4. URBAN REMOTE SENSING INVESTIGATIONS

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ABSTRACT

This paper deals with the research activities achieved by the team TELSAT/06-TELSAT/II/06-TELSAT/T3/003 of the University of Liège, in the framework of the National research programme on satellite remote sensing (National Scientific Policy Office). The team specialized in urban remote sensing and especially in applications relevant to urban, land and country planning and the monitoring of environment. Besides a theoretical approach of the methods of remote sensing, those trends imply a good skill of hybrid geographical information systems and an expertise in satellite mapping.

One the one hand satellite images are radiometric value matrices and must be exploited in a numeric way, on the other hand the needed references to ground-truth require to use visual interpretation methods. As most of the image processing systems have not or had not the necessary fonctions for extracting and enhancing information, the team has developed or implemented such tools. The main fields of these tools are : mathematical morphology, image segmentation, rasterization and vectorization, contextual filters, transformation of discrete data to spatial continous models. Various methods of optimization of classification are presented, e.g. use of neo-channels (textural or others), zone classification instead of pixels ones, morphological filtering applied to post-classification.

The superimposition of vectorial information produced by SIG on raster classification and the use of map publishing software allow to produce regular satellite maps. The content of landuse maps fulfills some needs of survey for country planning. For some applications, remote sensing methodology is more suited than traditional ones. This is the case to split up of country into homogeneous regions or for finding net density by use of dasymetric methodology. Another interesting way of working consists in the modelling of landuse map content with a quantitative geographical approach.

The raster and numerical nature of satellite images makes easier the construction of continuous models which can be assimilated to statistical surfaces. These surfaces allow analysis of geographical, hierarchical and chronological aspects of distribution. A specific interest can be found in the comparison of the urban potential statistical surfaces with the central place theory (W. Christaller) and with the economic polarization theory (F. Perroux).

Ecological zoning can be found by coloured composition of 3 statistical surfaces. The 3 most important categories of landuse (water, vegetation and concrete) can be seen as the main structure of biotops and lead to the interpretation in ecosystemic terms. The choice of satellite image allows to cover the full range of scales from cities to regional analysis. The applications concern mainly the "Euregio Meuse-Rhine" cross-border region and its urbanized core (Liège, Aachen, Maastrichr, Hasselt, etc.). The methodology has also been used outside of the Euregio (agglomeration of Luxembourg, metropolitan area of Lisbon, Warsaw, etc.).

Anyway, spatial landuse maps must be seen as a specific layer of a regional GIS. The crossing of satellite data with data stemming from other sources allows to set out and to solve a lot of problems relevant to country planning practise.

This paper analyses successively the constraints of applicability, the stade of the art in urban remote sensing, the used methodologies, the completed end- and sub-products, the assessment of the research and an exhaustive bibliography.

INTRODUCTION

Satellite remote sensing, appeared 20 years ago, must be considered as an expanding technique. The rational exploitation of this tool implies fundamental and applied research. To realize the difficulties of urban remote sensing, it is worth keeping in mind the main constraints peculiar to the method. Firstly, the image features are dependent on the recording characteristics : radiometric and geometric resolutions and frequency. On this subject, the urban environment imposes drastic restrictions due to the size and the variety of the objects to be distinguished.

The improvement of urban remote sensing is conditioned by the availability of high resolution images and by GIS simultaneously able to use coded information in vector and raster modes.

It is obvious that the analysis of urban area by remote sensing implies a very good geometric resolution. It has been demonstrated that 5 to 20 meters resolution was required for accurate analysis of European cities and even a better resolution for Asian towns [1][2]. In the same way, the scale range for the land use mapping falls in 1:25,000 (SPOT P or XS+P) to 1:50,000 (TM).

Concerning radiometry, the spectral signature of an object is defined as a set of values of reflectance proper to the object and measured in accordance with specified wavebands. Spectral signatures as obtained by the sensors and urban phenomena are rarely in a one-to-one relation and any precise identification needs complementary information. Moreover the alteration of the radiometry of the urban objects is emphasized by the different site conditions.

Frequently an enhancement of the raw data is achieved by combining the spectral properties of one system with the good geometric resolution of another. The techniques of band substitution [3][4] or transformation via the coding of colors in hue, saturation and intensity [5] can be applied.

The difficulties of urban analysis led the researchers to follow several ways to improve the techniques of classification. The simpliest technique consists in achieving a visual interpretation of the land covers, in an interactive way on screen or in a conventional way, on an analogic document. The support of interpretation often is built on a color composit with three bands or pseudo-channels [6][7][8].

Supervised classifications, particularly those using the maximum likelyhood algorithm, are mostly preferred. Raw data are often improved by integration of severally resampled channels issued from different sources. Moreover enhancement can be obtained according to methods relevant to mathematical morphology, stratified classification and adaptative filtering.

Nevertheless, it must be mentioned that the land cover legends suitable for image classification differ from the standard keys used in urban planning.

Urban and particularly suburban areas are dynamic environments where the modifications of the land covers are frequent. The repetitiveness of the satellite records seems to offer an interesting way for the diachronic analysis of the built-up areas and several solutions have been suggested : comparison between bands, PCA of the whole set of bands at a couple of dates [9] or the creation of a changing index [10].

The map issued from such treatments, so-called "space-map", may constitute a faithful representation of the existing situation. Nevertheless the urban reality give expression of functional variables, relating to land use and describing an economic, social or legal purpose of the considered area. This kind of information cannot be extracted from the sole satellite data.

Beyond the making of a space-map, the practical exploitation of satellite data, even the simpliest, implies an estimation of the acreage per land cover present or submitted to change. Because each pixel represents a known and constant area in the image, this computation comes down to simple counting. But this facility has to be realised on a operational basis, so it is necessary to introduce complementary

geographic data. These often are digitized in vector mode and force the use of an hybrid GIS able to handle raster and vector data simultaneously. Raster mode is becoming a necessity in GIS operating, due notably to better geometrical resolution offered by modern sensors, increasing use of digital orthophotomaps and digital terrain models, and suitability of this mode in performing spatial analysis and modelling.
If the remotely sensed data are associated to inventory tracts, the number of operating opportunities is rising : computing of drainage coefficient in urbanized watershed to optimize the sewerage system [11]; simulation of the population growth in accordance with spreading models based on the built-up area identified by remote sensing [12][13][14]; delineation of morphological areas [15]. If district delineation is accurate at the city-block level, for example, it can serve as a basis for zoning classification of the images rather than standard pixel-based classification [16].
The built-up area identified on satellite imagery can be used to establish the spatial base allowing to set up the sampling scheme for the evaluation of demographic data [17][18]. Recent works in this field give some importance to approaches based on image segmentation and mathematical morphology [19][20].
Among the applications related to spatial modelling of information, surface models hold the attention of many researchers nowadays. It is also possible to generate a population density surface or any other socio-economic indicator according to methods relevant to convolution processing. The handling of such continuous surfaces permits statistical comparison with other phenomena, either intrinsically continuous (accessibility field) or continuous after transformation (land cost surface, etc.). Scalar and vector interpretations can be derived from these surfaces (gravity models, spreading models, etc.) and they are graphically represented in many ways (isolines, grey tones, 3-D, etc.).

USED AND DEVELOPPED METHODOLOGY

1. GEOMETRIC CORRECTIONS OF REMOTELY SENSED IMAGES

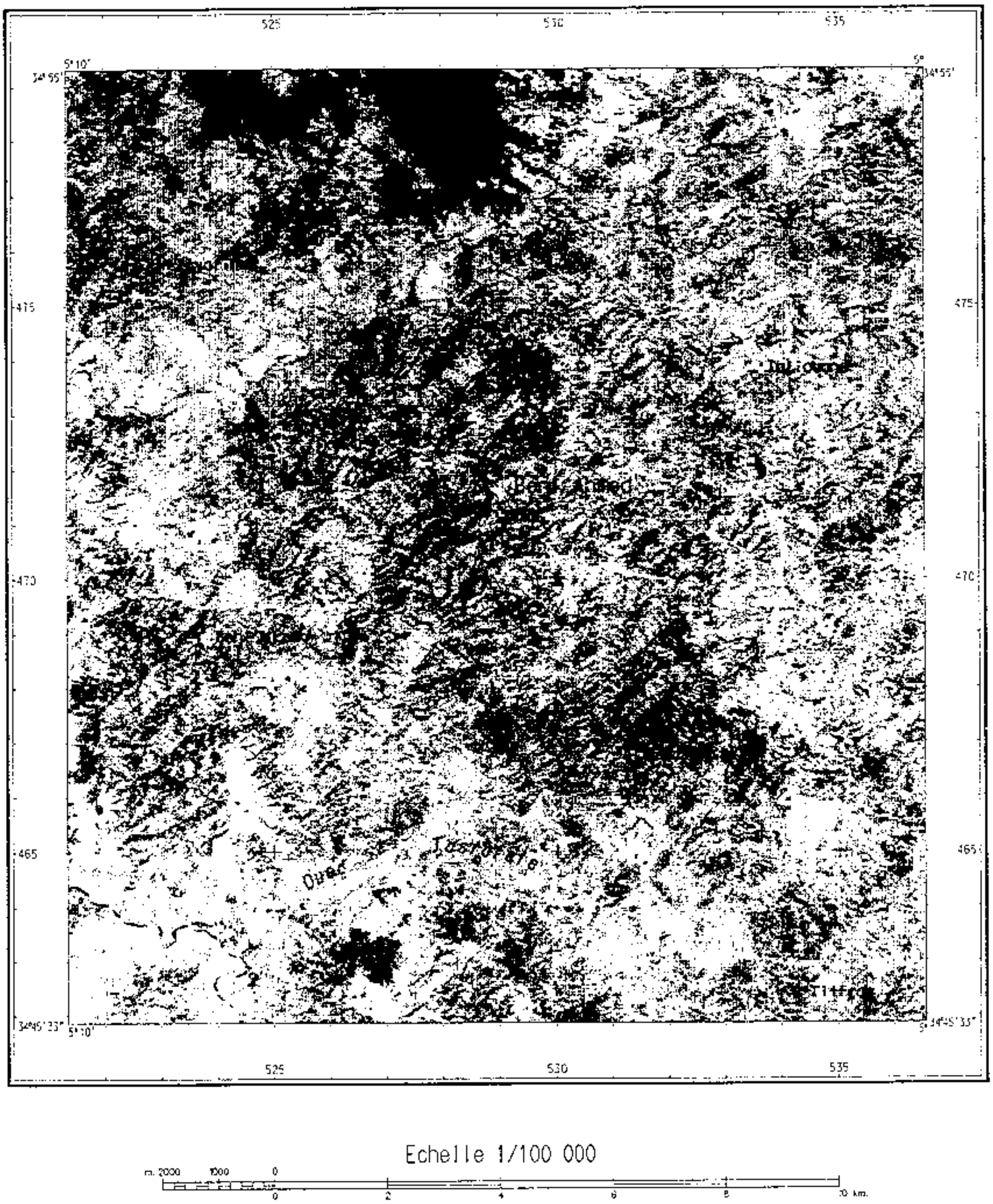
1.1. Warping

Remotely sensed images are geometrically distorded. Geometric correction is made up of registration of typical features on the image with corresponding features on a topographic map. Giving a set of ground control points (GCP), it is possible to establish a mathematical relation between the points on the image and the homologous points on the map. The user has to select the order of the polynomial for the best fit. Good results can be obtained with a first order approximation and it has been showed that higher order approximations do not give better results necessarily.
The radiometric values of the pixels generated in the corrected image depend on one of the three following methods: nearest neighbour, bilinear interpolation or cubic convolution. Only the first one seems to be useful when the corrected image is to be classified because it preserves original values.

1.2. Restitution

The restitution process generates a digital terrain model which implies a geometric and altimetric linkage. The first step, so-called external orientation, is achieved using parameters given by the image headers. The next step, or internal orientation, is interactive and it requires registration of the stereoscopic images to the map. Thanks to the control points, it is possible to triangulate the remotely sensed scene. This operation is followed by a correlation of the two images using regular grids with increasing accuracy. At the end of the process, it remains to calculate the intersection of the homologous rays stemmed from the two correlated grids and linking the corresponding ground points to get their elevation. The digital terrain model is obtained by interpolating between these reference points. To generate an orthophotomap, a subsidiary step consists in warping one image of the stereoscopic couple over the digital terrain model (Figure 1).

Orthophotocarte **BENI AHMED** 1 / 100 000



Source : SPOT Image KJ 35-280 (Panchromatique)
13 et 14 / 08 / 1991

Realisation : Laboratoire SURFACES
Universite de Liege, 1992

Projection conique conforme de Lambert Nord Maroc
Zone 1 - Origine Lat = 37 gr N - Long = 6 gr W
Ellipsoide de Clarke 1880

Module Digital Ortho ERDAS

Figure 1 : Orthophotomap of Beni Ahmed Region (Morroco) (Reduction)

2. INDICES AND PSEUDO-CHANNELS

A lot of indices suggested by literature have permitted to put some phenomenon to foreground. In the field of urban remote sensing the most frequently used are : vegetation index, brightness index and water quality index.
Texture analysis is another technique taking into account the neighbourhood of each pixel to generate genuine indices. Three textural indices have been adapted for urban applications from the TEXTRAN software[21] : contrast, entropy, and inverse difference moment indices. Before the computing of these indices, the number of grey levels have to be reduced. Textural indices are calculated thanks to co-occurrence matrices. These indices allow to decrease the altered effect of classification algorithm due notably to the large variance between pixels resulting from high geometrical resolution of current sensors.

3. PRINCIPAL COMPONENT ANALYSIS

Principal component analysis can be considered both as a data compression and an information analysis method. Roughly it is based on a change of the system of coordinates of the variables. The new axes or components are organized into a hierarchy and they are not correlated. The decorrelated components successively explain a decreasing part of the total variance extracted from the matrix of inertia built on the initial data. As an example of a data compression application of the PCA, the first three components of a multispectral image constitute one of the best ways to produce RGB images.

4. COLOR COMPOSITS AND VISUALIZATION

The power of visualization is emphasized by synthetic images. It is possible to create color composit with images of the same area recorded by different sensors or at different dates. One of the most useful transformation for urban analysis merges KOSMOS KFA1000 imagery (5 m resolution) and TM imagery (30 m resolution) or KOSMOS KVR1000 (2 m) and SPOT XS (20 m). Such experiments have been achieved over Warsaw (Poland) in the framework of our research programme.
Besides, it is a quite common practice to produce color composits for visual analysis or for computer assisted interpretation. They are also useful during the classification training step.

5. SEGMENTATION AND ZONING

The improvement of classification results needs to use morphological and textural characteristics. In a first step, the method consists in the creation of an image of contrast from one or several raw channels or pseudo-channels. This is achieved by successive contrast and edge detectors. Then the image is thresholded to generate a mask which, in turn, is submitted to a network-like processing. It includes : restoration of line continuity, major filtering and "skeletization". The resulting binary image is converted by an algorithm of propagation into an integer image in order for each pixel to contain the number of its own zone (labelling). Zones presenting concavities are splitted according to an erosion process followed by several dilatations completed from the fundamental nucleus [22]. The last step consists in grouping zones into classes. This methodology has been used for Maastricht[22], Aachen [23] and for Lisboa[24].

6. IMAGE GENERATION

6.1. Urban taxonomy

The nature of information provided by remote sensing concerns bio-physical milieu and it is not without consequences on the number and the characteristics of discernible classes.

The spectral signature of land cover classes roughly can be divided in three categories: water bodies, vegetation cover and mineral cover. This subdivision reminds the three main biotop components.
Water presents remarkable radiometrical properties. Among others, water absorbs infrared radiation, so generally it can be detected with a simple thresholding applied on the adequate band.
Vegetation areas have characteristic spectral signatures which can be discriminated according to a couple of standard procedures, not necessarily exclusive : the vegetation index and the supervised classification. Multidate approach makes the internal subdivisions of the vegetation category easier if images are recorded within the same vegetative cycle.
The processing of mineral areas is not so easy. The built-up area covering the city is made of heterogeneous material and the lack of specific signatures features is prominent in those areas. On the other hand significant subsclasses have to be relevant to criteria different from the strict spectral values and require miscellaneous ancillary data. Consequently complementary processings, including GIS operating, appear as a necessity to perform an efficient taxonomy of the built-up area.
In brief, the practice shows that, in a realistic urban application, no more than 16 land use classes can be distinguished from a monodate multispectral image.

6.2 Interpretative methods

The possible shortcomings of purely numerical methods can be fulfilled at least partially by visual interpretation assisted or not by computer.
According to this approach, a set of criteria is used to identify the objects, to delineate the clusters or to interpret the phenomena. In this respect, about ten criteria are able to be used, among which the main ones are in a decreasing order of interest : the shape, the structure, the size and the texture. In any case, it must be kept in mind that the photo-interpretation is not strictly reproductible.
To some extent visual and numeric methods seem to be complementary, a significant enhancement of the results being able to arise owing to the use of hybrid visual-numeric techniques of interpretation.

6.3. Pixel- and zone-based classification

Pixel-based classification methods often reach their limits of efficiency faced with high interpixel variation due to fine spatial resolution sensors. In those cases zone-based classification can be an improving alternative.
The delineation of the zones generally is provided by ancillary data recorded in vector format. Nevertheless the segmentation process is able to give a tessellation proper to the image valuable for this kind of classification method.
In rural environment the parcel constitute a significant system of limits. In the core of the towns, the city-blocks can play the same role. The situation is more complicated in the suburban areas where the blocks are not easy to define.
The practical usefulness of this method is slightly reduced because the complete sequence of implied processes is not included in the standard package of remote sensing softwares and it must be achieved separately.

7. POST-PROCESSING

Modal and majority filters are a quite common use in remote sensing post-processing applications. It provides some kind of generalization of the thematic image but this is paid by a couple of shortcomings: the lost of the weak frequency classes and the alteration of the image planimetry.
Another family of filtering processes is given by mathematical morphology. Applied on different masks issued from the classified image, it allows pixel contextual substitution : a pixel from a definite class is replaced by a pixel from another precise category if and only if a set of conditional statements related to the neighbourhood of the current pixel is fulfilled. The actual result depends on the type, the nature and the number of statements, on the ordering of the successive processes and on the size and the

shape of the convolution window (Figure 2, see p.252).
Morphological filters have dramatically improved the classified images submitted to space-map making. Notably, it provides a neat document with consolidated zones corresponding with the map style appreciated by the land planners.

8. VALIDATION OF THE RESULTS

The validation process consists in the comparison, on a set of selected places, of the real land covers on the field and the classified land covers in the image. The control points are sampled according to a random or systematic sampling scheme, stratified or not. The results are presented in a confusion matrix from which statistics of accuracy can be obtained globally or for each category of land cover (for example the Kappa index). However the notion of accuracy to some extent depends on the scale of analysis, itself dictated by the target of the analysis.

REMOTE SENSING AND SPATIAL MODELLING

It is possible to submit the contents of the image to advanced spatial models. This approach permits a restitution of the spatial reality, its structure and its functionning, according to their quantitative, qualitative and geographical aspects.

1. THE POTENTIAL MODEL

Most of the spatial models can be derived from the gravity and other statistical moment formula. The basic concept prevailing in these models is that the force of interaction between two bodies is in direct proportion to their masses (weights) and indirectly proportional to their distance.

1.1. Properties and interpretation of the potential model

The structure of the potential model is simple and easy to develop. The potential has notable statistical properties which are rather significant. The maximum of the potential field coincides with the harmonic centre of the distribution and generally with the modal centre too (Figures 3a and 3b). Moreover it is easy to derive a lot of scattering measures from the potential field. The potential can be considered as an index of proximity, of probablity of interaction, or as a measure of the friction of the distance.

1.2. Potential surface mapping

Owing to statistical moments, it is possible to transform a discrete distribution into a statistical surface. Scalar and gradient measurements are associated to each point of this spatially continuous field. The selection of the possible exponents of the distance and the size of the convolution window allow to complete complementary statistical surfaces corresponding to different levels of observation.
The informative value of the surfaces can be emphasized by numeric or color synthesis. A original graphic processing consists in overlaying urban and vegetation potentials. Each of them is sliced and displayed according to a gradation in one fundamental color, red and green respectively. The result of the overlay is a choropleth map of the residential environment where the colour of each class is obtained by the synthesis of two additive colours (Figure 4b, see p.253).
Complementary models can be applied to the urban potential surface, particularly when it is constructed on a plurimodal region at the regional scale. The sliced potential values provide an indicator of the urban hierarchy while an adequate segmentation of the potential surface retains the most important urban zones. A tessellation of their areas of influence is calculated by application of a gravity model,

weighted or not, such as Thiessen or Reilly-Converse. The model uses the pixels with the maximum potential in each urban zone as centres and the acummulated potential in each zone as a possible weighting. The results obtained for the MHAL (Maastricht-Hasselt-Aachen-Liège of Euregio), within the Meuse-Rhine transborder region, provide a regionalization which is in accordance with the reality as established by surveys.

2. DENSITY MODELS

The density model can be seen as a statistical inverse moment of 2d order as well as the potential model is an inverse 1st order moment. The building of a density surface uses the same technique as the one applied to potential surface. Nevertheless the size of the circular or square convolution window generally is reduced to an extent no greater than 10 hectares for the density surface computing.
The possible weighting values introduced in the model can be selected among the standard urban variables, such as built up and floor area indices, in such a way the methodology is able to satisfy the planners requirements.

3. REALIZATION OF SPACE-MAPS

One of the most frequent applications of remote sensing is the production of land cover space-maps (Figure 5, see p.254). Spatio-cartography has specific requirements and implies as well the adaptation of usual cartographic techniques as the definition of new ones, depending on the digital nature of the data and the technical means.
Spatio-cartography has to adhere to standards, so-called cartographic specifications. The main specifications determine the nature of the map : scale, planimetric feature and relief representation. Sheet line system, colors, lettering and border informations belong to the secundary specifications acting upon the map style (facture).
The fiability of a space-map, i.e. the degree of planimetric and thematic accuracy which can be confered on a part or the entire map, is variable. It is generally lower in hilly regions than in plain and it depends on the number of items of the taxonomy.
The production of space-maps is highly automatised including the preparation of the printing plates. The image data in raster format and the ancillary information generally in vector format have to be merged and associated with the adequate symbolic features. Then lettering and layout are introduced and the entire data set is converted in raster format at the resolution of the printing scanner. This operating sequence can be achieved thanks to the set of dedicated softwares acquired in the framework of the TELSAT programme. So a great number of space-maps have been completed and several among them were largely diffused in offset printed form.

OPERATIONAL USES OF THE RESULTS

As earlier mentioned, our field of interest covers city planning, land and country planning and environmental studies. The following list illustrates some of the practical opportunities of remote sensing applications relevant to these domains. With regard to the geographical extent, the selected examples concern Belgium, the Meuse-Rhine frontier region and its main urban centres, the Grand Duchy of Luxembourg and the city of Luxembourg and the metropolitan area of Lisbon.

Urban potential

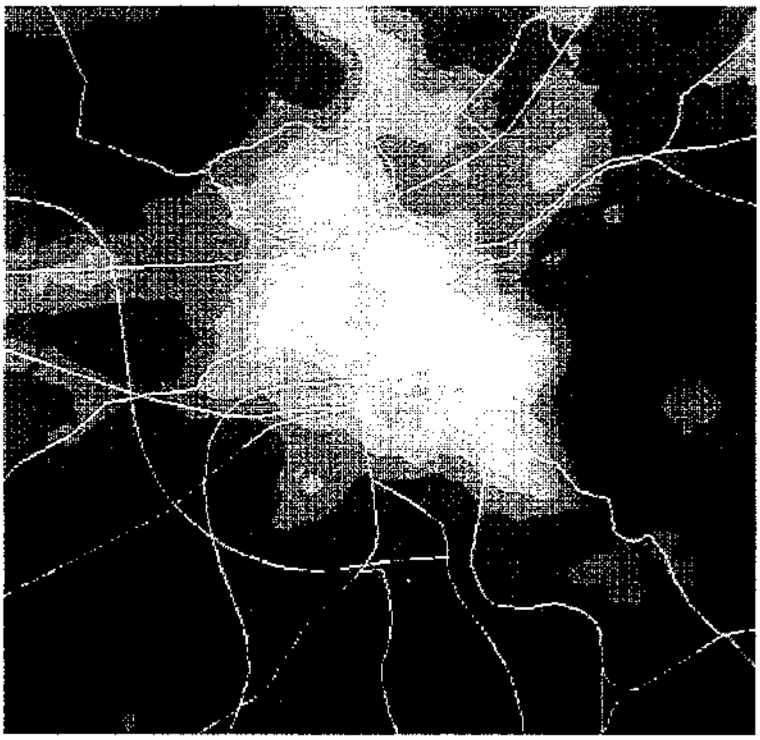
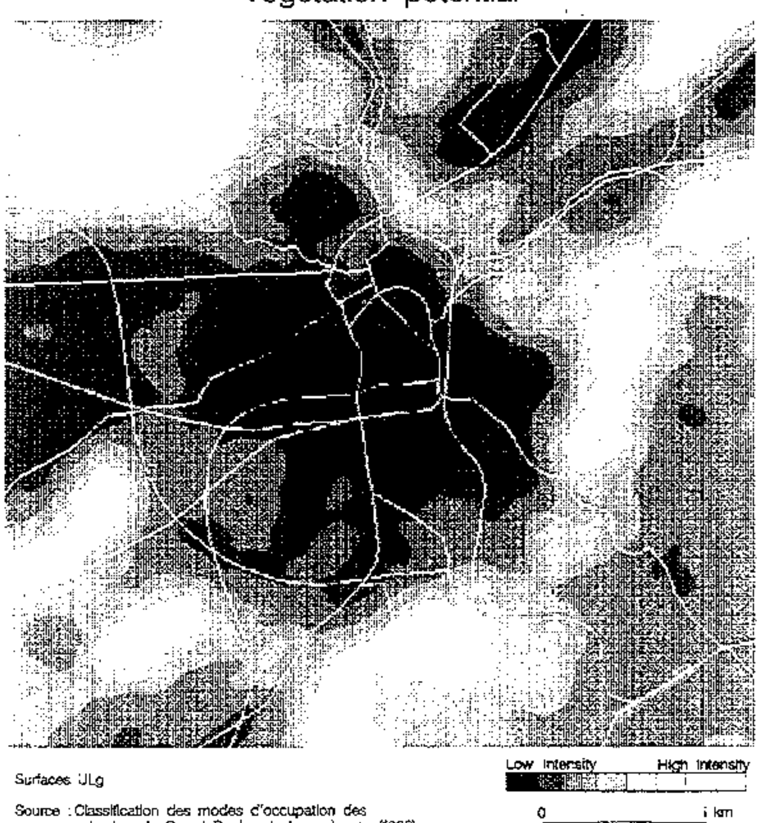


Figure 3 a : Urban potentiel of the agglomeration of Luxemburg.

Vegetation potential



Surfaces ULg

Source : Classification des modes d'occupation des sols dans le Grand-Duché de Luxembourg (1986)

Figure 3 b : Vegetal potentiel of the agglomeration of Luxembourg.

1. SUPERVISED CLASSIFICATIONS

1.1. Supervised classification of SPOT-XS image on the South-West of Grand Duchy of Luxembourg

A land use space-map covering the Southern Development District of the Grand Duchy of Luxembourg has been achieved at the request of the Ministry of Land Planning of this country. This 1:50,000 map makes use of SPOT-XS data recorded in 1989 and resorts to the entire set of techniques of classification, post-classification and map production earlier described. It was published according to the offset technique in 1990 and it was largely distributed by the project manager (Figure 4a, see p.253).

1.2. Supervised classification of SPOT XS+P image on Maastricht

Presently, SPOT XS+P imagery may be considered as the best suitable source for urban remote sensing works. The classification completed on Maastricht reveals a fine restitution of the structure and delineation of the built-up area. It drastically improves the selection of training areas and consequently the classification results. Even if the good geometrical resolution cannot increase the number of discriminated classes, it enhances sensitive themes as housing, industry and utilities.

2 DERIVED DOCUMENTS

2.1. Applications of the potential model on Luxembourg

The urban potential provides an image of the structure of the urban area. A rather radioconcentric scheme is revealed, highlighting the urban core and the internal hierachy of urbanization axes and secundary centres.
Roughly the vegetation potential can be seen as the negative image of the urban potential. The town is surrounded by a green belt wich only is interrupted in the Western part. However the agricultural areas as well as the presence of public parks enhance the value of vegetation potential toward the centre. Urban and vegetal potentials are obvioulsly compementary. The colour synthesis provided by the overlay of the two sliced potential fields translates a division of the urban area into ecological zones (Figure 4b, see p. 253).

2.2. Analysis of the urban area of Aachen

The city of Aachen has been analysed according to a couple of complementary approaches : the identification of homogeneous districts by segmentation and the detection of land use changes.
The segmentation technique makes use of textural and structural characteristics of the image to provide a morphological zoning. About 150 significant zones, from an initial set of 500, are found by the algorithm earlier described. Then they are grouped according to either spectral statistics consolidated per district or interactive interpretation.
The 12 bands of a couple of TM diachronic scenes (TM6 excepted) were submitted to a PCA to detect the land use changes occuring in the urban area of Aachen between 1985 and 1889. As expected, the modifications cluster on secundary components, 4, 6 and 7 in this case, carrying together about 5 % of the entire information of the scenes. Vegetation changes are cleared by masking because they are not of prominent interest in urban analysis. The remaining altered places have to be interpreted to know the nature and the direction of changing. Generally this job is worked out according to a specific ground survey.

2.3. Delineation of the built-up area and production of dasymetric maps on Liège

On the basis of a space-map completed on Liège, the keys of the land use legend relevant to housing, industry and services are selected and collapsed. This process generates a binary mask corresponding to

the buit-up area of the urban agglomeration. To fit criteria required for statistical purposes, the mask is submitted to buffering or filtering processes to delineate the morphological agglomeration.
The intersection of the resulting mask with a layer containing census tract boundaries provides a representation of the built-up area in every tract (Figure 6a, see p.255). Built-up acreage figures are valuable in the computation of densities or any other socioeconomic index associated with this specific spatial base, and they permit consistent applications of the modelling of the urban space. The technique is particularly effective for census tracts which contain a scattered housing settlement and vary greatly in size and form, ie., outersuburbs and rural sectors.
The mapping representation corresponding to this method is called dasymetric mapping and the fulfilment of such application makes use of the peculiar facilities offered by hybrid GIS (Figure 6b, see p.255). This kind of methodology has been used for an applied EUROSTAT contract.

2.4. M.A.R.S. project

In the framework of the M.A.R.S. project, completed in Belgium in 1992 by the teams of Gent (TELSAT/II/04) and Liège (TELSAT/II/06), a Belgian agricultural inventory has been achieved by remote sensing using SPOT raw data.

Among the by-products of this project, a genuine space-map of Belgium must be mentioned. Completed as a geometrically corrected mosaic of 16 SPOT scenes at 20 meters resolution, this space-map is published at the scale 1:400,000. The land use information issued from the processing of remotely sensed data is merged with planimetric features selected from the digital data base of the National Geographic Institute of Belgium.

2.5. Evolutive survey and qualification of water bodies in suburban area

Many ecological and landscape quality problems arise in the lower Meuse valley due to the growing extent of gravel pits, even if legally the restoration of the abandonned pits is mandatory.
The use of a couple of TM diachronic scenes (1985-1989) has proved to be an efficient and rather inexpensive way to analyse the quantitative, qualitative and evolutive aspects of the considered phenomenon.
Underwater zones were detected and their modification stated using relatively simple thresholding technique applied to the band 5. The turbidity phenomenon was highlighted owing to water quality indices calculated as linear arrangement of TM bands 2, 3 and 4. The restoration monitoring of foresaken sites was performed according to the vegetation index applied to the filled up surfaces.

RESULTS OF THE RESEARCH

The main achievement of research lies, not in the peculiar problem solving cases as valuable as they may be, but in a holistic approach to the remote sensing problems. This policy granted a good control over remote sensing tools and an expertise in connected ancillary techniques.
It is also worth to mention that the entire production of regular space-maps satisfying the most severe metric and aesthetic standards is now under control.
The development of some mathematical morphology functions, such as : image segmentation, contextual filtering or definition of internal structural bands presents theoretical as well as practical interest. The quality of classification, the cartographical representation and the zoning definition suiting the urbanistic practice, are greatly improved by the emphasis given to the morphological components.
The automatic delineation of isophene zones, issued from segmentation, can be followed by their internal categorization. The setting up of an algorithm for zone-based classification, applied to one part of the Lisbon agglomeration, lies in this connection. Unfortunately, this same approach has not allowed the restitution of the continuity of road network. This failure is due to the insufficient spatial resolution of satellite imagery and also to the excessive urban fragmentation of the area under survey.

Concerning diachronic analysis, it was not possible to employ the most sophisticated techniques. However procedures have been developed leading to successful treatment of many real cases.
The transformation of discrete distributions of pixels into continuous surfaces leads to the realization of statistical surface. These constructions, even more than other satellite images, lead to a fertile conceptualization and to numerous hypothesis formulation. This kind of study was performed in our laboratory since 1987, it happened elsewhere as well but sensibly later.Pertaining to the urbanistic practice, surface models operating morphometric criteria or land-cover indices have been developed. Concerning the more classical approach of discrete thematic cartography, the improvement provided by dasymetric mapping using remotely sensed data has been emphasized in the field of census operations.

CONCLUSIONS

However the satellite remote sensing techniques, development, diffusion and usage were somehow less important than earlier announced prediction, this market is now operating and grows following its own rules.
The rational management of natural resources, weaked in quantity and quality, and the necessary control of urbanization effects control favour the development of remotely sensed methods. In many cases, remote sensing is the sole rational and inexepensive means of problem solving. The remotely sensed image processing requires the use of hybrid geographical information system, able to handle raster and vector modes. This condition was often and longtime overlooked by those who conceive image processing systems. For most of the problems and applications treated in our laboratory, GIS reveals itself as an essential tool.
The decisive advantage of satellite remote sensing is perhaps its monitoring ability, detecting changes occured in the environment under survey. Practically, the multitemporal analyses are less widespreaded than the users' needs and the capacity of available tools lead to anticipate. A beter discrimination and effectiveness can be expected from the new sensor generation programmed on SPOT4 and LANDSAT7.
This partial inventory is by no means the limit of satellite images utilisation. The classification results lead to modelling and to simulation procedures. Thus digital remote sensing may become a precious ideas generation device.

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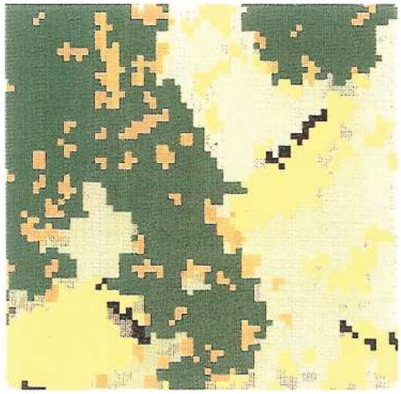

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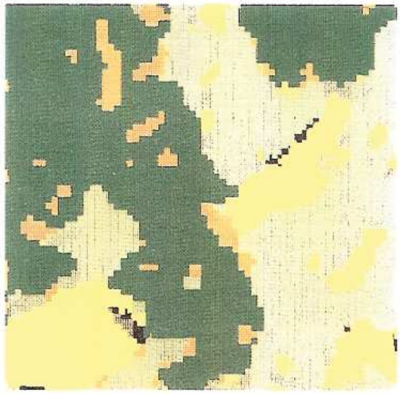

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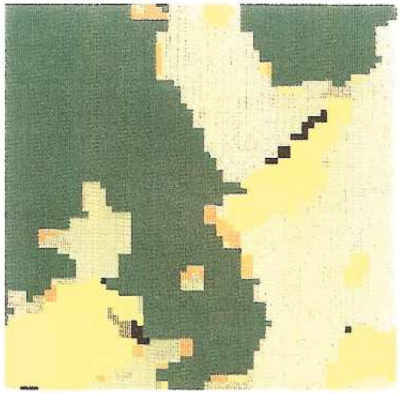


Contextual filter

Surfaces Ulg

1 ___ 100 m

Source : Classification des modes d'occupation des sols dans le Grand-Duche de Luxembourg (1986)

Figure 2 : Comparison between modal and contextual filters. (see p.41)

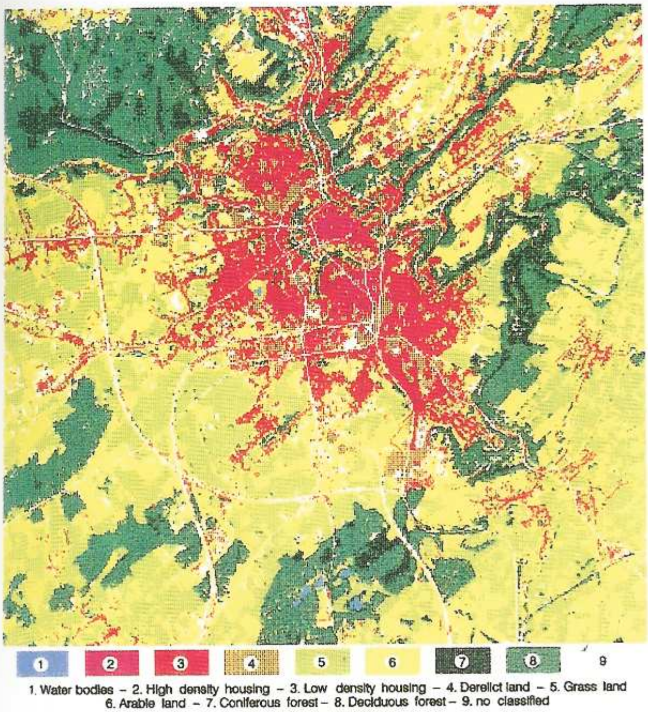
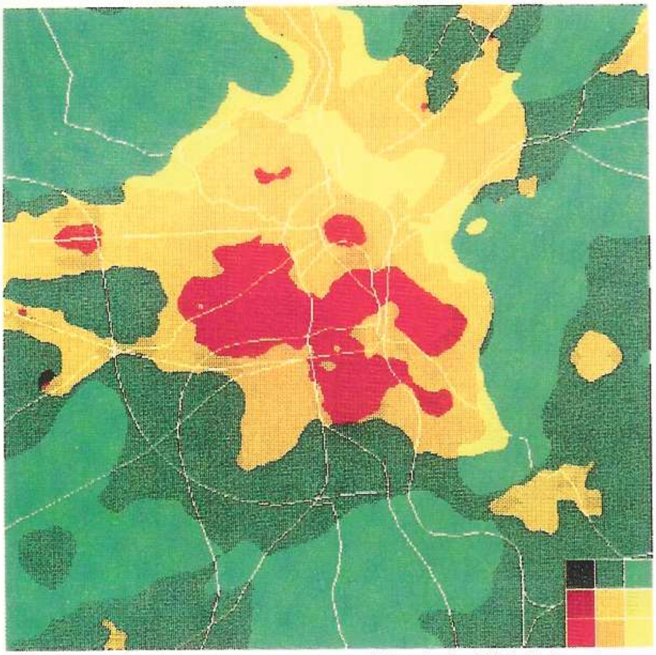


Figure 4 a : Land cover classification of the agglomeration of Luxembourg.



Chromatic fusion of urban potential (red) and vegetation potential (green) each subdivided in three classes.

Surfaces ULg

Figure 4 b : Evaluation of the residential environment of the agglomeration of Luxembourg. (see p.41)

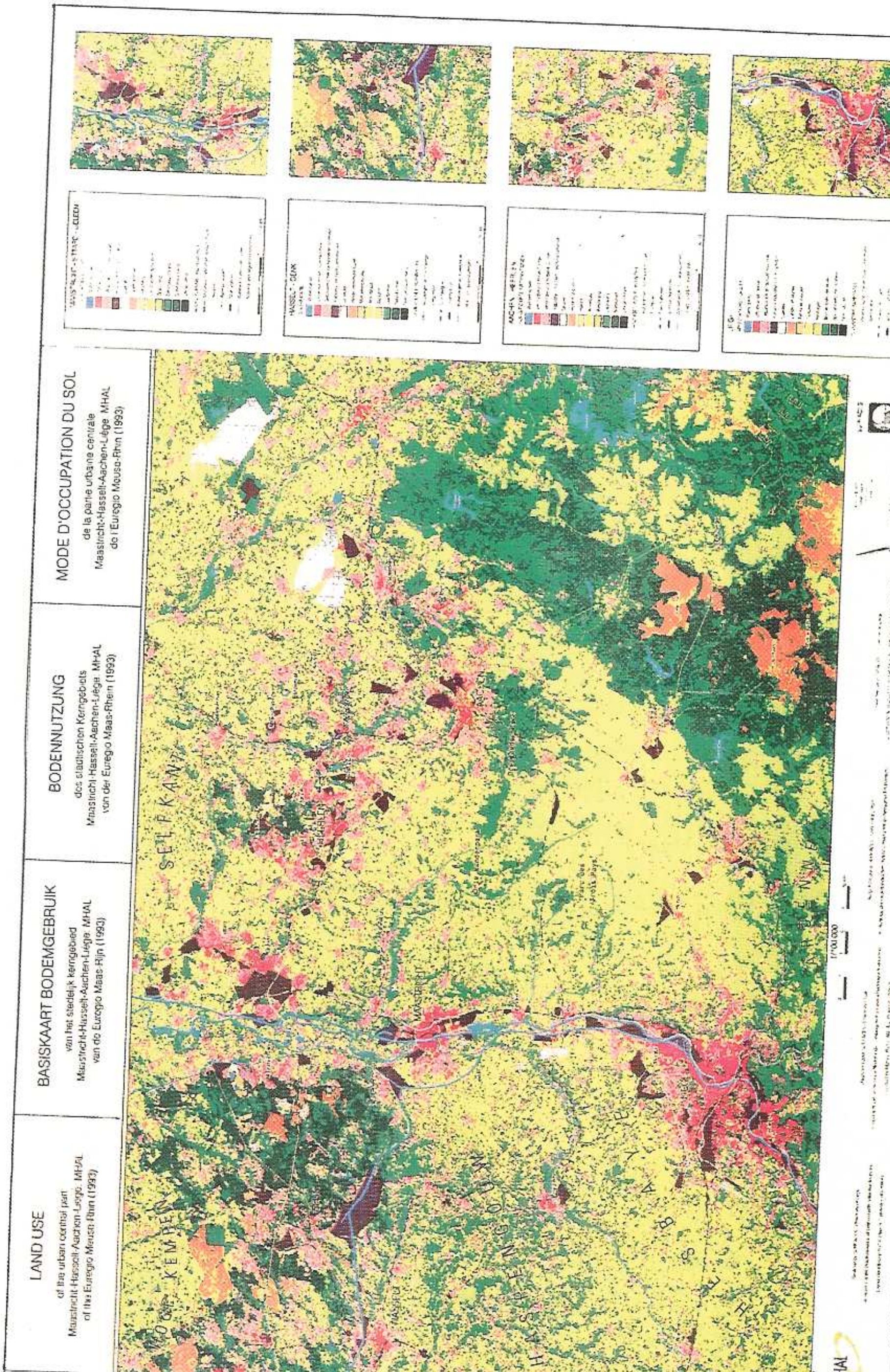


Figure 5 : Land Use of the urban central part of the Euregio Meuse-Rhin (1993). (see p.42)

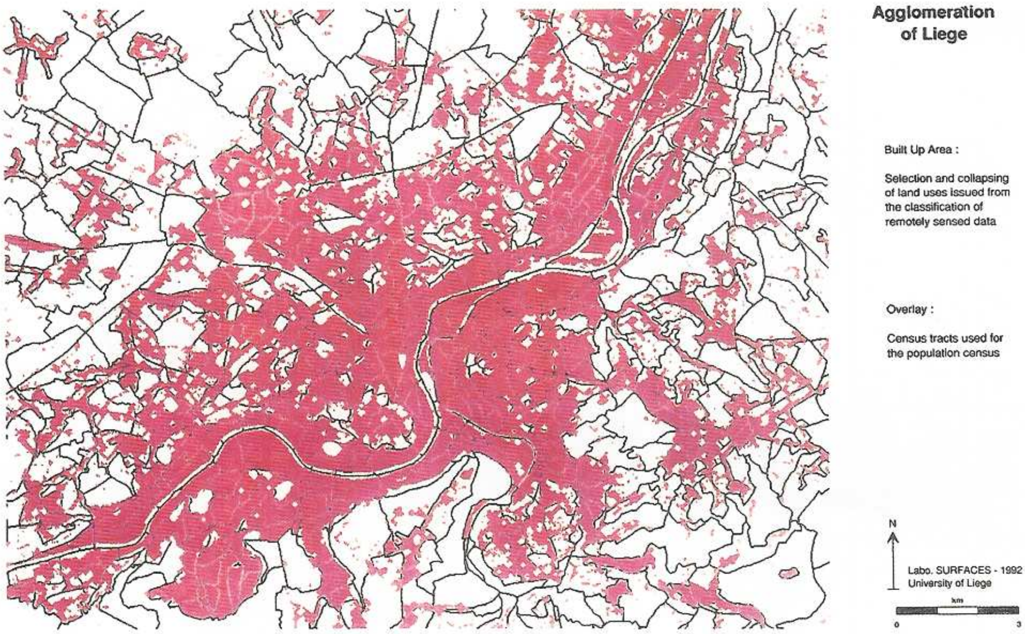


Figure 6 a : Agglomeration of Liege : Built Up Area.

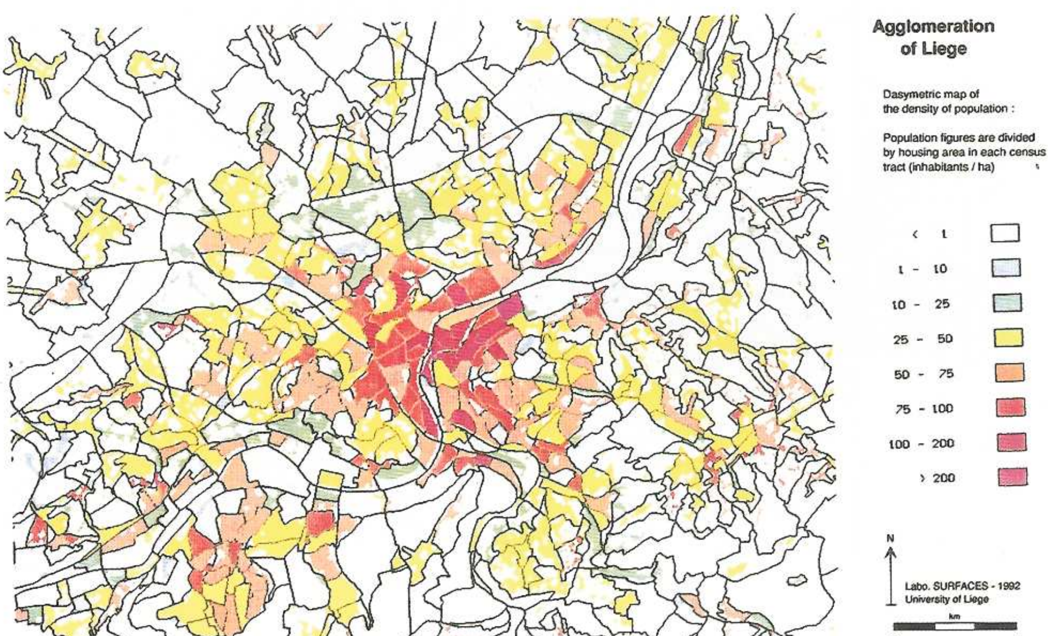


Figure 6 b : Agglomeration of Liege : Dasymetric map of the density of population. (see p.45)