, we argue that this sample was a good tradeoff between the valuable time to the in situ analysis and the reliability of the models.

Regarding the metrics selected by the models, all composition metrics have a negative effect on landscape satisfaction. This is particularly true of the presence of water, which is counter-intuitive given the many studies showing water to be the most attractive element of a landscape (e.g. Faggi et al., 2011; Kaltenborn and Bjerke, 2002), producing beneficial psychophysiological effects (e.g. Hartig et al., 1991; Parsons, 1991) or influencing the amenity value of residential locations (Mahan, Polasky, & Adams, 2000; White & Leefers, 2007). However, the water elements present in study area are not rivers and large expanses of water such as lakes. They are small streams whose unprepossessing character (lack of maintenance, unhealthiness) has been emphasized in the field. The negative effect of the view of the built elements appears consistent with Arriaza et al. (2004) and with studies about restorative environments claiming that the exposure to urban environments (in contrast to natural environments) has a negative role on affective states Ulrich (1979) and attention restoration (Kaplan & Kaplan, 1989). In our study, agricultural areas also have a negative influence on landscape satisfaction, whether grassland or cropland. It exists contradictions in the literature about the landscape satisfaction associated to cropland and grassland. For example, Howley et al. (2012), Stumse (1994) and Hietala-Koivu (1999) highlighted that grassland (or extensive agricultural landscapes) are generally preferred than cropland (or intensive agricultural areas), and Arriazza et al. (2008) claims the opposite idea proving in its study that people prefer intensive and homogeneous agricultural areas. Several studies focusing on grasslands have showed that their intrinsic characteristics influence the people preferences, for example the species richness or plants (Lindemann-Matthies et al., 2010) or the presence of dispersed trees (Ives and Kendal, 2013). In order to understand why in our case grasslands play a negative role on residential satisfaction, we think that more accurate and detailled information on their intrinsic composition and configuration could help to better explain it. The positive effect for people of landscape openness is recognized by many studies (e.g. Kaplan, 1985; Rogge et al., 2007), but depending on the type of landscape seen (Coeterier, 1996). Along the same lines, the positive role played by the overlooking position of the residential location is consistent with the *prospect-refuge theory* (Appleton, 1975)

explaining that people prefer places where they could have a wide view (*prospect*), while going unseen (*refuge*).

It is worth noting that the distances covered in the field around residential locations differ from the reticular distance for calculating GIS visibility metrics. Here, GIS calculations characterized the landscape within a relatively wide residential environment whereas field observations were limited to the near residential environment. Moreover, although the study bears on two ways of evaluating the same landscapes, the two groups of variables compared are not equivalent because certain variables are specific to the *in situ* approach. This is the case of the variables for aesthetics and the general configuration of the landscape, which seem to have an effect on satisfaction. To put this bias aside, the analysis could be supplemented by comparing variables that can be strictly transposed from the *in situ* to the spatial approach. For example, the forest variable that occurs in both groups has a better explanatory power in GIS visibility metrics (r2 = 0.139) than in *in situ* metrics (r2 = 0.071). Conversely for openness, the variable computed from spatial data gives an r2 of 0.006 whereas the corresponding *in situ* variable brings an r2 of 0.086. However, all of the equivalent variables in both approaches were selected only by one model (e.g. texture in the GIS evaluation, and openness in the *in situ* evaluation), confirming the complementarity of these approaches.

The return to the field on three residential locations (**Fig. 4**) allows us to better understand the limitations of GIS-visibility metrics. Locations D and F confirms the prospect-refuge theory of Appleton (1975). It may therefore be assumed that the shortage of information in the model based on spatial metrics contributes to overestimating the individual's predicted satisfaction value. Location G features an apartment building, although such housing is very scarce in the suburban areas of the study area and was not included in the architectural characteristics in the analysis grid. Spatial data also failed to differentiate between houses and apartment buildings. Concerning the unused semi-public residential area, the feeling of appropriation and of place attachment of a residential area are essential features in the way individuals perceive and enjoy space (Bonaiuto, Fornara, & Bonnes, 2003). However, noise pollution associated with road traffic in this residential area is a substantial explanatory factor of the degree of individuals' well-being and residential satisfaction (Gidlöf-Gunnarsson & Öhrström, 2007; Skånberg & Öhrström, 2002). It is important here to recall that the *in situ* observations were made off the premises of the individuals surveyed and were limited to consideration of the quality of their private space and their level of privacy. Moreover, it should be observed at this stage that the share of uncertainty observed in the models may also be related to personal variations in landscape appreciation.

D

F

G

Fig. 4. Photographs of selected residential locations

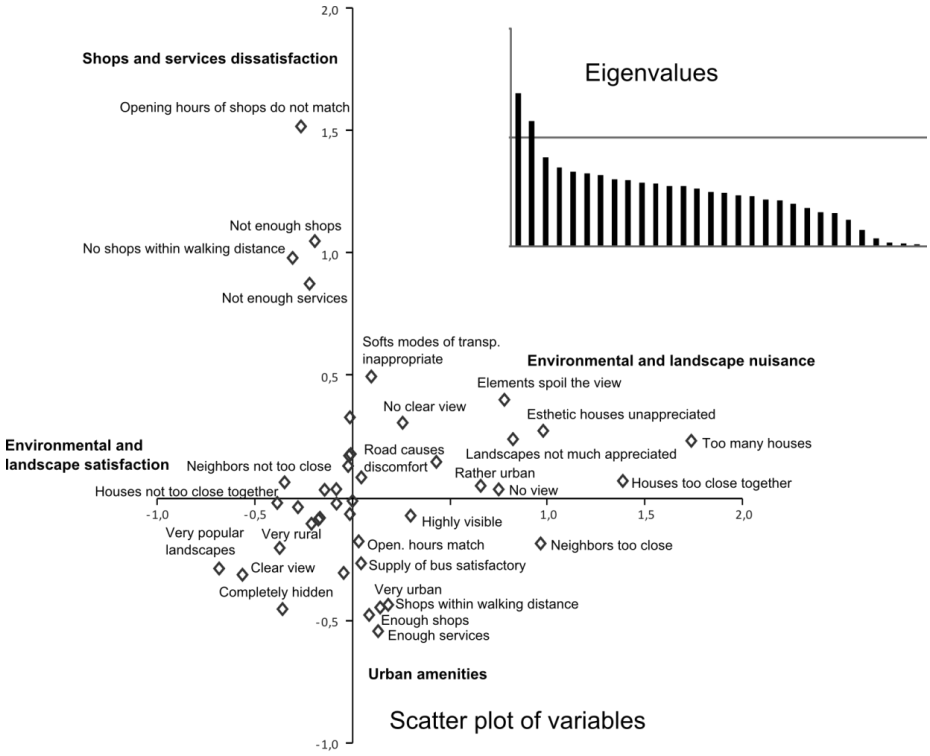
These three cases attest to the need for closer consideration of land use rather than mere land cover. Landscape and the residential environment more generally cannot be reduced to their material character alone. They are also interpreted and meaningful in terms of the use of the objects that compose them and those uses may be perceived as amenities or disamenities. Allowance for the quality of soundscapes of suburban areas might also be a way to improve models. To supplement this study, it would be instructive to test again the worth of GIS visibility metrics by using very high resolution data (e.g. Lidar) and by comparing the same variables over several levels of spatial resolution. The point that small landscape elements (pylons, power lines, advertising hoardings, walls, fences) that are not usually shown on land cover maps are not selected in the model based on *in situ* metrics is a further argument. However, this approach runs up against the problem of the cost of acquiring and processing very-high resolution data, which limits its potential generalization. In this perspective, it was said earlier that the use of high-resolution spatial data would make it possible to capture additional landscape features or to reveal a more complex landscape pattern. Another possibility would be to improve the descriptive quality of GIS visibility metrics, especially by transposing certain aesthetic landscape descriptors in the form of spatial indicators (Ode et al., 2008).

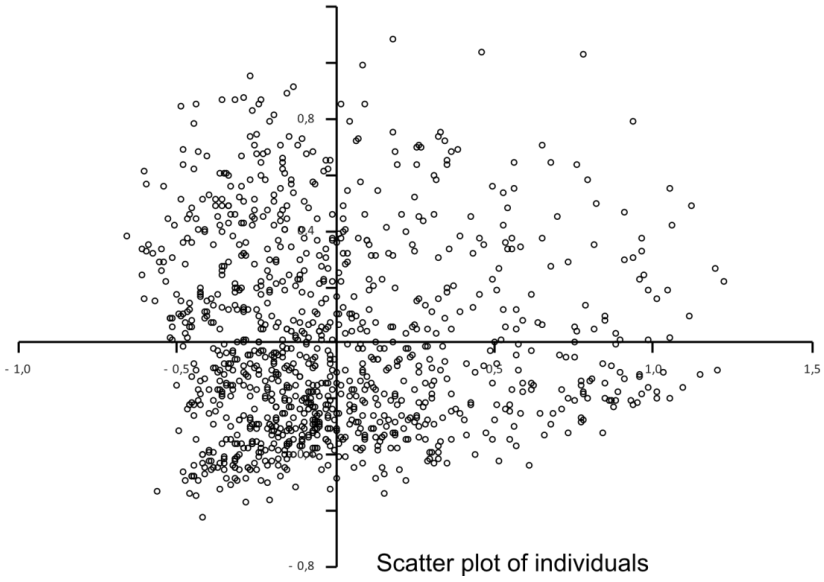
Ultimately, it is possible to discuss the reliability of residential satisfaction measures as response variables for the assessment of landscape quality. Indeed, surveys based on landscape photographs constitute another commonly used approach for landscape quality assessment (Natori & Chenoweth, 2008; Wherrett, 2000). But the advantage of residential satisfaction measures is that they take into account ordinary landscapes that are the living environment of people. However, the main shortcoming is that the landscape is only one of the components of residential satisfaction, and that taking into account other attributes of the residential area is likely to minimize the importance of the landscape. The same considerations may apply to econometric modeling based on housing values.

5. Conclusion

This study shows that residential satisfaction associated with landscape is explained just as well by GIS evaluation as by *in situ* evaluation. These results contradict our main hypothesis that richer and more subtle information of *in situ* metrics provides a greater explanatory power of residential satisfaction. However, they demonstrate the quality of the GIS visibility metrics created from spatial data, even if certain information about the landscape, such as that relating to landscape ambiance, can only be captured through field audits. The findings show, however, that each of the two approaches yields specific information that is complementary rather than redundant. One of the challenges of this study is to better explain satisfaction by refining spatial metrics. Several avenues have been contemplated for achieving this. Several ways could be followed to improve the assessment of individual satisfaction: the resort to high-resolution spatial data, the construction of metrics describing land use rather than land cover, and the development of metrics for visible landscape patterns to describe various aesthetic aspects of landscape. The aim is eventually to establish a method for evaluating landscape quality that can be generalized and could serve as a decision-making tool in regional planning and urban development. Even if our results are particular to a context of suburban areas, we argue that our protocol could be reproduced in other urban and landscape contexts with a step of calibration through conducting another residential satisfaction survey.

Appendix A. The results of the MCA





Appendix B. The assertions used to evaluate landscape satisfaction. F1 and F2 correspond to the coordinates of the assertions in the MCA factorial space.

	Assertions	MCA Factors F1	F2
Assessment of daily landscape	In your neighborhood, you feel that your home is		
	completely hidden	-0.36	-0.45
	a little hidden	-0.14	0.03
	rather visible	-0.02	0.13
	highly visible	0.30	-0.07
	You think that the environment around your home is		
	very rural	-0.37	-0.20
	rather rural	-0.01	0.33
	rather urban	0.66	0.05
	very urban	0.18	-0.44
	Around your home, you feel that the view is		
	completely blocked	0.75	0.04
	rather blocked	0.26	0.31
	rather unobstructed	-0.17	-0.09
	completely unobstructed	-0.56	-0.31
	Around your home		
	you do not appreciate the landscape	0.82	0.24
	you rather appreciate the landscape	-0.08	0.04
	you appreciate the landscape a lot	-0.68	-0.29
Accessibility to shops and services	There are enough shops in your neighborhood		
	Yes	0.09	-0.48
	No	-0.19	1.05
	Retail shops are within walking distance		
	Yes	0.14	-0.45
	No	-0.31	0.98
	The opening hours of shops match your needs		
	Yes	0.03	-0.18
	No	-0.26	1.52
	There are enough standard services in your neighborhood		
	Yes	0.13	-0.54
	No	-0.22	0.87
Perception of aesthetics and density of built surroundings	You feel that your neighbors are too close		
	Yes	0.96	-0.18
	No	-0.35	0.06
	In your home, the proximity of the roads causes discomfort		
	Yes	0.43	0.15
	No	-0.08	-0.02
	You enjoy the aesthetics of the houses in your neighborhood		
	Yes	-0.17	-0.08
	No	0.98	0.27
	In your neighborhood, you feel that the houses are too close to each other		
	Yes	1.39	0.07
	No	-0.38	-0.02
	From your home, some features spoil the view		
	Yes	0.78	0.40
	No	-0.21	-0.10
	You think that there are too many houses in your neighborhood		
	Yes	1.74	0.23
	No	-0.28	-0.04
Conditions of transportation and daily mobility	For your daily movements, the bus takes more time than the car		
	Yes	0.05	0.08
	No	-0.04	-0.30
	The supply of public transport is sufficient		
	Yes	0.04	-0.27
	No	-0.01	0.18
	It is easy to move in the neighborhood by using soft modes (walking, cycling)		
	Yes	-0.01	-0.06
	No	0.10	0.50

Appendix C. Details of configuration metrics computation

Metrics	Code	Description	Values
Skyline	SL	Obtained by dividing the total length of the horizon by a straight line whose length corresponds to the width of the view.	Close to 1 when the horizon is planar, and highest (unbounded) in the case of a very jagged skyline.
Openness	DISTave	Obtained by the mean of the length of sight lines.	Higher when the view is broader (in meters).
Contagion	CONTAG	Based on pixel adjacencies in the image (O 'Neill et al., 1988). It corresponds to the probability of finding a pixel of the landscape category *i* next to a pixel of the landscape category *j*.	Close to 100 if a same landscape category are clustered, close to 0 for images in which all pixels are dispersed.
Interspersion and Juxtaposition Index	IJI	Based on patch adjacencies of the landscape (McGarigal & Marks, 1995). Each category is evaluated according to its adjacency with all other categories.	Close to 100 if no regularity is observed and close to 0 if landscape categories are arranged in a highly structured manner.
Shannon diversity index	S	Based on the notion of entropy (Shannon & Weaver, 1971). It is used to measure the diversity of the visible landscape.	Close to 0 if there is a unique landscape category, and close to 1 if a significant number of categories are present in equal proportions.
Shannon distance	SD	Texture of the visible landscape, i.e. the greater or lesser variation of sight lengths, evaluated using DL (spatial variation of the view depth) and SD (normalized Shannon based on the ratio of sight lines in defined length classes). In the case of SD, five length classes were defined: less than 10 m, from 11 to 100 m, from 101 to 1000 m, from 1001 to 10 000 m, and more than 10 000 m.	Close to 0 when only a few variations in length are present and close to 1 when many variations occur.
Depthline	DL		Minimal value of 1 in the case of a circular-shaped viewshed, and high values (not bounded) in the case of marked variations in view depth.

Appendix D. Descriptive statistics of GIS variables aggregated for each residential location

Metrics	Min.	Max.	Mean	Variance	Stand. Dev.
SL	1.247	3.676	1.791	0.161	0.401
DISTave (in meters)	43.894	140.543	70.266	346.456	18.613
CONTAG (in %)	72.103	86.173	77.398	6.488	2.547
IJI (in %)	31.891	57.081	43.404	29.635	5.444
S	0.271	0.543	0.441	0.002	0.049
SD	0.405	0.779	0.648	0.004	0.061
DL	6.261	20.857	12.239	6.493	2.548
Shrubs	0.000	0.009	0.003	0.000	0.002
Cropland	0.007	0.092	0.025	0.000	0.017
Grassland	0.004	0.088	0.031	0.000	0.021
Artif. Ground	0.000	0.007	0.001	0.000	0.001
Forest	0.114	0.712	0.301	0.014	0.118
Resid. Area	0.035	0.174	0.114	0.001	0.033
Ind. Area	0.000	0.087	0.012	0.000	0.014
Water courses	0.000	0.012	0.001	0.000	0.002
Water bodies	0.000	0.007	0.001	0.000	0.001
Sec. Road	0.073	0.148	0.120	0.000	0.017
Prim. Road	0.000	0.065	0.006	0.000	0.015
Railroad	0.000	0.009	0.001	0.000	0.002
Resid. Build.	0.055	0.501	0.326	0.010	0.099
Ind. Build.	0.000	0.284	0.033	0.002	0.042

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