The use of GIS in modeling accessibility and its impacts on the growth of West London

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INTRODUCTION

The paper presents the results of a study that traces the emergence and evolution of London's metropolitan form from the second half of the 19th century to the present. A longitudinal land use database, developed by digitizing high-resolution historical Ordnance Survey maps, is used to capture the dynamics of regional accessibility and its impacts on the patterns of land use change. The underlying goal of this research is to address a chronic weakness of urban modeling concerning deficiencies in the quality of data used to build urban growth models (Longley and Mesev, 2000). This goal is pursued by the development of a unique database that stretches the boundaries of conventionally employed data in urban modeling along several dimensions related to spatial and temporal resolution.

DATA AND METHODOLOGY

First, perhaps less unique but very important for the analysis of metropolitan form generation, is the study area spatial extent which covers 200 sq km stretching from Hyde Park westward to the edges of London's Green Belt (Figure 1). This area was selected to explore a major axis of London's historic growth, covering one of the most dynamically evolving segments of London's metropolitan fabric.

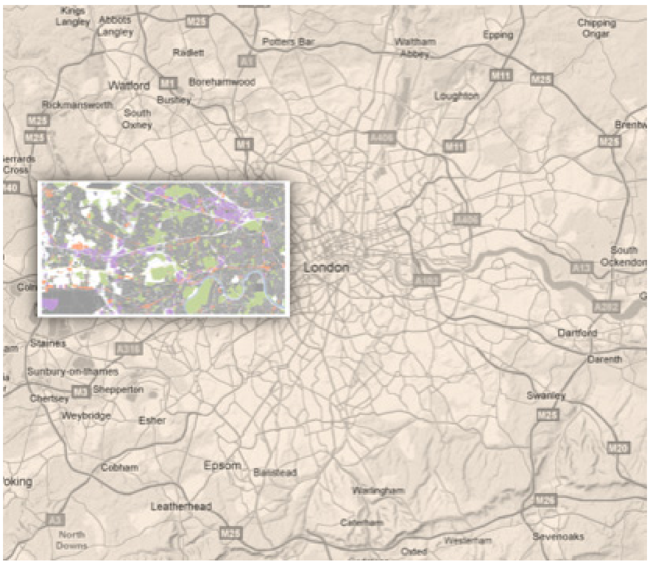

Figure 1: Study area

Second, the study uses highly detailed historic Ordnance Survey (OS) maps at a scale of 1:2,000, which allows the identification of a wide range of land use categories and building types with a high level of spatial and interpretational accuracy. This presents a significant improvement in data resolution compared to traditional land use and land cover databases derived from remotely sensed (RS) imagery. While most land use change studies rely on RS data with a pixel resolution in the 10 to 30 m range (limited by the resolution of available historical satellite images), the fine-scale OS maps allow the precise identification of over 60 land use classes and building types with an accurate representation of parcel boundaries (Table 1). The systematic and consistent cartography of the OS maps allows a precise classification of land uses with minimal problems related to data interpretation. The use of parcel-based cells and a fine-grained lattice (25 by 25 m cells) in the project allows for a more precise definition of land use interactions. It eliminates the problems associated with cell heterogeneity encountered in models based on lower resolution data sources.

	Land use classes	
used in model	**digitized in GIS**	**shown on OS maps**
residential	apartments	low and mid-rise apartments
	high-rise apartments	high-rise apartments
	cottage houses	cottage houses
	terrace houses	terrace houses
	mews	mews
	semi-detached houses	semi-detached houses
	small lot detached	small lot detached houses
	detached houses	detached houses
	lodges	lodge, inn, hotel
commercial	old fabric	old fabric
	general	general
	retail	retail
	entertainment	public houses, cinemas
	office	office
institutional	institutional public	city hall, library, police station, post office, hospital
	educational	daycare, school, college, university
	religious	church, convent, rectory, priory, synagogue, temple
	stadia	stadia
industrial	industrial	works, mill, wharf, dock, depot, brewery, malthouse
	utilities	water works, gas works, sewer works
airports	airports	airports
parks	parks	parks, commons, greens
	cemeteries	cemeteries, burial grounds
recreation	recreation	golf course, recreation ground, playground
	allotment gardens	allotment gardens
	nurseries	nurseries
	estates	estates
vacant	undeveloped	undeveloped
	farms	farms
water	water	water
transportation	roads	roads
	railway lines	railway lines
	rivers	rivers

Table 1: Aggregation of land use classes

A third unique feature of the database employed by this project is the extensive time coverage, which spans the last 130 years of London's urban growth. The developed data set includes time series land use maps showing the evolution of metropolitan form in 20–year increments, starting from 1875 onwards (Figure 2). The time coverage of the project stands in marked contrast with conventional urban modeling techniques, which rarely go back in time more than a decade or two. The unusually long time horizon of this study (reaching the pre-urban era of the metropolitan periphery) allows to trace the emergence and evolution of London's suburban fabric from its incipient stages of urbanization.

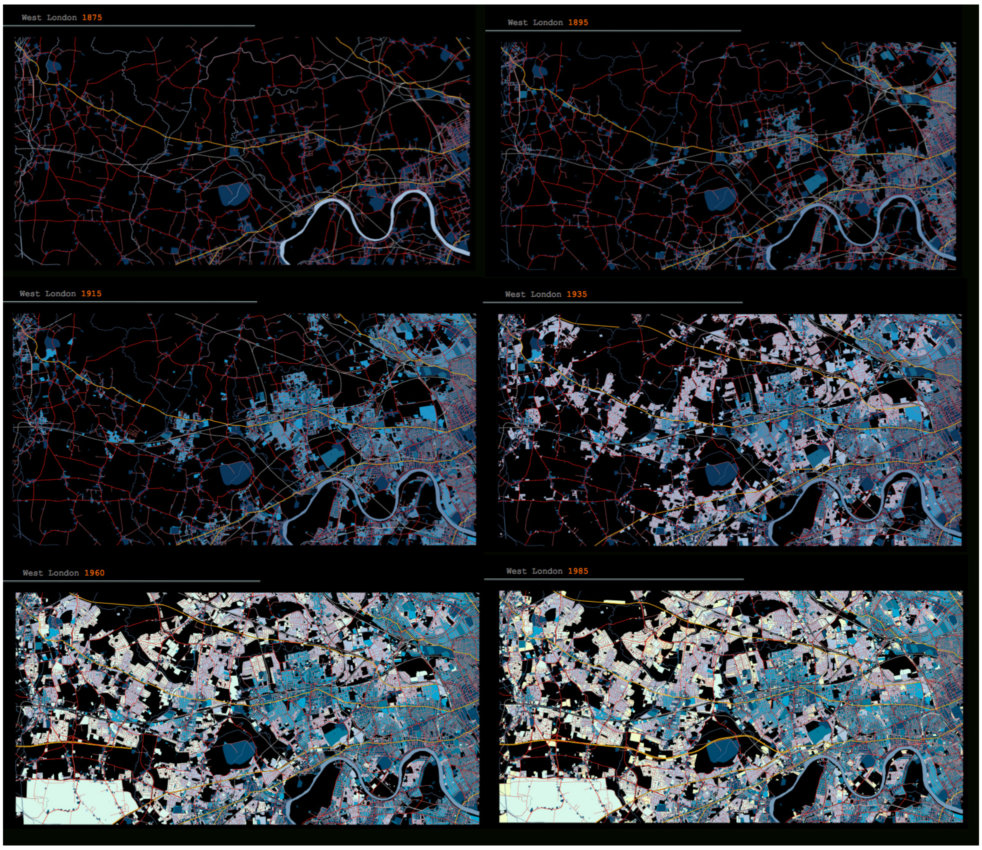

Figure 2: Land use growth patterns in Western London, 1875-2005

ANALYSIS

The high resolution of the data, the extensive longitudinal coverage, and the large areal extent of the study area serve an important purpose. They allow the development of a model that reveals the emergence of London's metropolitan spatial structure as a result of myriad capillary changes that have taken place on the level of individual parcels over the course of nearly one and a half centuries. The application of a cellular automata model, used in this study, is viewed as particularly suitable to capture such fine-grain local transformations of the built environment, demonstrating how local action generates global patterns (Batty, 1997). Unlike conventional aggregative modeling techniques, CA-based models can handle high-resolution applications easily in conjunction with the precision of high-quality data sets typically resident in GIS (White and Engelen, 2000).

Before the development of a model, the project analyzes the relationship between the identified land use patterns and several factors deemed critical in the formation of the spatial structure of metropolitan London, with a special emphasis placed on explorations of regional accessibility. Thus the growth of the metropolitan periphery is analyzed in conjunction with: 1) distance to the metropolitan center; 2) the evolution of the transportation network including roads, waterways, railways, tramways, and underground lines and stations (traced using the same time scale and increments as in the land use time series); and 3) distance to existing suburban centers/nuclei. Using ArcGIS Spatial Analyst, a series of raster surfaces is generated to represent each one of these parameters (e.g. distance to metropolitan center, distance to major road, etc.) with cell values based on simple Euclidian distance. The dynamics of the spatial relationships between land use classes and various types of accessibility measures are studied over the course of the study periods, highlighting major historical trends. The analysis shows, for instance, that commercial and residential land uses were most strongly dependent on access to railway stations (Figure 3)[1]. On the other hand, commercial development in the study area was least sensitive to proximity to the metropolitan center throughout the 1875-1935 period, whereas residential and industrial uses showed a higher level of attraction to the metropolitan core (Figure 4).

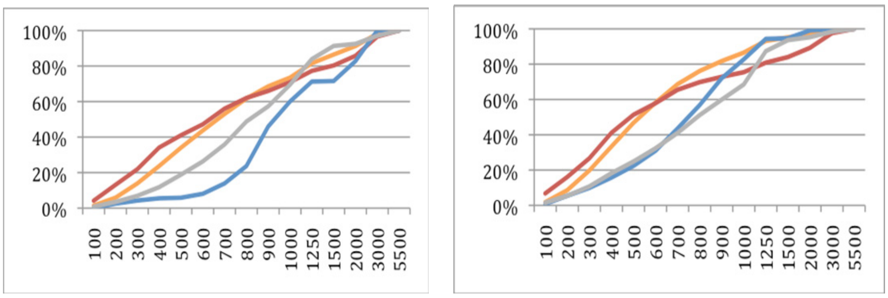

Figure 3. Cummulative distribution of land uses by distance from railway stations in 1875 and 1895. (red – commercial, orange – residential, gray – industrial, blue – institutional)

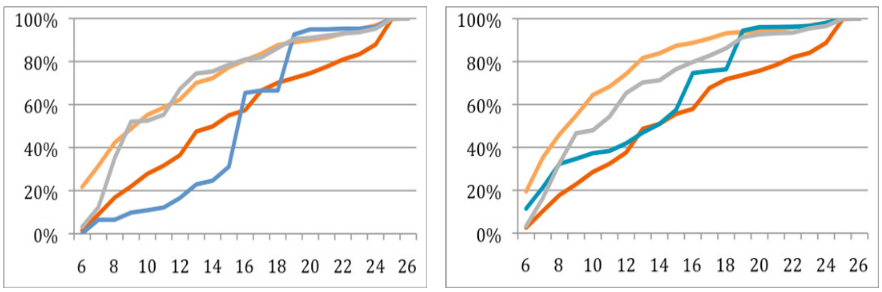

Figure 4: Cummulative dostribution of land uses by distance from the metropolitan core in 1875 and 1895

[1] Figures 3 and 4 show only select samples of the analysis performed for all accessibility parameters and for all study periods.

After the analysis of the individual accessibility factors, a composite regional accessibility map is generated combining the accessibility values of all of the above listed parameters (Figure 5). The study demonstrates a strikingly strong relationship between the composite regional accessibility map of 1875 and the patterns of urban development that took place in the subsequent decades, with the overwhelming majority of land developed in the forty-year period between 1875 and 1915 falling in areas characterized by high regional accessibility in 1875 (Figure 6).

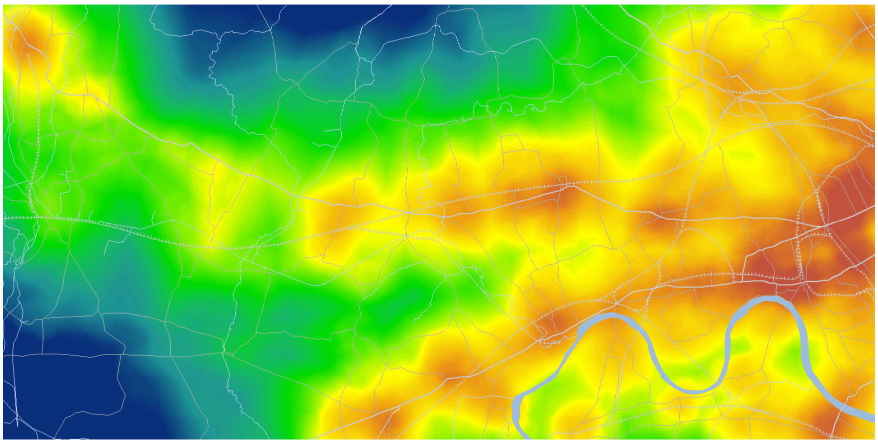

Figure 5: Composite regional accessibility map for 1875 based on distance to major roads, railway stations, city centre, and suburban nuclei.

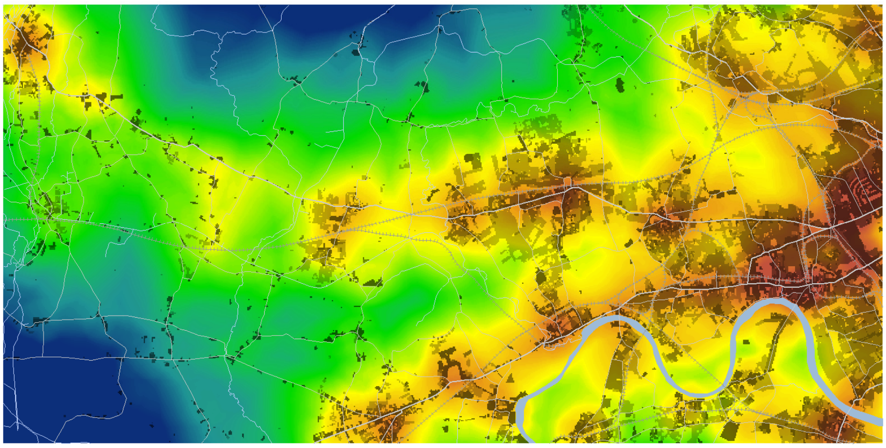

Figure 6: Land development 1875-1915 and regional accessibility in 1875

The results from the analysis of the observed spatial relationships, performed in ArcGIS, are then used to calibrate a CA urban growth model for all of the seven time periods (1875, 1895, 1915, 1935, 1960, 1985, and 2005). Besides the impact of accessibility discussed above, the CA model takes into account the impact of neighborhood land use characteristics as a main determinant of cell state transition. In addition, the model integrates the influence of policies related to the protection of parks and open space, most significant of which is the adoption of a Green Belt around London in the early 1950s. The model thus utilizes the advantages of CA approaches for exploration of complex spatial interactions between land use, accessibility, and public policies tracing the dynamic formation of patterns of nucleation, diffusion, and conurbation within the metropolitan fabric (Couclelis, 2002). Along with highlighting the importance of regional accessibility, the study illuminates the significance of the pre-urban cadastre (agricultural land ownership patterns, system of country roads, existing settlement structure) as major spatial determinants framing the subsequent patterns of urban growth (Figure 7 and 8).

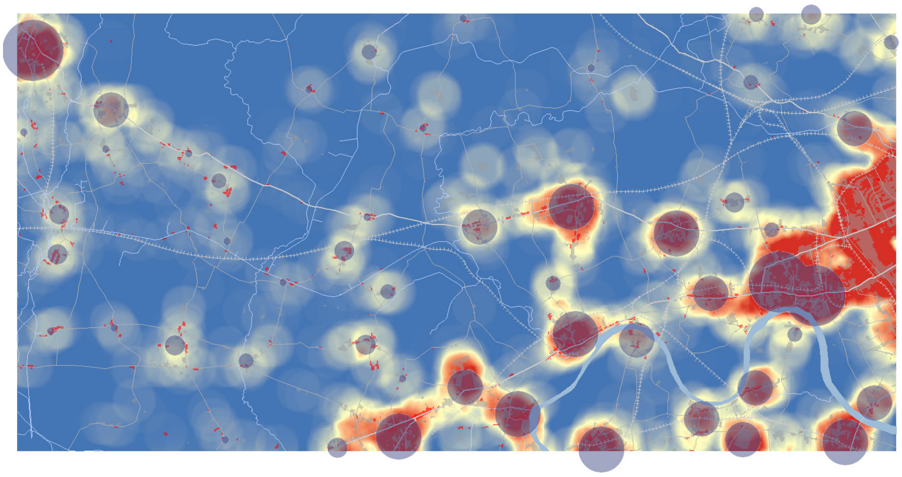

Figure 7: Identification of historical suburban clusters in 1875.

Figure 8: Infrastructure from 1875 overlaid on map of 2005.

The documentation of land use changes on a parcel level allows not only to trace the appropriation of agricultural and undeveloped land for urban functions, but to follow the processes of urban redevelopment as parcels transition from one urban use to another. Thus the dynamics of metropolitan growth are revealed not only as a process of spatial expansion into previously undeveloped areas, but as a process of internal spatial reorganization of the built-up territories. Thus the study tracks variations in the propensity of different parts of the metropolitan area to undergo dynamic transformations at different times and with different rates.

CONCLUSIONS

The study demonstrates the compelling impact of accessibility on the formation of London's metropolitan growth patterns. It highlights the utility of urban modeling as a powerful method of not just forecasting alternative future development scenarios but as a potent way of exploring the past – an approach which can provide valuable insights into the determinant forces shaping urban growth and assist the evaluation of theoretical assumptions.

The use of high-resolution data holds a promise for significant qualitative improvements in the fidelity of representing urbanization patterns and processes in the modeling world. While the availability of high-resolution historical data is still a rarity in most institutional contexts, this situation is changing rapidly with the progress of the digital revolution. Since 2000, many satellite systems offer RS data with an image resolution of 1m or even less. A tremendously accurate repository of global land use changes is being compiled yet the opportunities for performing urban analysis which would take advantage from such spatial accuracy are hugely underexplored. Urban modelers are charged to apply forward thinking, which should not be confined by the limitations of yesterday's technology. The authors of this study strongly believe that improving the level of realism in representing urban environments can lead not only to an enhanced comprehension of model design and outcomes, but to an enhanced theoretical and empirical grounding of the entire field of urban modeling.

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ACKNOWLEDGEMENTS

The project is funded by the European Commission's Framework Programme 7 through a Marie Curie fellowship.