

The Concept and Implementation of Perceptual Regions as Hierarchical Spatial Units for Evaluating Environmental Sensitivity

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Abstract: *Studies of human spatial behavior and life spaces are useful because they allow a better understanding of the relationship between people and environment. In an era when there is growing public pressure to understand this relationship, studies of life spaces may provide insight into the environmental sensitivity of different groups of people. In this article, we propose a method for characterizing life spaces based on perceptual factors and show how the method can be used to explore the sensitivity of humans to environmental quality and to study human spatial behavior in the form of residential choice. In particular, the perceptual regions that we introduce constitute new hierarchical spatial units of analysis that join location to activities, the two key concepts of life spaces. The structural and environmental differences of the perceptual regions in relation to the sociological characteristics of urban and suburban behaviors are explored for two districts within the city of Québec (Canada). The approach offers the potential for developing some interesting applications in urban planning: the means to be more sensitive to the wishes of individual households in decisions concerning urban spaces, and a tool to assist persons evaluating different residential locations. It is noted that the analyses performed may be largely automated.*

Introduction

Human spatial behavior expresses itself in many ways (Golledge and Stimson 1997). One of the most interesting, albeit highly complex, forms of such expression is the creation of life spaces, particularly built environments, such as are found in cities.

The concepts and methodologies currently used for studying life spaces are far from being widely accepted. The variety of approaches proposed is a result of both the complexity and the multidisciplinary nature of the subject. The best example of this complexity is probably the great variety of terms that are used to define life spaces. These vary according to both the disciplines concerned and the spatial scale. At its origin, the term “human territoriality” is a biological term. It concerns the locations that people own, occupy, or use for varying periods of time (Taylor 1988). The notion of “place,” on the other hand, taken from geography, represents both a position in society and a spatial location (Tuan 1996). Within this view, places are foci where we experience the meaningful events of our existence and points of departure from which we orient ourselves and take possession of the environment (Norberg and Schultz 1971). “Spatial familiarity” is a concept that links space and cognition. It implies a state of knowledge brought about by repeated association with the space concerned (Gale et al. 1990). “Neighborhood” is the most general term and has been defined as a series of dimensions that are independent of each other in certain situations while being

highly interrelated in other situations (Lyon 1987).

It appears from these definitions that the study of life spaces depends mainly on where people are and what they do. The two key concepts in each of these analyses are location and activity (Garling and Golledge 1993).

Research on the Implementation of Human Spaces in Analyses

Among the many recent approaches to the definition of life spaces and spatial perception, several address recommendations, difficulties, and perspectives for implementations. Crevoisier (1996) highlights three particular difficulties in the formalization of the concept of territory: the consideration of both physical and socio-economic proximities, the superimposition of the dimensions of social life, and the specificity of the territory in each case.

An important concept in the definition of human spaces is to consider the hierarchical interrelation of spaces. The evidence of hierarchical processing is emphasized by Fotheringham and Curtis (1992). Human sensitivity to space is at the center of a great deal of research, but the implementation or structuring of these hierarchies is often different from one work to the next. Among others, Hirtle and Jonides (1985) and Hirtle (1995) develop hierarchies based on the use of trees and lattices that were in turn adapted by McNamara (1986). On the other hand, Davis (1981) introduced inferences between cross-hierarchical repre-

sentations. The conceptual task of modeling hierarchies is very difficult, perhaps because of the complexity of human reasoning.

The means for incorporating the concept of the “home” in analyses have been extensively explored. The meaning of house and home in the United States was reviewed by John Adams (1984). Waddell and Shukla (1993) emphasized the importance of elaborating theories about home in a variety of local settings. Shanton (1986) elaborated on different types of areal concept associated with the idea of “home.” Aitken and Prosser (1990) further studied these areal forms, based on cognitive and behavioral data. Their findings indicate that there is a structural difference in the spatial familiarity of residents who perceive their neighborhood as an area and those who perceive it as a network.

Edwards (1997, 2000) developed a simulation of human spatial memory that structures experiential space based on reinforcement (see discussion of spatial familiarity above). This model does not distinguish in any fundamental way between externally experienced events and internally experienced events. Only actions are given distinct status. As a result, internal spaces are structured along similar lines, as are representations of external space, and there are natural links between the two. This provides a novel way to link perceptual and physical spaces.

Urban versus Suburban Location, Environment and Behavior

The space of a city is composed of an overlap of different land covers, land uses, and environmental characteristics. The urban area is characterized by a great density of buildings and, inversely, a scarcity of green spaces. The characteristics of this environment are one of the determinants in the choice of residential location. With simplification, urban inhabitants appear to have greater preference for the urban characteristics of the environment than do the inhabitants of suburban regions, who appear to prefer greenness, nature, and a greater house or lot size. Environmental variables are certainly important to characterize the different home spaces in a city. We can call this the “environmental description” or quality of the human space.

These spaces are used differently by people as a function of their activities, their environmental sensitivity, and their social characteristics. Pacione (1990) introduced the concept of urban livability, a relative term whose precise meaning depends on the place, time, and purpose of the assessment and on the value system of the assessor. Pacione emphasized the possible delimitation of sub-areas in the city based on the relationship between environment and social behavior. Remy and Voye (1993) have suggested a differentiation of spatial perception according to the spatial behavior of groups in situ. Activity patterns help determine the extent of perceived neighborhoods (Walmsley and Lewis 1993) and contribute to the “environmental structure” of the human space. It is likely, for example, that the environmental structure of space for persons who exhibit urban behavior is smaller and closer to their homes than for persons who exhibit suburban behavior.

However, there are two explanatory factors for such patterns of activities: the household (or family context) and the spatial

context. Accessibility issues will impact the patterns of everyday activities less in urban areas than in suburban areas, because of the density of places where activities may occur (Hanson 1982). Due to the variation among environmental characteristics, we can assume that, in general, the spatial context in urban or suburban areas will influence the structure of the individual life spaces of the inhabitants. More precisely, location affects the modes and frequencies of everyday mobility, the way in which knowledge about the environment is acquired, and the presence of opportunities and constraints in the local environment.

Objectives

From a review of the literature, that it should be possible to develop hierarchical spatial units that are representative of spatial behavior of people. Indeed, the shape of these units and the presence of additional environmental constraints constitute assessments of the environmental sensitivities of people. Although the survey shows that perception has been widely recognized to play a role, no single method for handling perception from a methodological perspective has emerged.

The objectives of this article are to propose a clear methodology for including perception in the analysis of environmental sensitivity of households and to explore the implementation of this methodology in a geographic information system (GIS) structure. In particular, we introduce the concept of perceptual regions, a new hierarchical set of spatial units that join location to activities, the two key concepts of life spaces. The structural and environmental differences of the perceptual regions are explored in relation to the sociological characteristics of urban and suburban behaviors.

In this article, the concept of perceptual regions is introduced. These are comprised of three hierarchical spaces where perception plays different roles. Following this, the methodology and hypotheses of implementation are presented. An analysis of environmental quality is then presented for two districts within the city of Québec (Canada) with different urban characteristics. The data are derived from remotely sensed images, topographical maps, and an origin/destination survey that provides information about the activity spaces. Discussion concerning environmental sensitivity in relation to urban and suburban residential choices and behaviors follows these results.

The Concept of Perceptual Regions

The concept of a perceptual region addresses the integration of the two key concepts in each of these analyses: location and activities (Garling and Golledge 1993). Associated with a location (or place) are a set of qualities and a set of activities carried out by agents within the location (Figure 1). The combination of these perceived qualities (to the extent that they are viewed in a positive light) and the activities undertaken generate a sense of belonging for the agents with respect to this location. These activities are everyday experiences carried out in and around one or more places. Furthermore, the everyday activities that occur within these regions enter into the agents’ memory and are reinforced or for-

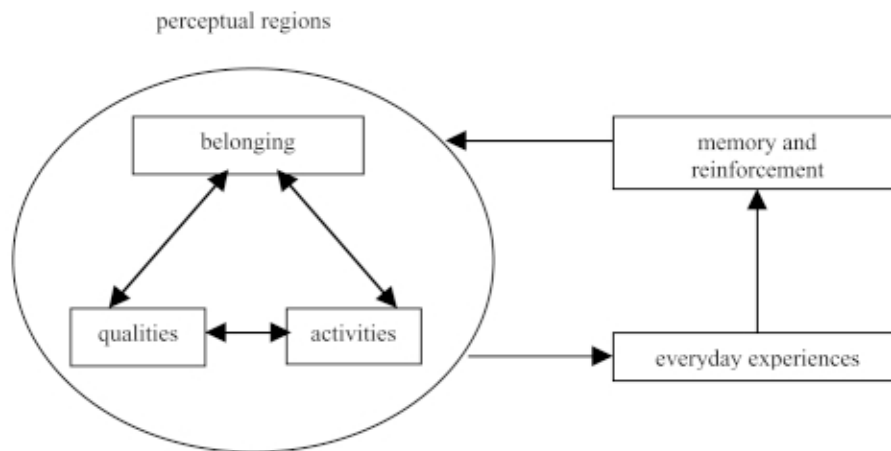


Figure 1: The concept of perceptual regions and the relationships between thematic elements addressed.

gotten as a function of how often the activities are repeated. Hence, frequency is a major determinant for which parts of an environmental space are perceived by individual agents. Different scales of perception correspond to different subsets of these activities.

The Perceptual Regions

The perceptual region is comprised of three elements in interaction: 1) a sense of belonging to a space, associated with a hierarchical structure; 2) a set of environmental qualities; and 3) a collection of activities (the perceptual regions are characterized by nodes and throughways where activities converge). Furthermore, the perceptual regions embrace at least three types of space or sub-region, which are denoted here as the vista space, the local displacement space, and the enlarged displacement space.

Vista Space

Vista space is the first space of the hierarchical structure and corresponds to the spatial node of the activities. It is based on the notion defined by Montello (1993): “as large or larger than the body but can be visually apprehended from a single place without appreciable locomotion. It is the space of single rooms, town squares, small valleys, and horizons.” We adapted this definition to the context of the evaluation of environmental quality: it is a spatial region with perceptually similar characteristics apprehended from a single place, but not determined by vision alone, and which corresponds to a sense of belonging resulting from activities carried out in that region. The vista space can be residential (and, hence, related to the concept of a home), a working place (for adults) or school (for children), or places for other activities. It is the space where the majority of variables of environmental quality are assessed (Reginster and Edwards 2001).

Local Displacement-Reinforcement Space

Local displacement space is the space surrounding the vista space and which comprises the place of frequent visits. To define it, we use the notion of reinforcement.

In related work, Edwards (1997, 2000) developed software architecture for simulating spatial memory. The model used by this simulation is based on the principle that knowledge about a spatial environment is obtained by traversing it many times. The reinforcement of matched events across different trajectories is used to build a number of representations of the space traversed. These representations include lists of reinforced events and event aggregates (chains of events, objects, group, and sites), as well as networks of sites and objects constructed from the trajectories. Distance estimates are likewise managed within the simulation via a set of independent algorithms for measuring distance that are combined into a weighted average. These algorithms include measures of subjective time, visual (angular) measures of distance, and the use of a characteristic distance associated with each aggregated event. The characteristic distance represents the typical separation of objects of a similar type. Using these distance estimates combined with a network representation of sites, it is possible to construct a map representation that assigns a characteristic spatial region to each object. Associated with each object is a reinforcement or importance rating in addition to this characteristic size. This representation is congruent with a similar device used by Kettani and Moulin (1999) to develop a reasoning engine for planning a route through an arbitrary cityscape.

This representation can be used to define the displacement spaces. The reinforcement rating is based on the frequency with which the location is incorporated into a household’s daily journeys, and the spatial region is a circle or ellipse that characterizes the spatial separation of the typical object at the location concerned with respect to other objects of the same type. The union of the set of overlapping regions with reinforcement above some

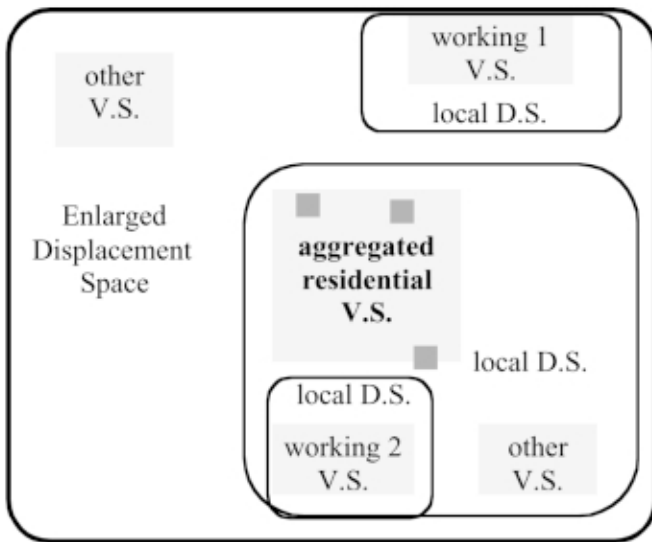


Figure 2: Hierarchical structure of the perceptual region of a district. Shown are vista spaces (V.S.) for residences, work, and other locations, local displacement spaces, and enlarged displacement spaces.



Figure 3: The residential vista space for Sillery, Québec (part of an infrared aerial photo, originally obtained at 1:15,000 scale).

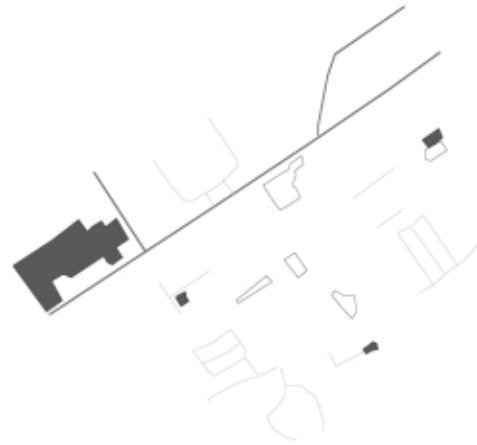


Figure 4: The local displacement space (part of the road network) for Sillery, Québec. Roads are shown in *red*, autoroutes in *dark red*, autoroute exits in *orange*, commercial zones in *dark blue*, schools in *blue*, and green spaces in *yellow*.



Figure 5: The enlarged displacement space (part of an origin-destination survey) for Sillery, Québec. All linear elements show actual displacements along the road system. The thicker and darker the line, the more frequent the displacements along that segment of road and the more heavily reinforced that element of the space.



Figure 6: The residential vista space for Charlesbourg, Québec (part of an infrared aerial photo originally obtained at 1:15000 scale).



Figure 7: The local displacement space (part of the road network) for Charlesbourg, Québec. Roads are shown in *red*, autoroutes in *dark red*, autoroute exits in *orange*, commercial zones in *dark blue*, schools in *blue*, and green spaces in *yellow*.

level can then be used as a map of the displacement space. In the first definition, the local displacement-reinforcement space will correspond to the region surrounding the home; it maps the limits of what is well integrated into the household's activities. Each spatial location (e.g., house, street, park, or school) can be assigned a reinforcement rating and a characteristic spatial region. The spread of the reinforced zones around the home may be used to calibrate the scale of the local displacement region used to approximate the reinforcement zone. This space, like the vista space, can be delimited by barriers in several directions. It corre-



Figure 8: The enlarged displacement space (part of an origin-destination survey) for Charlesbourg, Québec. All linear elements show actual displacements along the road system. The thicker and darker the line, the more frequent the displacements along that segment of road and the more reinforced that element of the space.

sponds to the sense of belonging to the immediate environment around an activity center such as the “home.”

An approximation of the local displacement space could be structured by the use of locomotion inside reasonable temporal limits; however, this has several undesirable characteristics. It leads to a sharp cut off between what is considered to be located within the local displacement space and what is outside this space. It is also subject to the need to define the means of locomotion, and hence might, in principle, lead to several local displacement spaces. However, in the absence of appropriate data in the form of activities in the immediate neighborhood of the residence or other activity locus, such an approximation may be readily developed using available cartographic data.

Enlarged Displacement-Reinforcement Space

The enlarged displacement-reinforcement space consists of the region that embraces both the activity islands beyond the local reinforcement region and the local reinforcement region itself. The enlarged displacement-reinforcement space is hence more a network-like space than an areal space (i.e., it is full of holes!).

Hierarchically Structured Perceptual Regions

The perceptual region, as we define it, includes a hierarchical structure, with a succession of spaces embedded in others, to which people may have a sense of belonging or attachment. Hence, vista spaces are embedded in local displacement spaces and the latter are embedded in enlarged displacement spaces (Figure 2). Larger spaces may also be envisioned (e.g., geographical space as defined by Montello 1993), but are not needed for the purposes of

this study. For the most part, the activities that take place in vista space are household or workplace activities, while activities that take place in displacement spaces are locomotive and broader in scope. Vista spaces will be heavily reinforced, local displacement spaces somewhat less so, and enlarged displacement spaces even less reinforced. There are clearly even larger regions that incorporate occasional displacements and perceptual regions that are acquired via information sharing with the perceptual regions of other agents. Another characteristic of the displacement spaces, highlighted by their origin in memory reinforcement, is that they are heterogeneous regions. They contain large holes where no information may be available (frequentation is nil).

Implementation and Tests on Urban and Suburban Regions

The concept of perceptual regions is implemented in a GIS for two districts within the city of Québec (Canada). These districts are homogeneous residential districts largely characterized by single-family dwellings. The definitions of the three spaces that compose the perceptual region are aggregated for the set of the inhabitants of each of the two districts. The areas chosen for the analysis within Charlesbourg and Sillery are homogeneous both in population and from a morphological point of view.

The district of Sillery, located in the western portion of the city, is closer to the centers of work (e.g., university, administrations, and shops) than the district of Charlesbourg. The area of analysis comprises 1.19 sq km and 1776 inhabitants. Figure 3 shows the an aerial view of the region used in the study to define the vista space, Figure 4 shows the cartographic data used to define the local displacement space, and Figure 5 shows the path traces of displacements derived from the origin-destination survey and, hence, constitutes a visualization of the enlarged displacement space of the neighborhood.

The district of Charlesbourg, located in the northern part of the city, is typically a suburban district. The studied part of the district comprises 4902 inhabitants who for the most part live in bungalows or cottages. The study area covers 2.23 sq km (see Figures 6, 7, and 8, which are comparable to Figures 3, 4, and 5 for the Charlesbourg district).

Data

The implementation requires two kinds of data: 1) spatial coverage including environmental variables, amenities, and constraints; and 2) information about the displacements and locations of everyday activities of family members of the households of the district.

The first type of information is partially derived from remotely sensed images and aerial photos. Greenness and sources of nuisances are extracted from these data. Information from maps, such as the location of amenities, is acquired to complete the spatial coverage. The vista spaces for both districts were extracted by determining the presence of visual barriers for a subsample of households in each district.

Information about the displacements comes from an origin-destination survey of individual daily mobility organized by STCUQ, the public transportation company of the city of Québec (Therault et al. 1996). This survey was done by telephone in 1991, for a population sample corresponding to 8.2% of the total population of the districts. The survey is used to assess the enlarged displacement space of inhabitants. Because of the type of survey and its goal, it was not possible to assess the local displacement-reinforcement space in the same way. Hence, we use the approximation based on the temporal limits of walking, as outlined earlier (Figures 4 and 7).

The data used and extracted from the survey concern:

- 128 households of the Charlesbourg district, which correspond to 402 inhabitants (8.2% of the total population) and 984 displacements (2.4 displacements/inhabitant).
- 51 households of the Sillery district, which correspond to 142 inhabitants (8.2% of the total population) and 296 displacements (2.1 displacements/inhabitant).

The Perceptual Spatial Region of the Districts

The perceptual spatial region of a district comprises three spaces:

- the residential vista space aggregated for the inhabitants of the district;
- the local displacement space aggregated for the inhabitants of the district and which could include non-residential vista spaces such as those for shopping centers; and
- the aggregated enlarged displacement space that includes and links the set of vista spaces of the inhabitants of the district.

Hypothesis and Implementation of the Perceptual Region of Each District

The identification and implementation of the perceptual region in an urban or suburban area require some additional hypotheses, particularly concerning the manner in which people define their sense of belonging in terms of these hierarchical spaces.

The most frequented space is usually the residential vista space. In the suburban region, the aggregated residential vista space is the set of homes and the green space surrounding it that is viewable from the homes even if not within the property of the household. This space can be limited by barriers such as main roads, autoroutes, reliefs, or walls. In suburban areas, this space is generally characterized by the presence of greenness. In urban areas, because of the proximity of buildings, the barriers are generally closer to the houses and the residential vista spaces are less green than in suburban areas. The identification of this space with fuzzy limits is possible on infrared aerial photos at the 1:15,000 scale. Hence, it is assumed that the perception of the environment is strongly determined by the sense of attachment to this vista space, and, in particular, to its greenness.

The local displacement space is assessed on the road and path network. The second definition of this space is used for implementation, characterized by a temporal limit of locomotion by foot. The limits used are 5 or 7 minutes (500 m) of a

normal walk by foot; this region is seen in Figure 4 for Sillery and Figure 7 for Charlesbourg). It is not expected that the results will depend heavily on small differences in the choice of this limit. To implement this second space, a hypothesis on the relationship between sense of belonging and the region characterized by the duration of a short walk is posed.

The enlarged displacement space is assessed from the origin-destination survey. It corresponds to the space frequented by people in a single day. Figure 5 shows the origin-destination data set graphically for Sillery, while Figure 8 shows the corresponding diagram for Charlesbourg. The lines shown correspond to displacements revealed by the survey. Thicker and darker lines are more frequent (i.e., reinforced) displacements. The identification of this third space exploits the hypothesis of a relationship between the sense of belonging to a space and those parts of the space actually visited.

The proposed implementation of the theoretical concepts developed earlier clearly represents a certain simplification. A more complete data set might use a digital elevation model with a detailed micro-relief to determine the vista space, as well as a survey that specifies displacements by foot and vehicle. However, the data set used for this study, along with these simplifying assumptions, appeared to be effective as a test bed for the methodology developed and proposed here, as can be judged from the results reported below.

From a first visual analysis of the component of the perceptual region of Charlesbourg (Figure 6), it is possible to underline the importance of the greenness inside the residential district. The residential vista space and the local displacement space are characterized by the presence of an important barrier and source of nuisances: an autoroute. The enlarged displacement space derived from the origin-destination survey presents a great variety of destination spaces with a general main direction to the south, where many of the work places of the city are localized.

The part of the Sillery district studied (Figure 3) is also characterized by a great deal of green. The road network is limited on the south by the presence of a cliff (Figure 5). The enlarged displacement space is more oriented than that of Charlesbourg. It is possible to identify one main direction of displacement to the east, toward the center of the city.

Development of the Tests Inside the Perceptual Regions

The validation of these perceptual regions is carried out by assessing environmental variables inside each space. The goal of the analysis is to test the environmental sensitivities of two different districts: a suburban area and an area closer to the center of work.

The environmental variables are developed from remotely sensed data and via geomatics tools. These are adapted according to the different structural elements of the vista space, the local displacement space, and the enlarged displacement space.

The suggested environmental variables are:

- the size of the spaces in relation to the number of dwellings,

which is a measure of density of the district;

- the greenness of the space which includes the gardens and public green spaces, an indicator of ecological quality;
- the presence of nuisances determined via the area affected by the negative influence of factories or highways (other sources of nuisances can include garbage dumps, quarries, an airport, etc.);
- the presence of barriers determined via the number of barriers for pedestrian or car locomotion according to the definition of the spaces; it is important to note that the definitions of barriers are different in vista space (view-based), in local displacement space (pedestrian definition), and in enlarged displacement space (car locomotion definition);
- accessibility is measured as a percentage of the area covered by public services (e.g., schools and shops) in the local displacement spaces or as the average distance inside the enlarged displacement space;
- the percentage of short distances (e.g., below a threshold) compared to all distances and to destinations inside the enlarged displacement space acts as an indicator of the life of the district;
- the percentage of long distances (e.g., above a threshold) compared to all distances and to destinations that are outside the zone of attraction;
- the length of the largest dimension for the enlarged displacement space per inhabitant, which is an indicator of length of the displacement of each inhabitant; and
- the length of the largest dimension for the enlarged displacement space not affected by other districts can be used to measure the displacements that are unique to the inhabitants of the given district.

Using some variables, it is possible to identify or establish what could be considered the best value by most people in terms of quality. A large value of greenness or a low value of nuisances could be identified as more desirable in accordance with ecological principles. Moreover, the presence of services could be considered as more desirable in accordance with accessibility priorities. It is important to note that some variables could have a double impact: positive in term of accessibility, but negative in term of nuisances. This is the case of the accessibility to an entrance to an autoroute, which could have noise effects. Some other variables are more dependent on the sensitivity of inhabitants. This is the case, for example, with the size of the vista space, which is typically representative of an attachment to urban or suburban sensitivities. A large vista space could be important for the preservation of private life, but could be considered as a social gap for others. From this set of variables, it is possible to develop a general indicator of environmental quality of the district or an interactive one in accordance with the priorities of individual persons.

Table 1: Comparison of the Two Districts with Environmental Indicators Assessed in the Perceptual Regions

	Charlesbourg (suburban district)	Sillery (closer to jobs)
Vista space size, normalized to a single household	0143 ha	0191 ha
Greenness of the vista space (maximum = 1)	0.31	0.44
Presence of nuisances in the vista space (maximum = 1)	0.19	0.01
Presence of barriers in the vista space	2	0
Local displacement space size, normalized to one household	0,227 ha	0,485 ha
Greenness of the local displacement space (maximum = 1)	0.28	0.43
Presence of schools inside the local displacement space	7	2
Percentage of the area of shops inside the local displacement space	1.8%	0.4%
Percentage of the area of parks inside the local displacement space	4.1%	2.3%
Presence of an entrance to an autoroute inside the local displacement space	2	0
Presence of barriers in the local displacement space	1	0
Average distance to a work destination (origin-destination survey)	7.47 km	5.94 km
Average distance to a school destination (origin-destination survey)	3.96 km	2.47 km
Average distance to a shop destination (origin-destination survey)	3.56 km	3.63 km
Percent of short-distance time (<5 min) to destinations (indicator of district life)	34.2%	53.9%
Percent of long-distance time (>25 min) to destinations	2.5%	5.3%
Length of the through-space/number of inhabitants questioned	16,161 m/inhab.	10,4

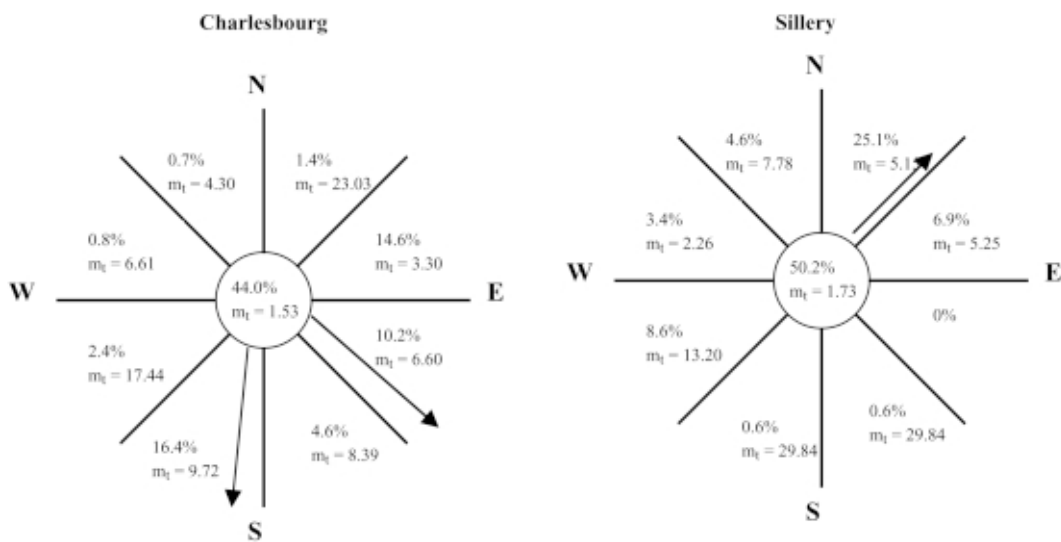


Figure 9: Oriented diagram of displacements for Charlesbourg and Sillery.

Results of Environmental Sensitivity Tests in Perceptual Regions

Comparison of the Two Districts with Environmental Variables

Table 1 compares the two districts in accordance with environmental variables assessed and adapted inside the three hierarchical spaces. A comparison of the two districts permits a better understanding of the environmental sensitivities of the inhabitants of the two districts.

- The district of Charlesbourg is characterized by a lower value of greenness than Sillery, although the values indicate a comfortable level of greenness for both districts.
- Charlesbourg is clearly affected by more nuisances and barriers than is Sillery.
- The accessibility variables of both districts are somewhat balanced. Charlesbourg includes much more service infrastructure than does Sillery. The accessibility assessed in the enlarged displacement space, however, is more favorable for Sillery, with lower average distances to work and school destinations. This last example underlines the importance of the spatial units used for assessment.
- The size of the local displacement space, normalized for the number of households, is higher in Sillery than in Charlesbourg because of the presence of barriers in the latter.
- The indicators of quality of life in the district extracted from the origin-destination survey present a better value for Sillery (53.9% of short-distance displacements versus 34.2%). However, Sillery is also characterized by a higher percentage of long-distance displacements (5.3% versus 2.5%).

It is important to note the relationship between environmental variables and home prices, as well as their influences on the residential choices of individuals. The environmental variables in the Sillery district are in general more advantageous in terms of quality; however, the average cost of housing is much higher than for Charlesbourg. The hedonic price is an econometric technique that allows for assessment of the implicit prices that people may be expected to pay for a given environmental factor or amenity. It allows the introduction of variables of comfort or house size as well as environmental variables, treated as independent variables in multiple regressions. The method was developed by Rosen (1974). Numerous empirical tests of these methods exist. Improvements have been made and carried out for detailed environmental variables by Reginster and Goffette (2001) and Reginster and Edwards (2001).

Descriptive Diagrams to Compare the Districts

The environmental functioning of a district or the environmental sensitivity of its inhabitants could also be assessed by the use

of diagrams. The one suggested here concerns the enlarged displacement space and is derived from the origin-destination survey. The diagram in Figure 9 reflects the orientation of the displacements of the inhabitants of a district. It allows a description of the major directions of displacements, of the presence of barriers in the enlarged displacement space, the directions and measurements of distance to the centers of work, and an indicator of the life of the district derived from the percentage of displacements within the district.

In Figure 9, " m_t " refers to the average time of displacement (in seconds/100), and the direction sign indicates the direction of the city center (center of work). A comparison of the two diagrams representing the enlarged displacement spaces allows the identification of a main barrier in the southeast direction for Sillery, which corresponds to a cliff and the St. Lawrence River. No such barrier is derived from the graphic for Charlesbourg, even if there are fewer displacements in the northwest direction. Charlesbourg appears to have a weaker district life than Sillery, as indicated by the percentage of displacements inside the district (44% versus 50%). This was mentioned in the previous analysis based on a different variable (the number of short-distance displacements).

Another diagram representative of the life of the district is a frequency diagram: the frequencies of the displacements as a function of their duration. The natural breaks in such a representation allow for the identification of thresholds for environmental variables as was done in Table 1 (the percentage of short-distance displacements to destinations within the enlarged displacement space for a duration of less than 5 minutes, and the percentage of long-distance displacements to destinations for a duration of more than 25 minutes).

Discussion and Applications

These methodologies and implementations could be enlarged to include all the districts of the agglomeration. They also can be adapted for other types of variables or by changing the level of analysis. One way to quantitatively present the environmental distinctions between the districts is to perform an analysis of variance. This method allows measurement of the separability of the district and, in this case, of the environmental quality. The procedure is hard to justify for the analysis of only two districts, but could be reasonably applied to a more thorough study of the entire city.

The values presented in Table 1 reflect only some aspects of the complexity of these two districts. Additional data could be obtained by obtaining a variety of other factors, such as, relative values of road safety or management. Such variables could include the percentage of the enlarged displacement spaces that are associated with highways or the presence of dangerous roads or crossroads in the vista spaces. These variables could be used to address applications relative to habits of transportation, traffic circulation schema, or public transportation policies.

The data derived from the origin-destination survey concern the displacements of persons during a single day. In the case

of another survey, the implementation of local and enlarged displacement spaces could be adapted from, for example, a weekly survey. This would provide more information concerning reinforcement of activity sites and should support a finer segmentation of household groups. This would also obviate the need to resort to approximations for the local displacement space, such as the 5- or 7-minute limit used in this study.

Although developed in this article at the spatial level of the district, the perceptual region can also be implemented at the level of each house. This individual level requires other hypotheses and techniques of analysis, and has other applications (Reginster and Edwards 2001).

Applications for these perceptual regions used as spatial units for analysis include characterizations of residential choice (see Reginster and Edwards (2001) for more details of the latter), closely tied to the analysis presented in this article. However, studies in travel and activities planning and retail choice may profit from the hierarchical nesting of the regions proposed. For example, the Huff model (1962) could be adapted to include perceptual reinforcement and applied using perceptual regions for different client groups. Other applications under study include integrated forest management, the development of landscape pattern metrics that incorporate perceptual factors, and the design of natural and urban park spaces.

In a general way, these spatial units could become the basis of new indicators of environmental factors such as quality. The typology of the structure of the perceptual regions could lead to a typology of the districts of a city as determined by the spatial behaviors of their inhabitants.

Conclusions

In this article, we have developed new spatial units that incorporate the cognitive and perceptual characteristics of human attachment to places. These spatial units could become the basis of new indicators of environmental factors for a variety of applications concerned with environmental sensitivity. The definition and identification of the perceptual regions are based on hypotheses concerning the importance of life spaces for a set of households. These hypotheses allow the integration of different types of human spaces: areal for vista spaces and network-like for the displacement spaces. These are a reflection of the different activities and different kinds of attention people give to their environment. Moreover, the hierarchical structure allows the adaptation of different measures to each of the spaces within the perceptual regions.

Also described in this article is a method for extracting these perceptual regions from appropriate data, including remotely sensed imagery, digitized cartographic data, and origin-destination

surveys; the manner in which these regions may be used is shown as structural units for aggregating spatial data appropriately for studies of human spatial behavior. Perceptual regions appear to offer a useful means of aggregating spatially distributed data in support of statistical analyses for a variety of applications (see Reginster and Edwards (2001) for a description of other types of analysis that may be carried out using perceptual regions).

Instead of using spatial units based on political divisions (district boundaries or census tracts), the proposed approach allows one to transform measures to correspond to the environments perceived by inhabitants of the territory (assuming disaggregated data are available to support this method). We have developed such an analysis by aggregating data across a neighborhood; however, the same kind of approach could be carried out based on other aggregation criteria. For example, children can be expected to have a different perception of environmental quality than their adult counterparts. The difference is partly due to the fact that the criteria they consider important are different, but also because the territory of which they are conscious is quite different than that perceived by adults.

This study is an attempt to formalize a certain understanding of the structure of residential space, with a comparison of different sizes of space. The approach offers the potential for developing some interesting applications in urban planning: the means to be more sensitive to the wishes of individual households in decisions concerning urban spaces, and a tool to help people evaluate different residential locations. More globally, this study constitutes an experiment in the comprehension of the relationship between behavior, residential structure, and environment.

Finally, it is worth pointing out that the analysis undertaken in this study can be largely automated. The extraction of vista spaces requires the combined use of remotely sensed imagery giving access to greenness measures and of view shed analysis based on digital elevation models. In this study, no significant view shed analysis was performed because the regions studied are flat. The origin-destination surveys can likewise be analyzed fairly automatically. As a result, it is possible to perform these kinds of analysis on large data sets such as major urban agglomerations and still obtain information at the levels of detail of individual households, provided that the supporting data exists (maps and origin-destination surveys).

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Acknowledgments

We would like to thank Dr. Marius Theriault for kindly providing us with access to the origin-destination survey developed in conjunction with the CTCUQ. Funding for this project was provided in part by the Industrial Chair in Geomatics applied to forestry and hence by the Québec Association of Wood Sawmills and Manufacturers (AMBSQ), the Ministry of Natural Resources of Québec (MRNQ), the Natural Sciences and Engineering Research Council (NSERC), and Rexfor. The final stages of this work were funded by the GEOIDE Network.

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