An urban growth model for strategic urban planning on a regional level: a proposed model prototype for Greater Cairo in the year 2050

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Abstract

Understanding and simulating urban growth patterns is the first objective for urban modelling. The goal of this paper is to propose a model prototype for urban growth on the regional planning level, which could show what will be the pattern scenarios for Greater Cairo urban growth in the year 2050; using a multi dimensional system that can deal with spatial, temporal and decision-making complexity. While system thinking has been widely accepted by urban planners and other decision-makers engaged in urban planning, we consider urban growth as a complex system. The exploration is conducted by answering the most important questions which are: Where is urban growth occurring? And what are its trends? The methodology consists of three approaches: first the theoretical approach including: the most important definitions of the study problematic, defining the variables of the urban growth, second, the paper links the theoretical approach with the major analytical approaches through model dimensions, finally proposing model prototype based on geographic information systems (GIS) with visual basic programming language within mathematical models.
Keywords: urban modelling, urban growth, strategic urban planning.

1 Introduction

Urban modelling has become one of the sub fields of geographic information systems (GIS) in the long-term research challenges, and digital technology is

WIT Transactions on Ecology and The Environment, Vol 155, © 2012 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SC120071

moving rapidly to distributed computing. GIS has already been adapted to several changes in computing architectures. The users of GIS today have access to an uncounted amount of high-resolution and high-quality environmental data through scanners, remote sensing devices, global positioning systems (GPS) receivers, etc. Furthermore, these datasets could be used by others from different fields with different perspectives in modelling urban growth. So GIS can benefit from distributed computing on the regional level. Urban modelling has the chance to lead GIS into a new growth modelling era in terms of computing paradigm, resource sharing pattern and online collaboration.

1.1 Problem and research context

Urban growth has a very wide sophisticated spatial, temporal and decision-making complexity. It imports a variety of planning strategies from highly specialized urban planners. On these dimensions a new developed programming will be the ideal approach. A multi-dimensional urban growth model can deal with urban dynamic changes on the coming years. The model can connect the urban planners, decision makers and administrative authorities,

2 Research methodology

2.1 Theoretical approach

2.1.1 Definitions within the context

Information Technology (IT): IT is a reflection of the human need for development and progress. A technological environment in which all elements integrate together to manage the use of information, include the following basic elements: computers as physical components – information components and human (using; designing; applying; maintaining the information).

2.1.1.1 Decision support systems (DSS) DSS are integrated systems connecting human resources with computer potentials to support decision making in solving problems on all planning levels.

2.1.1.2 Components of DSS The components of DSS are shown in Figure 3.

2.1.1.3 Urban modelling for DSS A concept of using GIS modelling as a new approach within mathematical and statistical programming for describing the built environment future; it could be developed to emphasize strategic urban planning objectives in spatial and temporal attributes (Malinovskiy *et al*. [3]).

2.1.1.4 Geographic information systems (GIS) GIS is described as all those disciplines attempting to develop a powerful set of tools for collecting; storing; retrieving; transforming; analyzing and visualizing spatial data from the real world.

Like all IT, it is used to support decision making. It provides decision makers with an organized environment for making the best decisions which take account of geographic locations (Magdi *et al*. [2]).

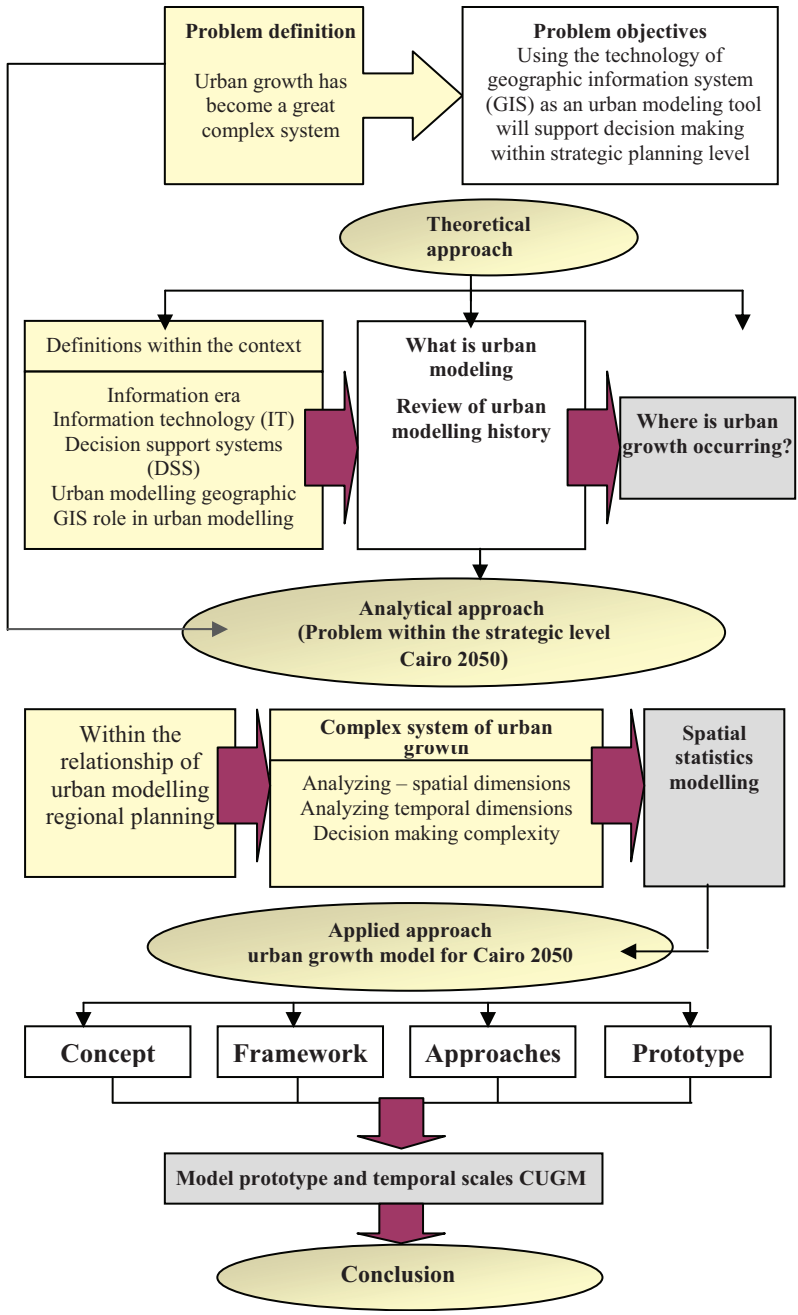

Figure 1: Research methodology.

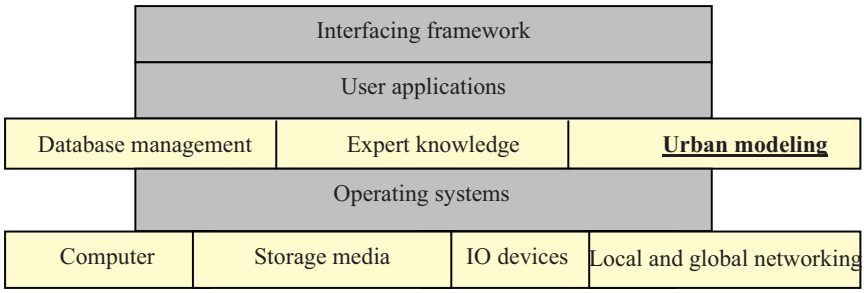

Figure 2: Information technology basic outline (adapted from Szabo [1]).

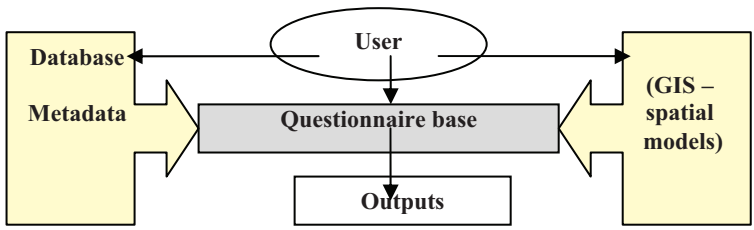

Figure 3: Decision support system components (Magdi *et al*. [2]).

2.2 Strategic planning

Strategic planning is a key concept in planning research. There has been little consistency in its conceptualization or measurement, by developing and validating a multiple indicator measurements of planning.

2.2.1 GIS role in strategic planning

Through urban modeling, a spatial database should be designed to accommodate urban planning analysis and the decision making process. GIS is the perfect tool; achieving strategic planning objectives with its accessibility; accuracy; availability.

2.3 What is urban modelling within GIS

The simulation models typically output massive spatially distributed data about several variables, including number of inhabitants, land prices and traffic (Vanegas *et al*. [4]).

Urban models: representations of functions and processes which generate urban spatial structure in terms of land use, population, employment and transportation, usually embodied in computer programs that enable location theories to be tested for predicting future location patterns (Xie [5]). I see urban modelling as the process of identifying appropriate theory into a mathematical model, developing relevant computer programs to be used in predicting future of urban growth.

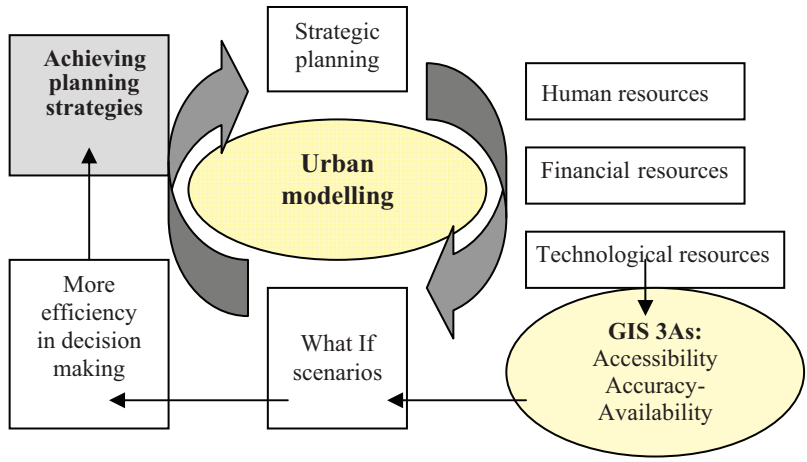

Figure 4: GIS role in urban growth modelling.

Spatial interaction: movements of people and information between different spatial locations; often referred to as origins and destinations. Such models form the basis of standard methods for describing and modelling interactions.

Urban dynamics: representations of changes in urban spatial structure through time of processes are often interlocking time scales ranging from life cycle to movements over space and time. (Malinovskiy *et al*. [3]).

Agent-based models (ABMs): developed since the 1980s; are based on representing objects and populations at an elemental or individualistic level which reflect the behaviours of those objects through space and time. These models generate emergent spatial and temporal patterns at more aggregate levels (Benenson [7]).

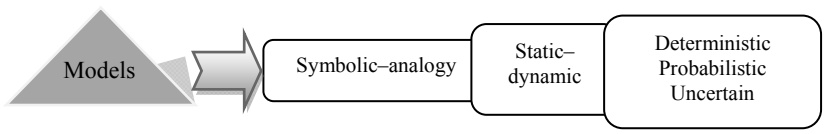

Figure 5: A classification of models. (Ashram [6]).

2.4 Review of urban modelling history

Urban modelling bloomed in the late 1950s and throughout the 1960s in both the USA and Western European countries. However, with the massive transformation from an industrial to an informational economy, urban modeling

gradually faded away as a dominant planning and decision-making paradigm in the late 1970s and through most of the 1980s (Acebillo *et al*. [8]).

Modeling techniques in the 1960s and till the 1980s were dominated by a-spatial, static linear. They have proved inadequate to reflect the complex, dynamic and non-linear factors inherited in urban systems (Sui [9]).

The time and space dimensions need to be incorporated into the urban modelling process by integrating with GIS and complexity and non-linearity theories. Urban models come in forms that have a complex diversity (Acebillo *et al*. [8]).

- Much of the contemporary urban land use modeling has proceeded on a foundation of descriptive or analytical models that have been steadily developed since the beginning of the twentieth century (Wilson [10]).
- Many of these models are weak in their capacity to describe today's regions, and are limited in their predictive powers (Torrens and O'Sullivan [11]).
- Since the late 1960s and early 1970s – a period in which the development of elaborate mathematical models for urban planning applications emerged – new scientific and technological development has considerably changed the fields of spatial modeling and urban planning (Malcolm [12]).
- The main purpose of the models is to serve as thinking tools to help the user learn about the nature and dynamic behavior of the real world system (Benenson *et al*. [7]).

Some methods are still in the theoretical stage or applied for artificial city analysis. They need very good data infrastructure. The question is: from a systematic perspective, where is urban growth occurring?

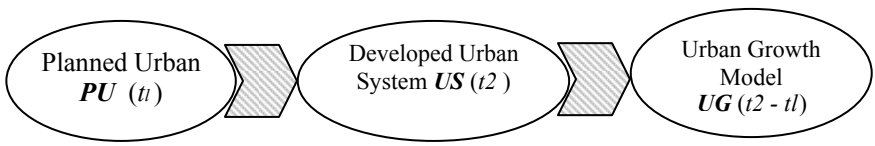

Figure 6: Where is urban growth occurring?

3 Analytical approach

3.1 Within the relationship of urban modelling and regional planning

Computer models may be developed to understand more about how a real system works. Such models must add flexibility to represent future behaviour under a variety of conditions and constraints (Gimblett [13]).

Recently, agent-based systems are increasing and being used as advanced computer-based technologies for spatial simulation modelling. They can be descriptive, explanatory, predictive and prescriptive on regional planning.

3.2 Complex system of urban growth

Integrated concepts for sustainable development at a local and at a regional level have to account for coordinating strategies at the upper level (top-down).

At the same time, they should be based on collaborative decision-making processes to meet the needs of the local and regional actors (bottom-up). In practice, there is a lack of approaches and tools that support a combined bottom-up/top-down dialogue in the urban planning processes (Schmitt *et al*. [14]).

As far as the type of urban development is concerned, it consists of physical expansion and functional changes.

3.3 Analyzing spatial dimensions

There has been a long tradition of urban modelling but only recently have emerged simulation approaches to understand urban dynamics (Batty [15]). A frequently cited shortcoming of GIS and most spatial analysis tools is their difficulty in dealing with dynamic processes. As a result, the first step to spatial modelling is to recognize the spatial complexity in the study. Spatial complexity may include multi-scale issues and structural or functional complexity; the complexity lies in the following facts:

- The impacts determined by an unknown number of factors and their spatial relationships are non-linear.
- The intensity of spatial dependence is spatially and locally varied.
- Land conversion includes probability (occurred or not), density (scale), function (land use) and structure (shape or morphology); each may have distinguished spatial dependence.

Urban growth involves a number of hierarchical structures. The spatial dimension includes different levels of shopping centres and road networks. From the perspective of land development, urban growth can be divided into different scales. Spatial complexity resulting on multi-scale modelling is impacted by numerous institutional factors, especially in developing countries.

3.4 Analyzing temporal dimensions

Urban growth is largely controlled or impacted by its economic development scale and environmental protection strategy. In the longer term, it might be considered uncertain and unpredictable. It means its development process is sensitive to unknown initial conditions such as war, natural disaster, revolutions, and new policies of the central government. These conditions are often not predictive, particularly in quantitative terms. From the perspective of regional urban planning understanding the dynamic process of urban growth includes the temporal comparison in various periods.

Temporal complexity could be indicated as follows:

- Patterns, processes and behaviours of urban growth are temporally varied with scale and time.
- The dynamic process of urban growth is non-linear in the longer term.

3.5 Spatial statistics modelling

Traditional statistic models, e.g. multiple regression analysis, principal component analysis, factor analysis and logistic regression, have been very successful in interpreting socio-economic activities (Lopez *et al*. [16]).

Logistic regression has been reported as being widely used for modelling urban growth with varied strengths and weaknesses.

3.6 Decision-making complexity

Decision-making complexity is indicated in the unit and process of decision-making, and actors (decision-makers). The decision-making unit and process of large-scale projects are relatively more complicated than those of small-scale ones. Comprehensive decision support requires the effective integration of GIS and non GIS techniques (Al Hagla *et al*. [17]). Consequently, the decision making for urban growth is a completely multi-agent, dynamic system.

4 Applied approach

Hence the interaction between the spatial, temporal and decision-making processes is much more complicated. This paper proposes a Growth Model Prototype for Greater Cairo region based on the concept of dynamic models focusing on longer term temporal dynamics in the year 2050. Using visual basic programming language in building mathematical models within Geo Media Professional. I think that this approach appears to be the best way of estimating growth probabilities on the basis of complex modelling.

4.1 Model concept

Utilizing GIS with programming of mathematical models in a combination of linear programming will provide a wide range of optimization of a specific flexible urban growth system which can be described in the following framework.

4.2 Model framework

Building urban models within GIS is the key to explaining and predicting spatial patterns and processes. Geomedia Professional 6.0 software and Visual Basic 6.0 are rich platforms for spatial analysis with the combination of mathematical models and linear programming. A procedural urban model allows the integration of a set of rules for generating and visualizing urban development scenarios, which include a set of rules for urban quality (Schmitt *et al*. [14]).

The following model can be generalized in order to be applied to Egyptian regions. The model could be applied on a regional scale as a typical self-organized system. Then it could answer the questions: how can urban growth be directed or controlled in the year 2050?

Resulting from the outcoming model within strategic planning, policies, processes and patterns will be included.

A- Policies are the level proven to be the most influential factor or driving force of urban growth on the macro scale.
B- Patterns are the lowest level, which have a directly observable outcome.
C- Processes indicate the dynamics of urban growth.

4.3 Database building

The initial database building step is the most important time consuming phase of this model. It involved establishing the spatial context extents of the study area and assembling the various spatial and temporal data to be used in this study.

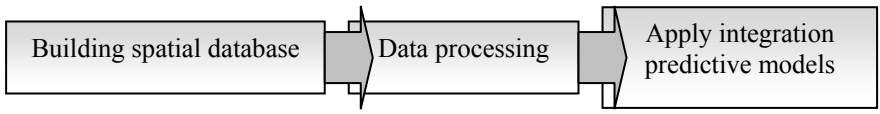

Figure 7: Model main phases.

4.4 Urban growth model prototype

The Cairo urban growth model (CUGM) involves four different factors: *P(Population)*, *D* (Density), *U*A(Urban area),and commercial centres C(Centres) to model their dynamic interactions at varied spatial and temporal scales. On the suggested regional scale, all data could be accessed as aggregated data are based on annual statistics. The main focus of that model is to be indicative rather than predictive. A population growth concept could be as follows:

Aggregate population change from time $t-1$ to t defined as $\Delta P(t)$ can be modelled as max $\Delta P\ t = \eta P\ t\ P - P\ t$, (2) where η is a composite growth/change rate and max P is the maximum population that the system can take. This is classic logistic growth that appears to occur in the proposed system below to show the population in an urban growth model for Greater Cairo 2050.

4.5 Urban growth model for Greater Cairo 2050

The urban growth model for Greater Cairo 2050 is shown in Figure 8.

5 Conclusion

- The building of spatial decision support systems applications from GIS has been facilitated by recent technical development within GIS software and programming tools.
- Complexity of (spatial and temporal) data limits the understanding of temporal in urban growth and decision making.
- Urban planners will need to use some methods which are more effective on a regional scale

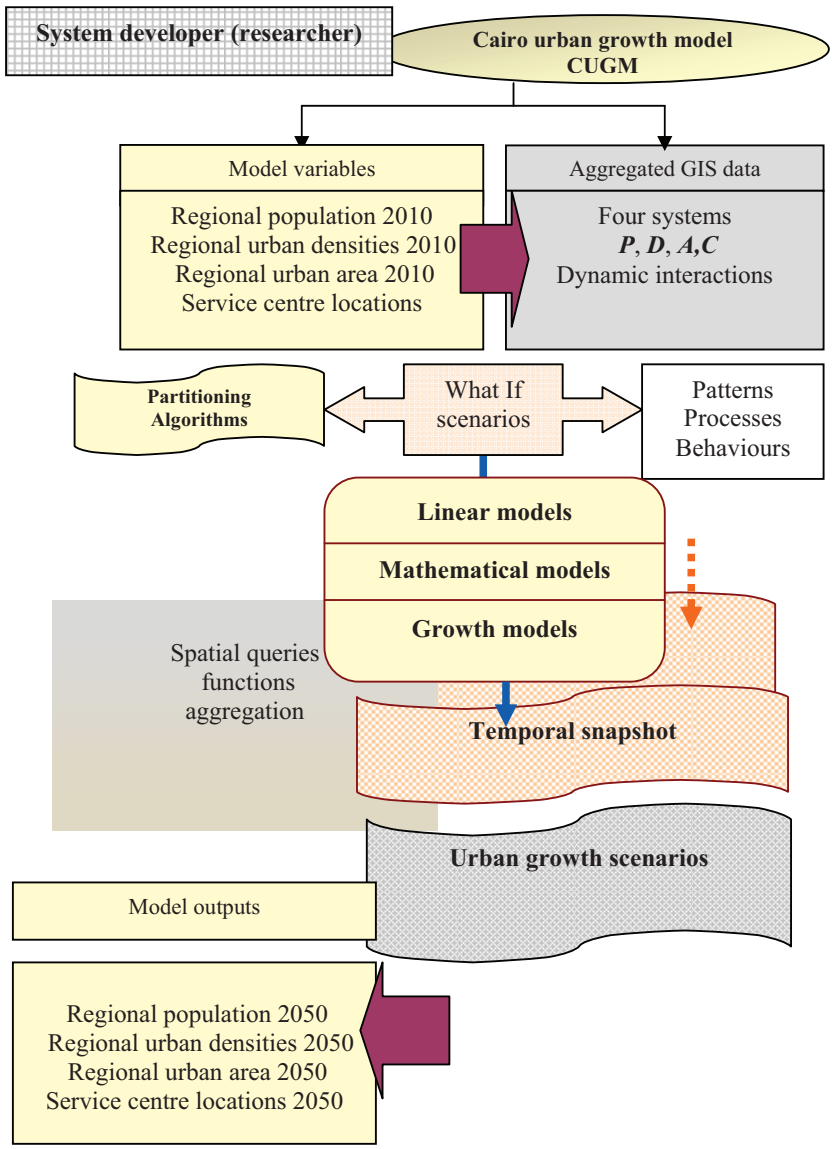

Figure 8: Model prototype.

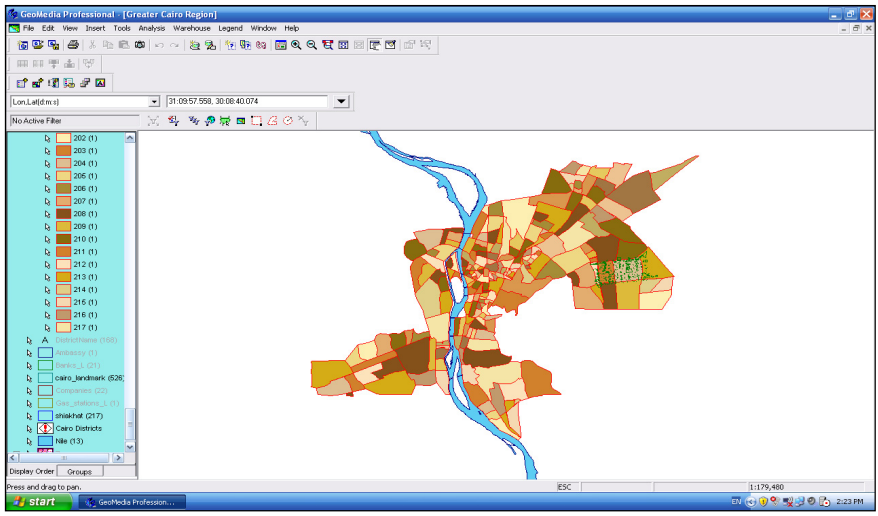

Figure 9: Greater Cairo region population and densities.

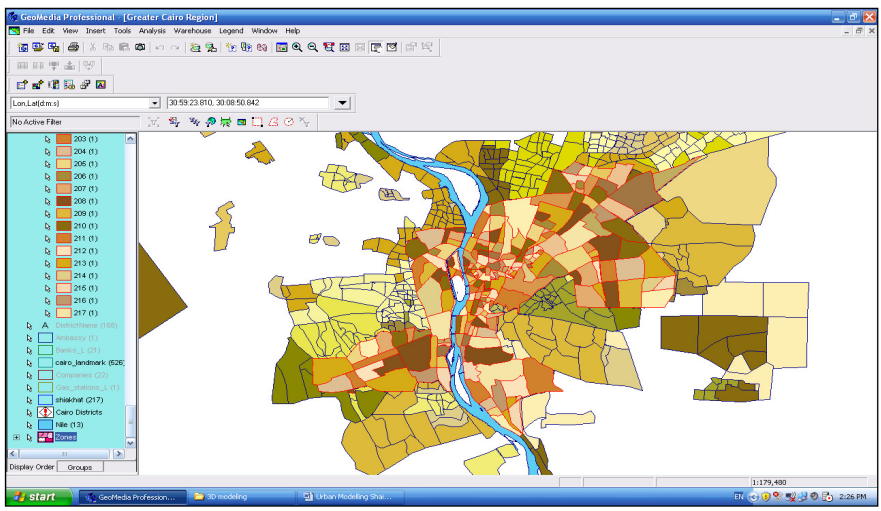

Figure 10: Greater Cairo region population and densities in 2050.

- Utilizing the powerful and easy to use GIS models emphasizes the potential of the Internet for community information systems.
- Using the proposed model as an introduction to a national project will provide great potentials for understanding and predicting urban growth complexity for the greater Cairo region in 2050 as a strategic vision.
- This model should be a trend driven by the relevance of regional spatial information in Egypt's future.

- The proposed model has the chance to lead GIS into new urban modelling in terms of a regional planning level in Egypt; the interpretation of a statistical model is desirable for gaining knowledge of the causal factors driving spatial and temporal phenomena.

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