The MURBANDY / MOLAND Methodology and its Potential to Support Sustainable City Development

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Abstract

Mit der Ratifizierung der Agenda 21 der United Nations Conference on Environment and Development in Rio de Janeiro im Jahre 1992, verpflichteten sich die Nationen für eine Verbesserung der sozialen und wirtschaftlichen Bedingungen und der Umweltqualität in städtischen und ländlichen Siedlungen sowie in der Lebens- und Arbeitswelt aller Menschen, insbesondere der städtischen und ländlichen Armutsgruppen.

Das Projekt „MURBANDY / MOLAND" wurde 1998 von der Europäischen Kommission initiiert, mit den Zielen, mittels der Kombination von Erdbeobachtungsdaten, GIS-Daten und statistisch erfassten sozio-ökonomischen Daten die Anforderungen einer nachhaltigen Stadtentwicklung zu unterstützen. Hierfür erfolgte zunächst eine Landnutzungsklassifizierung von 25 europäischen Städten auf der Basis einer erweiterten CORINE-Landnutzungslegende im Maßstab 1:25 000 für 4 Zeitpunkte innerhalb der letzten 50 Jahren. Das Datenmaterial wird in einem geographischen Informationssystem (GIS) verwaltet.

Der vorliegende Artikel diskutiert das MURBANDY / MOLAND Konzept und analysiert anhand von Beispielen dessen Potential für eine zukünftige, nachhaltige Stadtentwicklung.

1. Introduction

'Cities are the major loci of production, consumption and civilised creativity as well as the source and site of much environmental damage' (European Commission, 1996). The understanding of urban systems is one of the most complex tasks within the field of land management for sustainable development. With the adoption of Agenda 21 of the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, the nations entered into a commitment […] to improve the social, economic and environmental quality of human settlements, and the living and

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working environments of all people, in particular the urban and rural poor (United Nations for Environment and Development, 1992).

A lot of research is focused on the development of new methodologies for a better understanding of urban and environmental development. One of the most investigated fields of urban research concerns the definition of specific indicators for the sustainability of urban areas. However many of these indicators are focused on the thematic and temporal dimension, and do not include the spatial distribution. The spatial aspect must be included to improve the social, economic and environmental quality of human settlements. The inclusion of earth observation data in urban analyses meets the requirement for the spatial dimension. In addition, earth observation data offer the added possibility to have a look into the cities' history by reproducing the same datasets and indicators for the past, based on the same methodology.

In 1998, the Directorate General Joint Research Centre (DG JRC) of the European Commission launched the MURBANDY (Monitoring Urban Dynamics) project. Based on the above-mentioned points, the main aims are firstly, to develop and secondly, to provide measurements of, the extent of Europe's urban areas and their progress towards sustainability, and thirdly, to model urban growth scenarios to define strategies for sustainable development. The developed methodology must allow a comparison and cross-analysis between different cities and different themes. For purposes of this paper, seven cities – Bratislava, Dresden, Dublin, Munich, Prague, the Ruhr Area, and Vienna – have been chosen as demonstration areas.

MURBANDY was extended in 1999 to a broader project called MOLAND (Monitoring Land Use / Cover Dynamics). The two main objectives of MOLAND are to study areas experiencing fast land use dynamics, both within and outside the European Union, and to extend the methodology of MURBANDY to support regional and sub-regional policies with territorial and environmental impacts.

2. Methodology and Analyses

The technical reference framework for the MOLAND Project is provided by the European Spatial Development Perspective. It is based on the EU aim of achieving a balanced and sustainable development, in particular by strengthening economic and social cohesion. 'In accordance with the definition laid down in the United Nations Brundtland Report, sustainable development covers not only environmentally sound economic development, which preserves present resources for use by future generations but also includes a balanced spatial development. This means, in particular, reconciling the social and economic claims on land use with the area's ecological and cultural functions and, hence, contributing to a sustainable spatial development that is balanced at regional level' (European Commission, 1999).

In order to assess the extent of Europe's urban areas, and their progress towards sustainability, multi-temporal geographic datasets were processed for the cities under study. This first phase is called 'Change'. These datasets are then analysed, indicators derived, and combined with socio-economic and environmental data. This second phase, called 'Understand', aims to provide a better understanding of urban growth and dynamics, commuting issues, and the status of transport and energy infrastructure, from the point of view of sustainable development. A model for simulating the urban growth process is being applied to the MOLAND database, including both earth observation and non-space data. This third phase, called 'Forecast', supports the development of strategies for sustainable development.

2.1 Phase 1: 'Change'

The methodology of the 'Change' phase involves the creation of four land use databases – one reference (present) and three historical – including the road and rail networks of the corresponding years. The databases are derived from remote sensing data for twenty-five selected European cities or regions, over the last fifty years.

The reference land use classification is based on recent data (1997, 1998) from the panchromatic Indian Remote Sensing (IRS) satellite. The historical database is created using satellite imagery or aerial photography from the mid-1950s, late 1960s, and mid-1980s. All images and products are geo-coded. Visual image analysis techniques are used for classification. To conform to European Commission standards, the nomenclature for the cover types is based on an extended version of the legend of the CORINE Land Cover Project. In the case of MOLAND, however, for all cities and regions, land use maps were produced at a scale of 1:25,000. The minimum mapping unit for a polygon is one hectare for artificial surfaces and three hectares for non-artificial areas. In addition, a fourth level is included for the classes artificial areas and water courses. The road, rail, river, and canal networks are digitised as linear features, and as polygons when they are broader than 25 metres.

The study area for all cities is represented by the inner urban area (i.e. the 'core' area), corresponding to artificial surfaces, plus a buffer around this core area. The width of the buffer is computed using the following standardised formula:

$$\text{Buffer area} = 0.25 * \sqrt{\text{Core Area}}$$

This formula enables comparison between different cities, since the relation between the size of the core area and its surroundings is the same for all cities.

After data processing, a validation for all land use data sets is carried out in order to guarantee a high quality of land use classification products, and to enable comparison of statistics for all cities.

2.2 Phase 2: ‘Understand’

An important task in the framework of research on sustainable development for land management and protection, is to understand the complexity of urban systems, and the development of each city, including issues related to growth and dynamics.

The ‘Understand’ phase of MOLAND consists of the spatial analysis of the derived GIS data, and involves the derivation and calculation of urban and environmental indicators. The aim is to gain a better understanding of the past and future dynamics, and of the impact on the cities and on the environment, with the consideration that without a spatial (i.e. territorial) component, any set of urban indicators that aims to address sustainability would be incomplete.

2.2.1 General Statistics and Basic Indicators (Information)

To get an overview of each city, general spatial statistics - e.g. ‘total area’, ‘total urbanised (agricultural, natural) areas’ or ‘motorway and railway network densities’- were first calculated, based on the processed datasets.

As already mentioned, the use of earth observation data allows statistics and indicators to be produced for both the present and the past, using the same methodology. Dynamic indicators – such as ‘increase in artificial areas’ and ‘loss of agricultural (natural) land due to urban sprawl’ – can also be calculated.

An important factor in urban sustainability is to improve the social, economic and environmental quality of human settlements (‘quality of life’). This includes such aspects as access to employment and adequate shelter, stable social networks, access to recreational areas, etc. This requires the definition and implementation of such indicators as ‘percentage of total green urban areas (sport and leisure facilities) in total urbanised areas’, ‘percentage of commercial areas (public and private services) in total urbanised areas’ and ‘distance from residential areas to commercial areas’.

Table 1 shows selected spatial and ‘quality of life’ indicators for Munich, Dresden, Vienna, the Ruhr Area, Bratislava, and Prague. In order to get an overview of each city, Table 1 shows the total area and the total artificial areas.

By analysing the increase in artificial areas between the mid-1950s and late 1990s, it can be seen that Bratislava had an increase of 207 per cent, and Munich about 44 per cent. Comparing the statistical values for the railway density, it can be seen that Dresden and Vienna had no increase, Bratislava shows a large increase (related to industrial development), and the Ruhr Area shows a decrease, due to the fact that railway land of old industrial areas was redeveloped. Another example is the ‘percentage of total green urban areas in total urbanised areas’. For example, nearly 15 per cent of Dresden’s total urbanised areas are ‘green urban areas’, so that Dresden may be seen as a ‘green’ city. In contrast to that, the heavily industrialised Ruhr Area had for a long time the image of a polluted environment with endless cities without green areas. In fact, its percentage of ‘green urban areas’ is 1.3.

	Munich	Dresden	Vienna	Ruhr Area[1]	Bratis-lava	Prague
Total area (km^2)	797.8	631.2	841.8	352.6	462.7	797.6
Total artificial areas (km^2) End 90s (Mid 50s)	356.9 (246.7)	238.6 (182.6)	341.1 (249.7)	273.9 (219.8)	123.3 (40.7)	288.4 (186.9)
Increase in artificial areas Mid 50s – End 90s (%)	44.7	30.7	36.6	24.7	207.5	54.8
Loss of agricultural land (%) Mid 50s – End 90s	29.3	16.2	21.6	65.8	28.7	22.2
Railway density (km/km^2) End 90s (Mid 50s)	0.44 (0.47)	0.20 (0.20)	0.30 (0.30)	0.78 (1.30)	0.41 (0.27)	0.35 (0.31)
Percentage of commercial areas in total urbanised areas (%)	5.9	2.5	4.6	7.9	2.6	0.2
Percentage of public and pri-vate areas in total urbanised areas (%)	6.1	4.5	7.4	9.3	7.1	5.8
Percentage of total green urban areas in total urbanised areas	8.6	14.8	5.7	1.7	4.7	4.4

(1) Area size was defined by JRC

Table 1:
Examples of spatial and ‘quality of life’ indicators, derived from the processed data set for the reference year (mid-90s)

In addition to the general statistics, a basic spatial indicator was calculated for all MOLAND cities and regions, showing the land use changes of the three main classes (urban, agriculture, nature) over a 50-year period. In particular, the changes from agricultural and natural areas to urban areas are investigated, documented, and their statistics calculated. An example is given in Figure 1 for the Ruhr Area.

Figure 1 shows the land use situation for the Ruhr area, which includes the four major cities of Essen, Duisburg, Oberhausen and Mühlheim an der Ruhr, for the years 1952, 1969, 1989, and 1998. The changes from agricultural and natural areas to artificial surfaces are also shown. The Ruhr Area is one of the most densely and industrialized parts of Germany. From Figure 1 it can be stated, for example, that:

1. between 1952 and 1969 more than 3000 ha have changed from agricultural areas to artificial surfaces;
2. there is a declining trend for agricultural areas to become artificial surfaces;
3. the number of areas which changed from natural areas to artificial surfaces peaked during the period from 1969 to 1989.

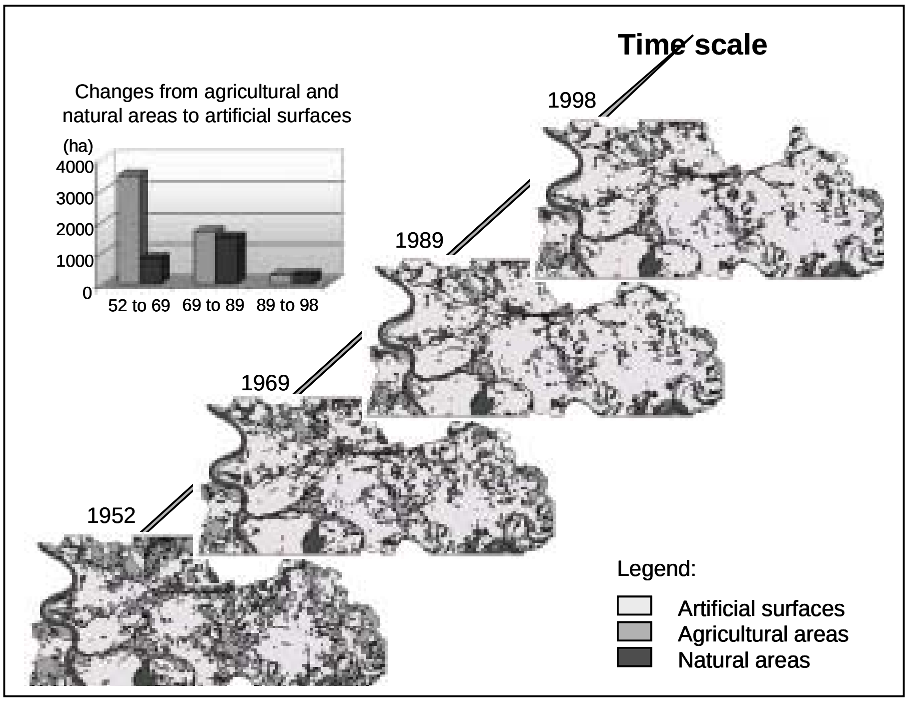

Figure 1:
'Urban sprawl' of the Ruhr Area – changes from agricultural and natural areas to artificial surfaces

2.2.2 Analysis of the MOLAND Datasets

As well as the process of statistics calculation, an interpretation and analysis of the land use data was carried out. Two case studies are discussed below.

Case study 1: Industrial development of Bratislava and its correlation with the rail network

Although Slovakia was a traditionally agricultural country until the Second World War, Bratislava always played an important role in industry, trading, and as a residential centre. After the communist regime took over the government, the new centrally planned economy of the country was directed towards the industrial sector, with an emphasis on military production and chemical industry.

Analysing the development of industrial areas in Bratislava, it is clear that there is a strong relation between new industrial areas and the rail network (Figure 2).

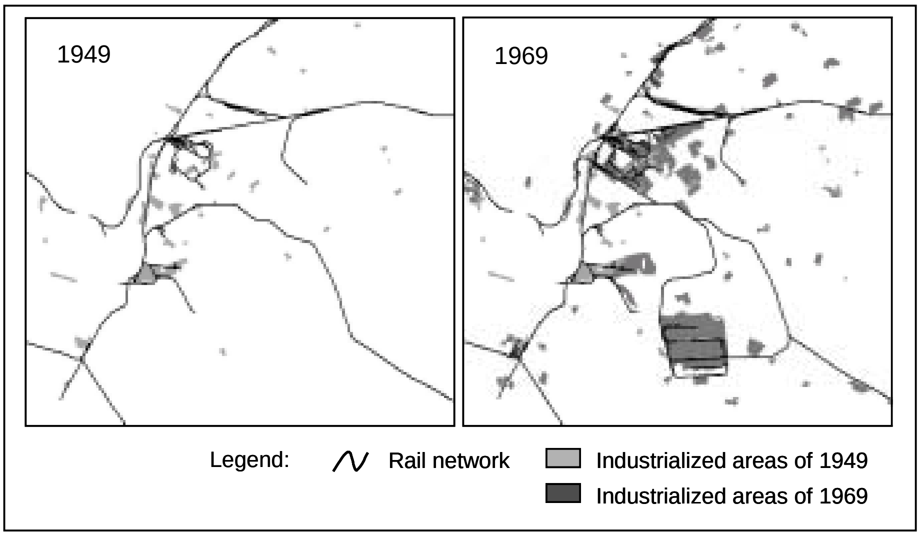

Figure 2:
Industrial areas and rail tracks for 1949 and 1969 (subset)

Figure 2 shows a subset of the industrialized areas and rail networks for 1949 and 1969. Comparing both images, it can be seen that:

1. the major industrial areas are all very well connected to the rail network system;
2. the growth of industrial areas is closely linked to the building of new rail tracks, since newly built up industrial areas got new rail tracks and, therefore, a connection to the national rail system.

The relationship between new industrial areas and new rail tracks continued until the breakdown of the communist regime in 1990.

Case Study 2: Comparison of the development of industrial, and commercial areas, and public and private services (Munich – Dresden)

The second case study shows that the MOLAND database can be used to compare different cities, with formerly different economies, over a period of fifty years. The investigation concentrates on the classes 'industrial areas', 'commercial areas', and 'public and private services' of Munich (market economy) and Dresden (formerly a centrally planned economy).

Based on the MOLAND datasets, the classes 'industrial areas', 'commercial areas', and 'public and private services' were extracted and their size calculated. The statistical values refer to the respective core area of both cities.

The diagram on the left side of Figure 3 shows the statistics for Munich, the right one represents the values for Dresden.

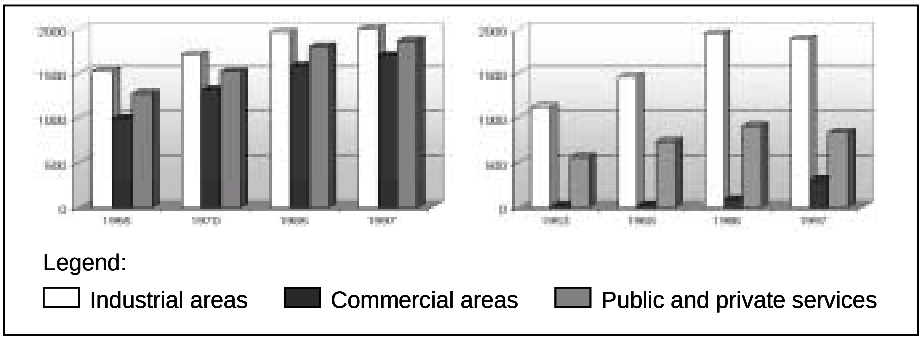

Figure 3:
Comparison of the development of industrial, and commercial areas, as well as public and private services between Munich (market economy) and Dresden (former centrally planned economy) inside the cities' core area

The difference can clearly be seen at a glance. Both cities are very highly industrialised. Dresden had a lower starting point, but under the communist regime the development of new industrial areas was higher than in Munich. In the middle of the 1980s, Dresden drew level with Munich in terms of industrial areas.

In comparison with Dresden, commercial areas and public and private services are also very well developed in Munich. The public and private service of Dresden is still well developed, but until 1986 not many commercial areas can be detected. This changed after the German reunification in 1990, which included the change from a centrally planned to a market economy. For West Germany, this change opened new markets. In Eastern Germany, a trend emerged to build up new huge (industrial) and commercial parks along main roads and motorways. This trend is shown in Figure 4 for Dresden. The light grey colour in the background shows the situation of industrial and commercial areas as well as public and private services for the year 1986. The darker grey values are the new (industrial) and commercial areas, built after reunification. As already mentioned, it took place along the main roads ('Ausfallstraßen') and the motorway.

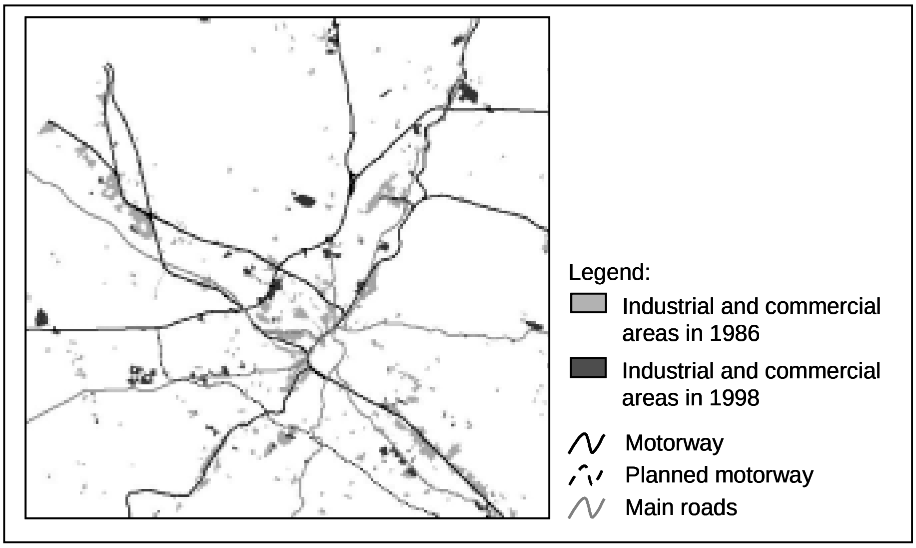

Figure 4:
Industrial and commercial growth in Dresden along main roads and motorways

This example shows that the MOLAND concept permits the investigation and comparison of different cities with formerly different market economies. This information is important to understand the cities' past development. However, it also shows future risk areas: too many (industrial) and commercial areas have been built and some of them already have economic problems. This information is important to support sustainable development in future.

2.2.3 Combination of MURBANDY Data With Socio-Economic Data (Vienna)

The analysis of urban and socio-economic development involves three dimensions: thematic, temporal, and spatial. Up to now, only limited attention has been paid to the spatial dimensions. Therefore, there is a need to integrate spatial policies with those on the socio-economic and environmental levels. The MOLAND concept includes the combination of its spatial datasets with (empirically) recorded socio-economic statistics. Data from EUROSTAT and GISCO have been selected and this thematic information has been – where it is available for the cities – linked to the spatial MOLAND database. Selected parameters are for example: population per community, population density per community, income, commuters, percentages of the three sectors (industry, agriculture, services), age distributions, and so on.

Figure 5 gives an example of the combination of the MOLAND dataset with the population density for the city of Vienna.

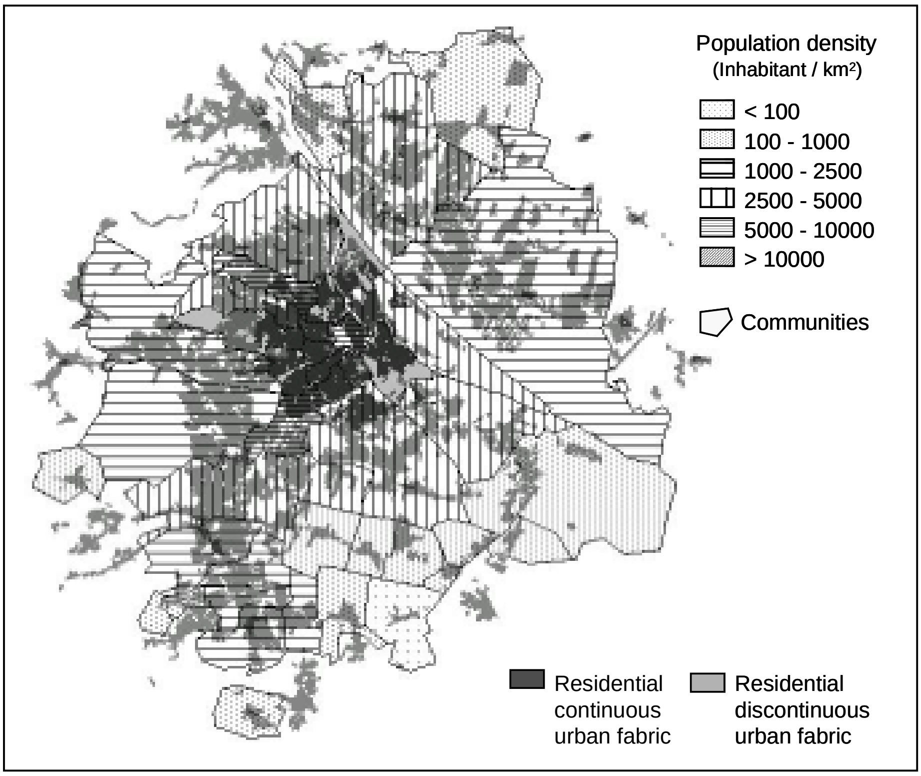

Figure 5:
MOLAND dataset in combination with socio-economic data

In the background, the MOLAND classes ‘residential continuous urban fabric’ and ‘residential discontinuous urban fabric’ (reduced to classification level 3) are highlighted. Overlaid is the population density per square kilometre per community. This example shows that the highest population density is in communities which are (most) completely covered by residential continuous urban fabric. Outside of Vienna’s core density, there are communities of lower population density. Figure 5 shows not only the population density, but also the distribution of residential areas. This means, that the real population density is for many communities even greater when there is a concentration of residential areas.

2.2.4 Fragmentation Analysis

As part of the MOLAND Project, changes in the spatial structure, or fragmentation, of the urban landscape are measured and analysed using landscape structural analysis software (i.e. FRAGSTATS) that has been specially modified for use with the Moland land use databases. This is done in order to gain a better understanding of the impact on urban environments of current and future European Union policies. Landscape fragmentation is quantified by analysing the properties and configuration of the spatial elements or 'patches' that make up the landscape. The trends over time of the various fragmentation metrics computed by FRAGSTATS (i.e. area metrics, patch density and size metrics, edge metrics, shape metrics, core area metrics, nearest neighbour metrics, diversity metrics, contagion and interspersion metrics), are interpreted in the light of known environmental and demographic factors for the different urban areas. The fragmentation analysis is currently being applied to eight cities in the Moland database: Bratislava, Dresden, Dublin, Helsinki, Milan, Munich, Prague, and Vienna.

Prior to being used as input for fragmentation analysis, the MOLAND land use databases must first be converted from vector (i.e. polygon) format to raster (i.e. image) format. In order to preserve the spatial detail that is contained in the MOLAND vector coverages, it is necessary to specify an appropriate output pixel size for use in the vector-to-raster conversion. The smaller the output pixel size used, the more spatially detailed is the output raster image. Using an output pixel size that is too small, however, results in extremely large output raster images, leading to problems during fragmentation analysis, such as very slow processing times, insufficient computer RAM (random-access memory), and insufficient disk storage space. Following extensive tests, an output pixel size of 5x5 metres was found to be small enough to preserve the spatial detail of the input MOLAND vector data-sets, but large enough to produce output raster files of manageable size.

In addition to the fragmentation metrics mentioned above, the fragmentation analysis software has been modified so that it computes, for each land cover class, the length of the edge between that class and each of the other classes. Thus, the various edge types in the landscape can be quantified, and changes in the edge types over time can be monitored. Based on this information, it is possible to identify those land cover classes in a landscape that directly affect a given land cover class of interest by their adjacency to it. In an urban environment, information on edge types can be used, for example, as an indicator of the potential negative impact of major traffic corridors on residential areas. The composition of the total urban edge, computed for the Moland land use databases for Dublin in 1956 and 1998, is shown in Figure 6. (Note that total urban edge is defined as the total length of the edge between Moland class "Urban fabric" and all other land use types). As can be seen, in the case of Dublin there has been a huge increase in the amount of edge between "Urban fabric" and "Artificial non-agricultural vegetated areas" (including green urban areas). This indicates that much of the new "Urban fabric" in Dublin has been developed in conjunction with "Artificial non-agricultural vegetated areas".

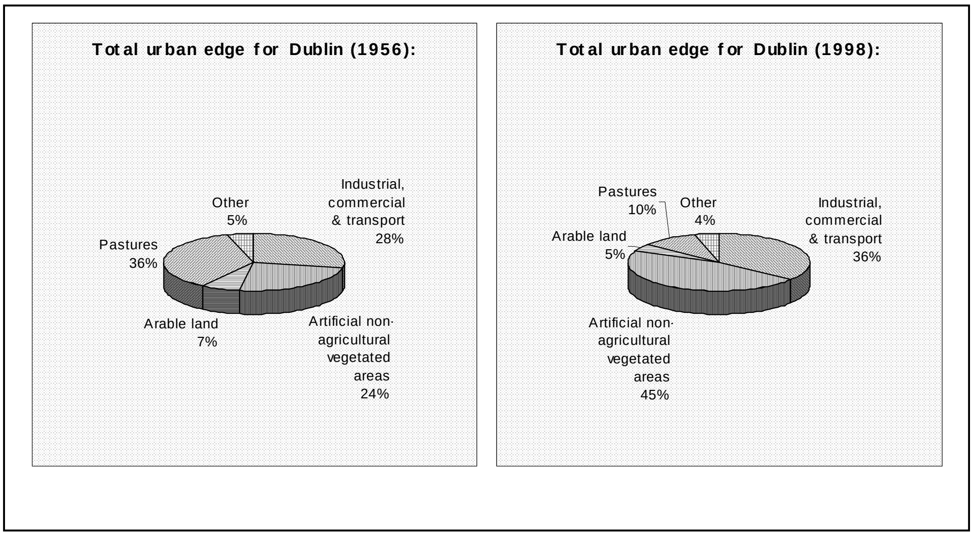

Figure 6:
Change in total urban edge for Dublin (1956-1998)

2.3 Phase 3: Forecast

The main objective of ‘Forecast’, the third phase of MOLAND, is the development of scenarios for urban and peri-urban areas, using information derived from both earth observation and non-space data. The scenarios are produced using modelling techniques based on cellular automata. The question is examined of whether a single model can be applied to all cities, with minimal modification for national, regional, and city-specific factors, or whether different models are necessary. The resultant scenarios are a major input for formulating and evaluating medium- and long-term strategies for the sustainable development of urban areas in Europe. This modelling part is probably the most difficult part of the urban planning process, because future impacts of actions and policies are normally not very well known.

An overview of the cellular automata urban model developed in MOLAND, is shown in Figure 7. The urban area of interest is regarded by the model as a euclidean space, divided into an array of identical cells. Each cell is characterised by vectors indicating the suitability and zoning status for the various land use types, as well as the relative importance of accessibility to transport networks. The underlying idea of a cellular automata model is that the state of a cell at any time depends on the state of the cells within its neighbourhood. This is the neighbourhood effect. For each cell, a set of transition potentials (one for each possible land use) is computed from the suitabilities, accessibilities, zoning, and the neighbourhood effect. Each cell is then changed to the state (i.e. land use) for which it has the highest potential, based on a set of transition rules. This process is repeated within the model at yearly intervals, for a period of twenty years. The urban model is currently being tested and calibrated using the MOLAND reference and historical databases.

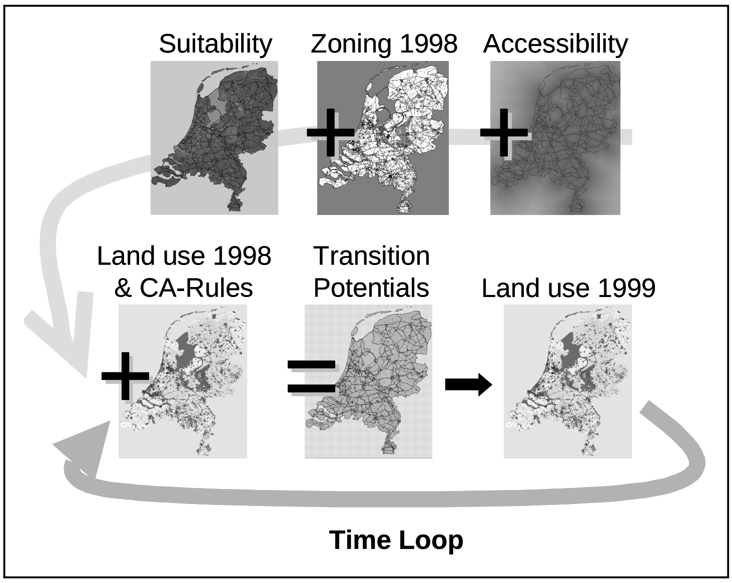

Figure 7:
Overview of the MOLAND urban model

3. Conclusions and Outlook

Sustainable urban and rural development is not possible without the spatial dimension. But until now numerous studies have focused on the thematic and temporal dimension and have not included this spatial aspect. The MOLAND methodology is based on a spatial approach.

This paper discussed the three phases of the MOLAND concept, with an emphasis of the 'Understanding' phase. With this concept, it is possible to provide a global picture of the spatial, thematic and temporal development of urban areas, which helps to improve the understanding of the changes that have occurred over the past decades and to provide an instrument for future planning activities. Including the spatial dimension, it is now possible to support the improvement of the social, economic and environmental quality of human settlements and living and working environment of all people' as stipulated in Agenda 21.

The most important advantage of this technology is its flexibility; it is easy to implement, to update, to reproduce the past in the future with the same procedure, and to disseminate the information.

The MOLAND methodology is designed so that mega-cities can be also be included. Seven mega-cities – Bangkok, Buenos Aires, Chongqing, Mexico City, New Delhi, Pretoria-Johannesburg, and Seoul - are currently under investigation.

Using GIS technologies to manage such huge amounts of data also opens up new possibilities for collaboration between remote sensing experts, urban planners, international, national and local ministries, and experts in transport and communications. Furthermore, a comprehensive European database for cities could help international organizations involved in urban environmental policies and research to identify pilot projects, to pursue European-scale solutions, and to create new technological networks for information exchange and cooperation between the different players at local and regional level.

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