Application of geotechnology to urban configuration

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Rômulo José da Costa Ribeiro and Frederico de Holanda
Universidade de Brasília, Brazil

Abstract
Remote sensing and the geoprocessing techniques constitute powerful tools to monitor the evolution of urban growth, to manipulate various sorts of data and to simulate models that help in developing urban plans. Satellite images will be used, because of their low cost, temporal resolution (time to acquire a new image of the same point) and spectral resolution (sensibility of sensor to capture data of small spectral band).

This work is an exercise in dealing with different sorts of data. This first one deals with areas according to environmental attributes, i.e. their natural characteristics. The aim here is to identify environmental restrictions for human occupation. Cross referencing of legislation and thematic data will be done by means of the technique of algebra of maps emphasising Boolean operations.

The second sort of data refers to areas which have already been occupied. The aim is to reach a diagnosis of such occupation, by way of the analysis of the suitability or otherwise of the human uses found here. The main innovation here, concerning the first and the second sort of data, is the use of neural networks for classification of satellite images. This new method uses a sampling system that does not require a definite metric of statistical distribution of parametric data, nor previous knowledge of this distribution.

The third sort of data refers to urban form variables: Integration Measure and Dispersion Index. The first computes the relative accessibility of each urban axis in relation to all other axes in the system; the second indicates distances inhabitants have to travel between home and the Central Business District (CBD). Finally, geoprocessing tools are used to bring together all types of information.

Keywords
Urban zoning, urban syntax, geoprocessing, neural networks.

rjcribeiro@uol.com.br
fredhol@unb.br

1. Introduction

Urban expansion presents today serious environmental as well as sociospatial problems: water shortage, soil erosion, energy shortage, air pollution, bad housing quality, long distances from home to work etc. These affect the life of millions of people who live in cities and their surroundings. There is a need for tools that help in monitoring these problems more effectively. This will help to formulate better urban policies.

There are two steps to the problem. There are areas too sensitive for occupation. Expansion here could damage the environment seriously and irreversibly. The first step should thus be to define which areas should not be occupied – then we are left with the permissible areas for urban expansion. This begs the following questions: of these, which should actually be used? Expand in what directions? What form should expansion take? How intensive should expansion be? This set of questions is related to a "theory of good urban form".

Research has advanced in both directions. Knowledge is accumulating concerning criteria towards the definition of environmental restrictions, thus leading to a better definition of permissible areas. On the other hand, urban form variables allow the diagnosis of problems of urban form itself – the manipulation of which will provide answers to the set of questions referred to above.

This means that a huge amount of information needs to be processed, data of various sorts need to be interrelated. Development of remote censoring and geoprocessing have constituted powerful tools for doing this, helping to better monitor urban growth, thus allowing the making of better development plans. The use of such tools is still very limited due to lack of knowledge of urban managers, lack of specialised professionals, and high initial cost of projects. Discontinuity of projects due to political circumstances has also inhibited the use of these tools. Despite all this, the use of GIS has grown and new applications have been discovered. This paper exemplifies the use of these tools, both in the definition of restriction areas and in the way permissible ones should be used.

2. Method

The most effective form of obtaining knowledge of wide areas is through remote sensor images; that is, through technology that allows for the acquisition of object information without the direct physical contact with these (Novo, 1992), such as aerial pictures and satellite images. In this work we use satellite images due to their low cost, temporal resolution (time of acquisition of a new image of a same point) and spectral resolution (sensibility of the sensors to the reception of data of small spectral strips).

Satellite images of the year 2001 will be used with the objective of identifying the urban areas. With the gathering of environmental and urban data, and the support of techniques and modern calculations for their treatment and modelling, we have established indicators for the systemisation of urban zoning.

The main idea is to use the best available technology (satellite images, spatial database, GISs, among others) and, considering the legislation about restrictions on land use, to define the main environmental indicators of use restriction and urban indicators for expansion. Together, they will help to define both the permissible areas and ways of their occupation

Finally, urban form variables, from space syntax as well as from other theoretical sources, will be used to assess the already built area. The area selected for study is the Administrative Region of the Lago Norte, Brazil's Federal District (FD), one of its 19 political-administrative regions.

3. Results

3.1 Definition of restricted areas for use and occupation

This first level deals with areas according to environmental attributes, i.e. their natural characteristics. Aspects as pedology, geology, structural behaviour of the rocks (when available), areas of water recharge (when available), will be dealt with. The question to be answered is: what attributes of such categories make the area unsuitable for human occupation?

What makes the GIS different from other systems is the possibility to realise spatial analysis using spatial and non spatial data, their storage in a data bank, and the simulation of real world phenomena. Comparison between law information and theme-maps data (that describe the spatial distribution of a geographic phenomena, like soil, geology, etc.) will be done in a similar fashion, through algebra of maps techniques. For the purpose of this project we will use Boolean operations.

Boolean operations are simple and easy to manipulate, but care should be taken with the distribution of equal importance for each one of the combined criteria; their weights should be appraised depending on their relative importance (Bonham-Carter, 1994). The use of logical operators such as AND, OR, NOT, >, <, DIFFERENT FROM, EQUAL TO, among others, allows the comparison between two or more sets of information (maps).

The thematicsets of information that will be used are data of pedology, geology, structural behaviour of the rocks (when available) and areas of water recharge (when available), as well as the definition of the sensibility criteria for each theme (e.g. very high, high, medium, low and very low). Comparison of such data will result in the Map of Restrictive Environment Areas.

For thematic data it is first necessary to define sensibility degrees, in agreement with each data type and the sensibility to alteration or destruction of corresponding phenomena. Each type of data will be converted into a numeric matrix known as grid, according to the sensibility degree (these should be numeric values); each pixel size should be compatible with the scale of generation of data. With all thematic data converted into a grid, it is possible to select the areas with different restriction degrees, in an extremely fast and precise way, thus obtaining the map of vulnerability to use (Figure 1).

1	1	2
1	2	2
3	3	4

A

AND

1	1	1
1	1	1
1	2	2

B

=

1	1	0
1	0	0
0	0	0

C

Figure 1. Schematic Example on algebra of maps using Boolean operators. A and B are two thematic maps, with their respective sensibility degrees; C is the result of the Boolean operation, where selection of the degree EQUAL TO 1 was asked in maps A and B; operator AND was used in order to unite maps A and B, strictly referring to degree EQUAL TO 1. Value zero represents white areas, that is, that do not fit the conditions of the Boolean operation.

The generation of the map of environmental restriction is similar to the one for thematic maps, with the difference that it is necessary to generate the maps with the restrictive parameters contained in the legislation, before the conversion to a grid and the subsequent data comparison[1]. The parameters found in these laws will be evaluated in order to define the areas of environmental restriction.

The final map (Map of the Restrictive Environment Areas), will be generated by cross referencing the maps of environmental restriction and of vulnerability to use, using Boolean operators, through which the restrictive areas of each map will be individualised. After this, a unification will be made among the various restriction degrees, thus generating the map of restriction to use.

The PDOT-DF/1997 (the last comprehensive development plan for the FD) has been adopted as a procedure, a simplified zoning of environmental restriction areas in the territory, with the support of four basic thematic maps, constituted by the mapping of slopes, soil types, areas of permanent preservation and land use patterns. The manipulation and the comparison of the spatial data was done as follows.

In the map of declivities three classes slopes are defined: up to 10%, between 10% and 30% and above 30%. Restricted areas were those with declivities above 30%. In the pedologic map the soil types that were more susceptible to erosive processes were marked. This typology was grouped in order to obtain two or three susceptibility categories (a procedure similar to the one used for the map of the restrictive slopes: soils considered very strongly susceptible to erosive processes were marked: cambisoils and quartz sands)[2]. The overlap of those two maps (one with restrictions of slope and the other with restrictions in soil patterns), resulted in a first synthesis-map of delimitation of the larger susceptibilities to environmental degradation of surface areas.

In the hydrologic map the areas of permanent preservation[3] were identified: forests and other natural vegetation areas located along the rivers; a minimum strip of thirty meters along any water course less then ten metres wide; a minimum circle fifty meters diameter around any fountains, even when intermittent, in any of topographical situation; in the top of hills and mountains.

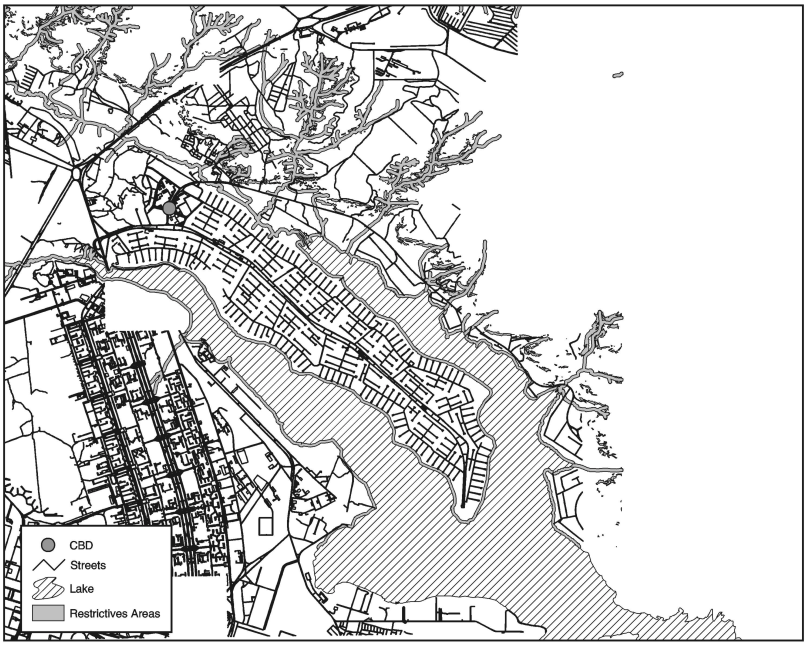

Figure 2. Map of environmental degradation of surface areas with the areas of permanet preservation.

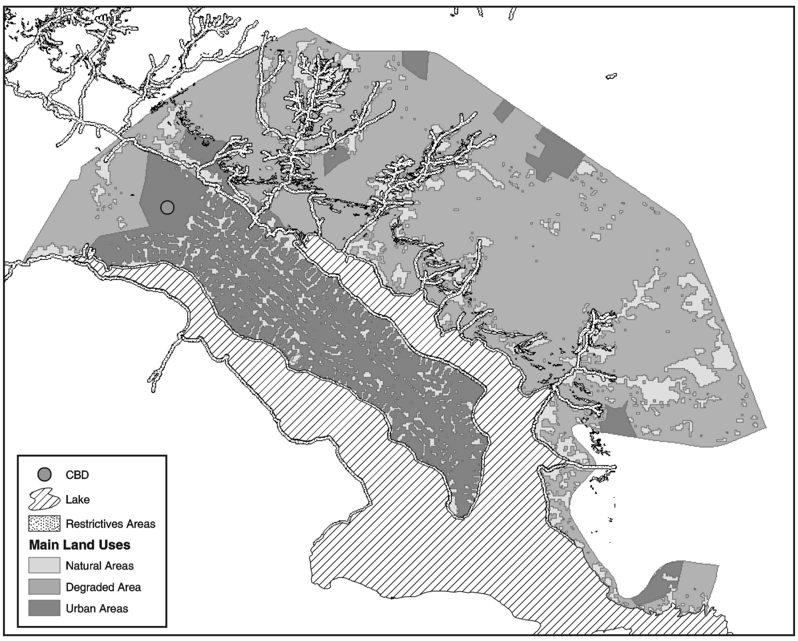

Figure 3. Map of Restrictive Environment Areas. Main land uses inside the restrictive environment areas:
Degraded Areas – 58,06%;
Urban Area – 11,84%;
Natural Areas – 30,10%.

From the map of soil use, usually containing a huge amount of spatialised data, we have extracted, basically, information related to degraded spaces (deforestation, exposed soils, burning areas and erosions), urban areas and to extensions of natural features (forests, savannahs, fields and veredas). This document was elaborated from the satellite image of 2001.

Finally, the combination of the three maps (the first one with the greater susceptibility to the environmental degradation of surface areas, the second one with the areas of permanent preservation, and the third one with the degraded and natural spaces) has resulted in the Map of Restrictive Environment Areas. The document thus generated has as its main spatial result the distribution of the areas susceptible to surface degradation still covered by natural features and, also, spaces already degraded and/or occupied, occurring in these areas of environmental restrictions (Figures 2 and 3).

3.2 Mapping soil use and occupation

In contrast with the first part, this section deals with areas which have already been occupied. The aim is to reach a diagnosis of such occupation, by way of the analysis of the suitability or otherwise of the human uses found here.

The configuration of a city is extremely dynamic, particularly in countries such as Brazil, where migration movements from the rural areas are still very intense. In Brazil, urban population today amounts to 81.25% of the total population of the country (IBGE, 2001).

We have a powerful tool to capture this reality: satellite imaging. This allows the preparation of images of the same place at different dates (temporal resolution). This provides the possibility of mapping the evolution or involution of the limits of the urban areas. We can thus evaluate the speed, the directions and the form of such growth. It is possible to characterise whether the limits are being enlarged restricted areas, or how much of the city is already occupying such areas. Policy elaboration can be done on the basis of this valuable information, in order to change such a problematic scenario.

Among several forms for the definition and monitoring of this growth, statistical methods of recognition of patterns for procedures of image classification, are the most important and most used. However, these traditional methods of classification imply previous knowledge of the statistical distribution of the classes, constituting a limiting factor for the use of data obtained from different sources.

New technologies have been developed in order to improve these methods. In recent years, the interest for researchers using artificial neural nets applied to the recognition of patterns of classes has grown. The big difference is that this new method uses a sampling system, and does not require the parametric nature of the statistical distribution of the data, nor previous knowledge of this distribution. According to Lee et al. (1990) "(...) neural nets seem to carry out the task of classification of images as well as, or even better than, statistical techniques (...) ".

Several models of artificial neural nets have been developed for various purposes. "This is the case with the neural perceptron multi-layer net, which assumes as areas of similar decision those formed by a statistical classifier, but with inputs which are not correlated and with different distributions for data (Lippmann, 1987). Besides, those nets are trained by an interactive algorithm of learning, called backpropagation, that allows the development of a correct associative behaviour when confronted with situations with similar characteristics." (Galo, 2000).

A lot of research has been developed using artificial neural nets for the classification of data from remote sensors. Most of it allows not only the use of multispectral data, but the incorporation of data acquired from other sources.

Methods that use artificial neural nets can be applied to different situations, due to the flexibility in the entry of data for classification, the possibility to incorporate data from other sources to a set of input data, and to the fact that its application does not imply the statistical distribution of data.

We have used the method of classification of patterns through neural nets for the classification of satellite images, in order to obtain the main land uses. This data was used in order to compare the main use types with the restricted environmental areas, thus allowing the identification of areas more susceptible to environmental degradation, according to its use and environmental characteristics.

The generation of a neural net is extremely complex. We have used the software ENVI 3.5, that possesses a module for classification of images of remote sensors through neural nets.

We have used neural nets applied to the technique of classification of feed-forward layers. Neural net techniques use backpropagation pattern for supervised learning. Learning occurs by adjusting the weights in the nodes in order to minimise differences between output node activation and desired output. The error is backpropagated through the network and weight adjustment is made using a recursive method. Neural Net classification can be used to perform non-linear classification (Figure 4).

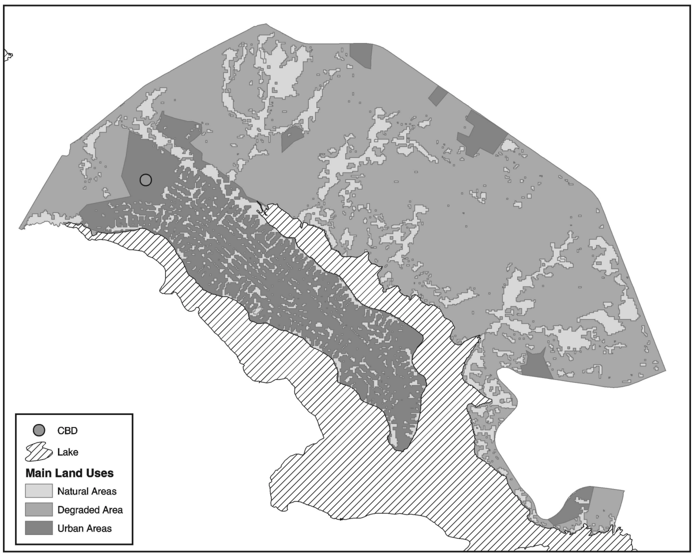

Figure 4. Main land uses, obtained by neural net classification of satellite image.

3.3. Urban form variables

In Section 3.1 and 3.2. we have commented on the restrictions to the occupation of vacant land and the problems of existing occupation. Now we shall turn to the discussion of the attributes of urban form and their performance, mainly related to the appropriation of space.

3.3.1. Measure of integration

Cities present more integrated and more segregated parts, vis-à-vis the urban configuration as a whole. This is quantifiable by means of the measure of integration, a corner stone of space syntax theory. In order to calculate the measure of integration, the street system is reduced to axial lines. The map thus obtained (the axial map) is processed electronically and the integration measure of each of those lines is revealed[4]. This measure indicates how much each line is topologically accessible from the system as a whole[5]. This means that the most integrated lines are those which present, in average, the shortest number of intervening lines vis-à-vis the whole set of lines of the system (Hillier and Hanson, 1984). The integration core is the set of the most integrated lines.

In previous work on the metropolitan structure of the Federal District we have commented on the imbalance between integration, location of houses and location of jobs (Holanda et al. 1999). Summarising, this revealed the integration core lay outside the greatest concentration of jobs and a large number of inhabitants were located in highly segregated parts of the city. In this paper, we are working with a much smaller area, and the use of more sophisticated GIS tools has allowed a more precise characterisation of urban imbalance.

We have divided the area into parts which correspond to the 2000 demographic census sectors (IBGE, 2000). These were the minimum spatial units of analysis. From the census we have used only demographic data (number of inhabitants per hectare per sector; this is illustrated in Figure 7). We wanted to check what relations there were between people thus deployed in these sectors with other configurational attributes. In order to do so, the following steps were taken.

The processed axial map was superimposed on geo-referenced maps containing other sorts of information. First, axial lines were superimposed on the sectors. Since sectors were the spatial units of analysis we had to reduce somehow the measure of integration to them. After calculating integration measures, data was transported to the software ArcGis 8.1. The software allowed the automatic calculation of the average integration of lines completely contained in each of such sectors (Figure 5). This average, then, was considered “sector integration”.

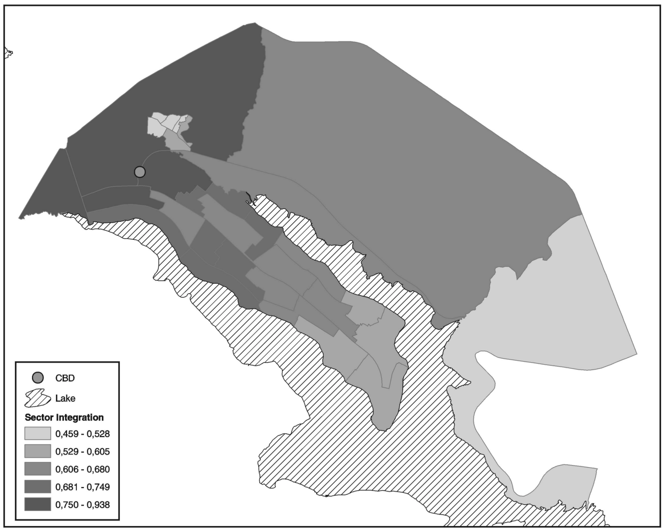

Figure 5. Sector Integration

A first imbalance was revealed. The correlation between sector integration and sector inhabitants was poor: –0.219. This means that highly integrated places do not correspond well to where most people live. Our present conjecture is that this does not correspond to “good city form”. Research has shown that high integration means a greater number of people in public spaces, which brings with it a concentration of central activities, which generate a greater number of trips etc. Minimising distances between inhabitants and central activities would mean minimising distances from home to work/services, energy saving etc. The way to do this is to bring more people to live in the most integrated places. Previous work has also shown that this city denies this, and that the "theory of natural movement" does not apply here (Holanda, 2002), whereas it is verified with great force in "vernacular" towns (Hillier et al. 1993) ("Vernacular", in this paper, is understood as a certain way of organising space, based on "social knowledge", as opposed to ways adopted by "professional knowledge", e.g. Brasilia).

We have also experimented with a metric dimension (for integration is of a topological nature). By means of GIS software we have also automatically calculated distances of sectors (considering their respective geometric centres) to the regional CBD (Figure 6). Another imbalance is revealed: as correlation between inhabitants and distances to the CBD was only -0.270. In other words, more people do not correspond well to smaller distances to be CBD. It is interesting that this metric dimension confirms the topological one of the integration measure. As to "good city form", a similar reasoning applies here: more people should live metrically (as well as topologically) closer to the CBD.

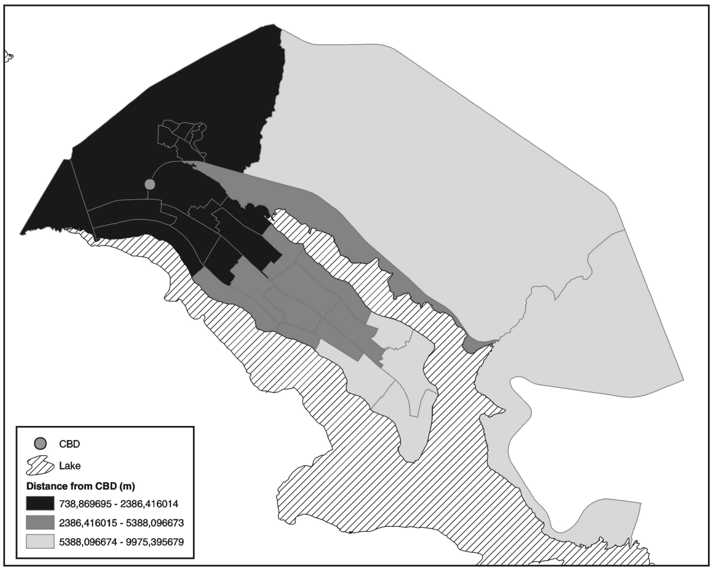

Figure 6. Map of sector distances from CBD.

3.3.2. Dispersion index

Another variable seems to be of great interest in analysing urban form: dispersion index. It is based on Bertaud & Malpezzi (1999). It is used to analyse the way in which a city is more or less dispersed, taking into account the distance of each and every inhabitant to the CBD. The actual form of the city is compared to that of a hypothetical circular city with a similar area. For the sake of greater clarity, we have adapted Bertaud & Malpezzi's formula thus:

$$\rho = \frac{\sum_i d_i p_i}{PC}$$

where “(INSERT FOMULA 2)” is the dispersion index, “d” is the distance from the geometric centre of each sector to the CBD, “p” is the population of each sector, “P” the total population of the area under analysis, and “C” is the average distance of the points of a circle the area of which is equal to the total area under analysis, to its centre (this is equal to 2/3 of its radius, a value that is obtained by means of integral calculus). Bertaud & Malpezzi (1999) have also suggested that we may illustrate dispersion by representing the urban sectors as prisms, the height of which would correspond to their respective demographic density. We have prepared an illustration of the index by means of the 3D module of analysis of ArcGis 8.1, according to what Bertaud & Malpezzi have suggested (Figure 7).

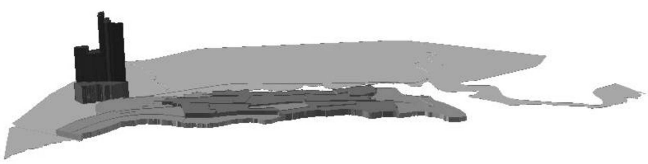

Figure 7. Illustration of dispersion. Height of prisms are conventional and indicate demographic density of demographic census sectors.

It was very easy to calculate the dispersion index through automatic processes, by means of a GIS software. Using ArcGis 8.1 we have generated the necessary data: the geometric centre of each sector was identified, as well as their respective distances to the CBD. It was also by means of the calculation tool of the software that we have arrived at the final value for the dispersion index of the area = 1.64.

Of course the main aim here is to illustrate a procedure, rather than to arrive at a positive diagnosis of the situation. Still, a comparison throws some light on this case-study. In a sample of 35 cities around the world, Bertaud & Malpezzi have found a minimum index of 0.78 (Shanghai) and a maximum of 3.08 (Bombay). In Brazil, Curitiba has presented 1.14 and Rio 1.97. Our own work has indicated a dispersion index for the whole metropolitan area of Brasilia of 2.55, capturing well the huge discontinuities in the urban tissue of this city[6] (if we compare this to Bertaud & Malpezzi study, only Bombay is more dispersed). The area under study in this paper is still rather dispersed, but naturally more compact than the whole Federal District, for it represents one single administrative region.

Dispersion index complements the analysis done before, since it stresses urban diseconomies. Research is building up concerning city compactness (or dispersion, for that matter) (Jenks & Burgess, 2000). Again, since energy saving is a must, dispersed cities are not exactly equal to "good city form".

3.4. Bringing together all layers.

The final step is to bring together all layers discussed above, in order to arrive at a "good urban form". Admittedly, this implies more variables than the ones dealt with here. To give an example, symbolic aspects have not been considered, and they are extremely important, all the more so as this area is part of Brasilia, the only modern city considered by UNESCO to be a World Cultural Heritage.

A redesign for the area under study is part of the forthcoming work. What we will offer as follows, are only some guidelines made possible by the forgoing analysis.

a) There are no restrictions today as to the occupation of many areas with severe environmental restrictions. Data from section 3.1 should be considered in any project aiming at expanding urban areas in the place. Polygons should be delimited, considering more than the mere margins of water courses marked in the maps, perhaps by means of definition of permanent areas for preservation.

b) Present uses already occupy areas with environment restrictions, as shown in data from section 3.2. Design policies should prevent, at least, intensification of occupation of such areas or, ideally, the removal of its population to areas more suitable for urban development.

c) By looking at the integration map, we have seen that there are segregated urban parts very close to the CBD. Of course one of the most permanent city elements is its street system, particularly in consolidated areas. Still, we may conjecture that with minor modifications of the street system this segregated parts might be incorporated to the whole in a less segregated fashion. Urban performance would increase.

d) Imbalance was evident between inhabitants and distance to the CBD. It is possible to identify areas in which we may improve residential density – greater densities in greater proximity to the CBD, for example. Again, this would improve relations between houses and jobs/services, reducing energy costs.

e) The area is not very compact. Greater densities near the CBD (as above) as well and an inventory of areas which are so far poorly or unoccupied would help establish design policies aiming at improving compactness, and in similar fashion as guidelines above, reduce energy costs.

4. Conclusions

The use of state of the art geoprocessing and GIS technology constitutes a powerful tool so far very little explored in urban design, particularly when used together with theories of "good city form". More often than not geoprocessing is purely a tool to describe an existing reality. In turn, theories of city form that do not use these high level technologies fail in dealing with the huge and significant amount of information which constitutes urban reality. The simultaneous use of the two instances will help improve both. Theories will be improved by the introduction and manipulation of new variables and geoprocessing will be challenged to identify new urban attributes which bear upon the performance of city form.

We envisage great advances in calibrating theoretical categories. Take the measure of integration, the backbone of space syntax. In cities designed according to the modern paradigm, in which exclusive land use and spatial discontinuities are paramount (e.g. Brasilia), correlations between integration and, say, pedestrian/ vehicular flows are poor (Holanda, 2002). The exercise carried out in this paper suggests it is very promising to calibrate integration measure with demographic information and metric distances, for example. Recurring tests could be done in an easy and fast fashion, something practically impossible without geoprocessing and GIS tools. In Brasilia, integration measure, duly calibrated, might prove to be as useful as it has been in other contexts in predicting pedestrian/vehicular flows: a simple and expeditious procedure obtaining as good as, or even better, results than laborious and expensive techniques – traditionally used in traffic engineering, for example. Future work will tell.

Notes

[1] Federal legislation that restricts land use follows the parameters defined in the following laws: Law nº 4.771 of 15/09/1965; Law nº 7.511 of 07/07/1986; Law nº 7.803 of 18/07/1989; Medida Provisória nº 2.166-67 of 24/08/2001; Law nº 6.766/79; Law nº 10.257 of 10/07/2001

[2] It was used as source of information the Map of Recognition of the Soils of Distrito Federal – DF (EMBRAPA/snldc-1978)

[3] According to the laws nº 4.771 of 15/09/1965, nº 7.511 of 07/07/1986 and nº 7.803 of 18/07/1989.

[4] The software used here were "Axman" and "Ovation", Space Syntax Laboratory.

[5] We have carried out a study of a sample of urban areas of the Federal District, and we have found integration measures varying from 0.82, for the most segregated area, to 3.34, for the most integrated (Holanda, forthcoming).

[6] Holanda, F., forthcoming, "Uma ponte para a urbanidade", Revista Brasileira de Estudos Urbanos e Regionais.

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