

# The application of geospatial technology to urban morphological research

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**Abstract.** *This paper reviews the development of geospatial technology in recent years and its use and potential use in urban morphology. Such technology has been enabled by the rapid advancement in computer technology in both hardware and software. Remote sensing, photogrammetry and GIS are particularly important and suitable for use in urban morphological research. The availability of geospatial data in digital form has facilitated town-plan analysis and metrological analysis. Three-dimensional GIS allows the form and function of a town or city to be realistically visualized. Urban simulation is also possible with geospatial data, thus enhancing understanding of the processes of growth of a city and the associated built forms.*

*Key Words:* GIS, photogrammetry, urban simulation, urban morphological research, remote sensing, GPS

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Urban morphological research has a long history of development that can be traced as far back as 1832, when Quatremere de Quincy used the town plan to understand the history of a town's development (Gauthiez, 2004). The scope for research in urban morphology was enhanced greatly when reliable topographic maps and plans became available in the eighteenth century. In the British tradition, urban morphology developed in close relation to the study of the geography of settlements, in which urban settlements constitute a major part (Hudson, 1970). M. R. G. Conzen's classic work on Alnwick (1960) is characteristic of this approach: through town-plan analysis he traced the historical development of the town, exemplifying the urban morphogenetic tradition (Larkham, 2006; Whitehand, 2001).

Studies of both the form and function of a city can benefit from the very rapid advances in geospatial technology in the past decade. The term geospatial technology is used here to

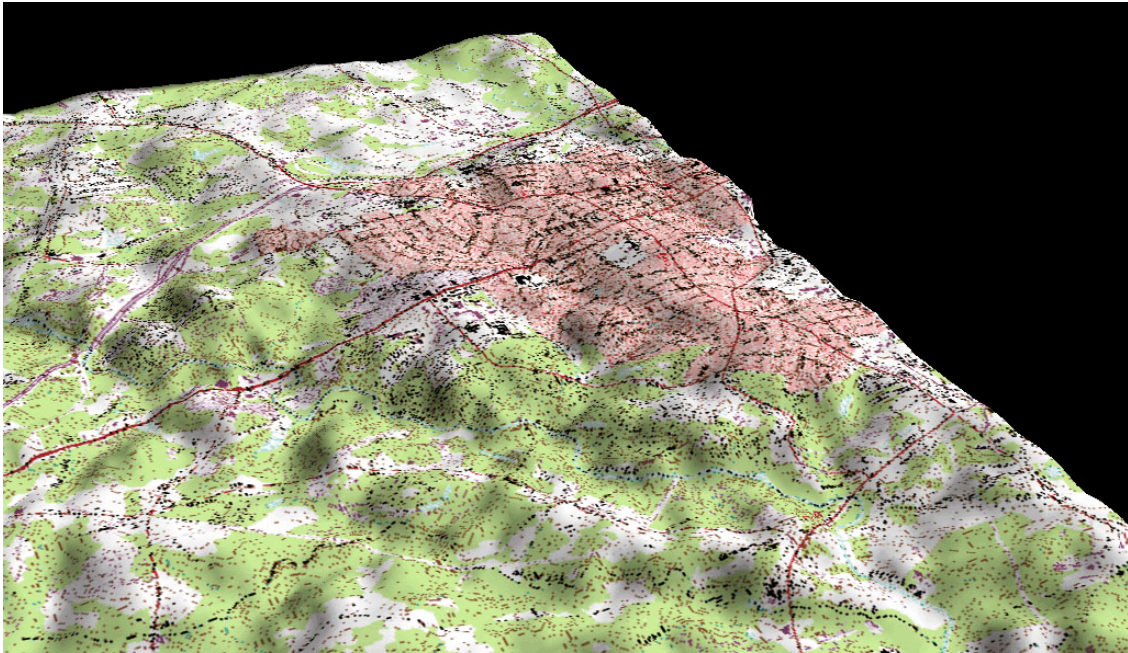
include the following: photogrammetry, remote sensing, Global Positioning System (GPS), cartography and Geographical Information Systems (GIS), all of which can also be subsumed under the term Geographical Information Science (GISc). The development of GISc in recent years has been revolutionized by rapid advances in computer hardware and software. In this paper, the application of each of these types of geotechnology will be explained, with the aim of demonstrating their use and potential use in urban morphological research.

## **Photogrammetry**

Photogrammetry is the use of aerial photographs to extract reliable metric and semantic information about a place. Traditionally, it is employed to produce topographic maps, as is done by such government agencies as the



**Figure 1. (A) An orthophoto image of the University of Georgia Campus, which can be matched exactly with (B) a large-scale topographic map of the same area**

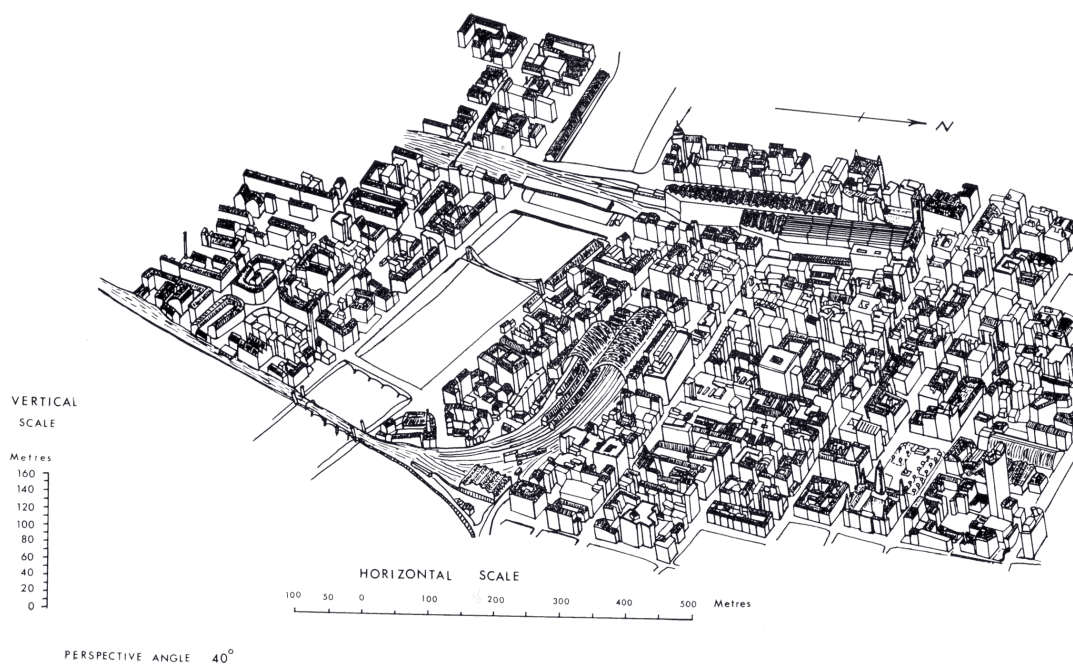


**Figure 2.** A topographic map of the city of Athens, Georgia, USA, draped on the DEM.

Ordnance Survey (OS) in the United Kingdom and the Geological Survey in the United States (USGS). In recent years, photogrammetry has evolved from the manual analogue approach, using analogue stereoplotters, to the semi-automatic digital approach using computer workstations. For the digital approach to be possible, analogue aerial photographs have to be digitized to become raster data (a regular array of grid cells of a specific size that represents the spatial resolution of the data). This is achieved normally using photogrammetric scanners. Today, digital mapping cameras, albeit expensive, are also available and can produce high quality digital images of the Earth's surface directly for use in digital photogrammetric workstations. The digital approach allows terrain heights to be extracted automatically from a stereomodel using stereo-correlation or image matching techniques. In addition to producing conventional topographic maps, it can also generate the Digital Terrain Model (DTM), in which the heights of the terrain are stored together with their locational co-ordinates. The DTM can also be converted into a Digital Elevation Model (DEM) using spatial interpolation techniques

to produce a regular array of terrain heights, which can also be employed to generate orthorectified photographic images. An orthorectified image can be treated like a map because all the tilts and relief displacements have been removed. With the same georeferenced co-ordinate system, a town map (in digital form) can be superimposed on top of the orthorectified image for comparison side by side (Figure 1). In addition, DEM data can be used to generate the terrain relief of a town to help in urban morphological analysis. Figure 2 illustrates the draping of a topographic map over a DEM of the same area, thus providing visually a 3D perspective of the city and its environment. One further advantage is that photogrammetry can help extract accurate heights of buildings.

Nearly 40 years ago, this author used an analogue stereoplotter coupled with a pantograph, called Persktomat, to produce manually a three-dimensional map of a part of the city centre of Glasgow to study its urban form (Figure 3) (Lo, 1970). Such a map can now be produced much easier with the use of 3D GIS and digital photogrammetry, to be discussed later in the section on GIS.



**Figure 3. Three-dimensional map of part of the city centre of Glasgow.**

### Remote sensing

Remote sensing technology has advanced to meet the increasing availability of digital image data from polar orbiting earth resources satellites launched since 1972, notably the Landsat series from the USGS. These image data have been used to produce land use and land cover maps with specific image processing software, using computers. Initially, the spatial resolution of these satellites was rather low, ranging from 79 m for Landsat MSS data to 30 m for Landsat TM data. However, in 1986, a French company launched the first commercial satellite, called SPOT, which has a much higher spatial resolution of 10 m for its panchromatic band and 20 m for its multi-spectral bands, and has the capability of producing stereoscopic images for photogrammetric application in topographic mapping. In 1999, an American company launched a satellite called IKONOS, which has a spatial resolution of 1 m for its panchromatic band, and 4 m for its multi-spectral bands. In 2001, another American company launched another satellite, called QuickBird, which is capable of imaging the earth at a spatial resolution of 0.61 m in the

panchromatic band and 2.44 m in its multi-spectral bands. Even SPOT has launched a new satellite in 2002 to compete with a spatial resolution of 2.5 m for its panchromatic band and 10 m for its multi-spectral bands. The spatial resolution of these new satellite data is so high that it is comparable to that of aerial photography, but it has the advantage of covering a much larger area of the earth. In addition, like aerial photography, all these satellites can produce 3-D stereoscopic images so that digital photogrammetry can be applied to produce topographic maps or DEMs. These very high spatial resolution satellite data can help in research on urban form and town-plan analysis (Mesev, 2005). However, the cost of these ultra-high spatial resolution data from these commercial companies is very high, and many researchers have to resort to the use of Landsat data, which are much cheaper to acquire. The National Aeronautics and Space Administration has also launched a relatively high spatial resolution instrument on the Terra satellite. The sensor known as ASTER, which is capable of producing a 3-D stereomodel at a spatial resolution of 15 m for its three visible and near infra-red bands, can be acquired at low cost and is particularly suitable for urban

form study (Hirano *et al.*, 2003; Welch *et al.*, 1998). Finally, satellite data have the advantage of a good temporal resolution because they record the earth at regular intervals through their orbital cycle. This allows changes in the city or town to be mapped. All these satellite images have been used mainly for land use and land cover mapping. A land use and land cover map of a town gives insights into the functional zones in the town and their changes over time, allowing changes in building forms and functions to be related.

Despite the costs of the ultra-high spatial resolution satellite data from commercial vendors, the abundance of satellite images and digital aerial photographs from governments has benefited the public through the World Wide Web. This has allowed free access, notably, through Google Earth, which displays any cities in the world on demand with quite detailed images.

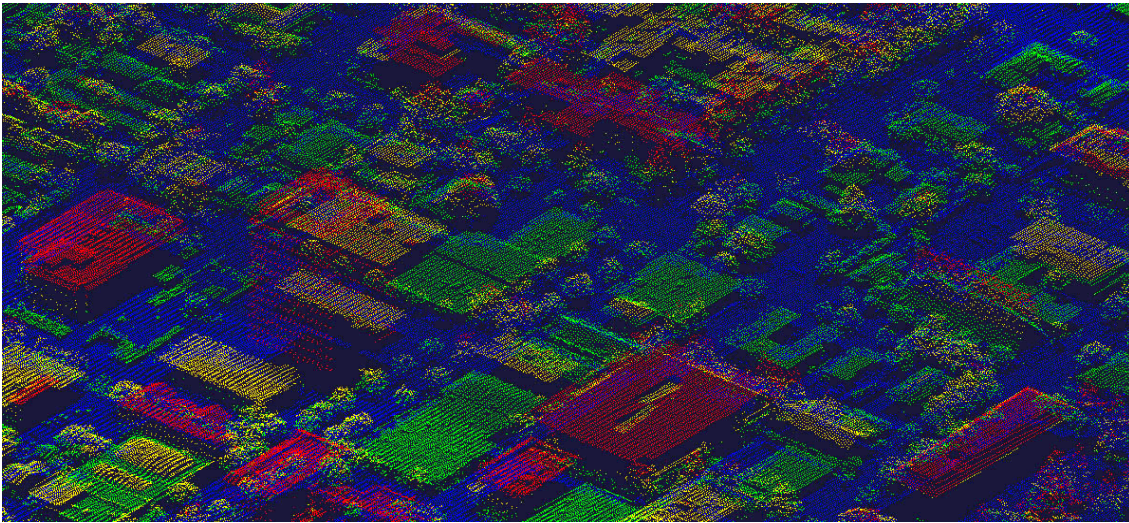
In recent years, a new form of remote sensing, known as LIDAR (Light Detection and Ranging) has taken on an important role in 3D terrain modelling. LIDAR is an active remote sensing system that can collect thousands of elevation values per second with unprecedented detail and accuracy. It is an airborne system, which can be mounted on board a helicopter or a fixed-wing aeroplane. In conjunction with the use of Global Positioning Systems (GPS – to be discussed in the next section), accurately positioned data of the terrain in X, Y, and Z co-ordinates can be obtained to produce a Digital Surface Model (DSM). An accuracy of 15 cm can be achieved for bare-earth surface. LIDAR has been successfully applied to capture data over cities with high building densities, and research has been conducted to extract buildings in 3D form automatically from the data (Madhavan *et al.*, 2005; Vogtle and Steinle, 2005). These data provide valuable insights to the third dimension of the city with an accurate record of the heights of the buildings. An example of applying LIDAR to a city in the United States is shown in Figure 4. The data can also be presented in the form of contours.

## Global Positioning Systems

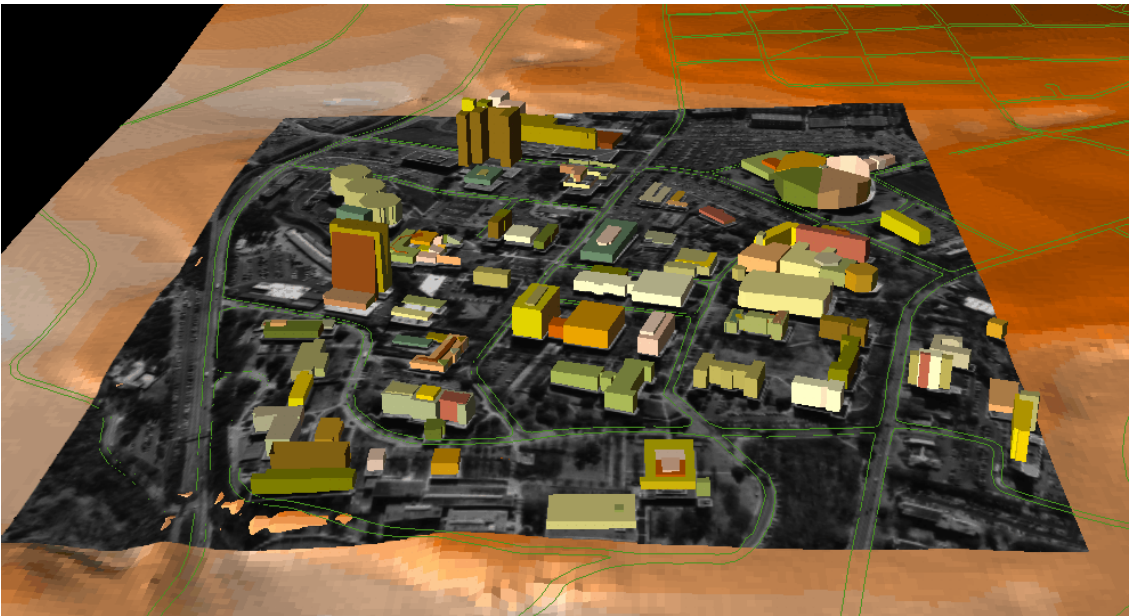
GPS is another major advancement in land surveying that has facilitated topographic mapping. By receiving signals from four or more satellites known as NAVSTAR (Navigation System with Time and Ranging) in space, the GPS receiver fixes the co-ordinates (X, Y and Z) of the position. NAVSTAR consists of 24 high-altitude *c.* 26 600 km) satellites revolving around the earth. GPS makes use of the time arrival of the satellite signal to determine the distance between the satellite and the GPS unit, having known the speed of travel of the signal (a form of electromagnetic energy). GPS can be conducted using static, kinematic and differential approaches. The differential approach, which requires the use of two GPS units, produces the most accurate results.

GPS has been used in conjunction with GIS in town-plan analysis and metrological analysis. Lilley *et al.* (2005) used differential GPS for the field survey of the medieval English town of Winchelsea. Observations were taken at selected street intersections, plot boundaries, buildings, and earthworks, giving an accuracy of  $\pm 2$  cm. From the field survey and the measurements of plot and street patterns, units of measure used to plan a medieval town could be established. The collected GPS data were input to a GIS (for example, ArcGIS – a standard GIS software), which was used to store, manipulate and analyse the spatial data. The GPS elevation points were spatially interpolated using a nearest neighbour algorithm, thus producing a 3-D terrain surface. The GIS allows the third dimension of the town to be incorporated. By incorporating a 3-D function of GIS (notably the 3D Analyst feature of ArcScene), digitized urban features can be draped on the terrain surface model. Thus the town can be related to its underlying topography, in a manner similar to that shown in Figure 2 using DEM.

Much of the work done with the GPS can be done also by using stereo-photogrammetry and LIDAR, both of which are less labour intensive.



**Figure 4. A LIDAR image of a city in California, USA. The heights of the buildings are shown as contours. The highest contours are shown in red and the lowest (at street level) in blue. Reproduced by permission of Optimal Geomatics.**



**Figure 5. A 3-D map of the University of Georgia campus, produced using digital photogrammetry and the function of 3-D Analyst in ArcView GIS.**

### **Cartography and Geographical Information Systems**

Since the advent of computers, particularly in the form of personal computers (PC), cartography has changed tremendously. Map production, a tedious and time-consuming task in the past, is now replaced by a much more

efficient digital approach by which the maps are produced by computers. There are at least two classes of maps: topographic and thematic. Topographic maps are no longer produced in such large numbers in hard copy form. The spatial data required for the production of topographic maps are usually stored in the computer in a GIS, so that a topographic map

can be produced of a particular place on demand. The availability of a digital base for a town or city is therefore very useful to urban morphologists. If old town plans can be digitized, comparison between old and new plans can be easily achieved and some form of quantitative analysis is possible (as in the metrological approach).

Cartography has evolved from being a discipline producing static maps into a dynamic computer-based GIS, capable of storing and manipulating geographical data to solve spatial problems, in addition to producing maps in hardcopy or softcopy form (Lo and Yeung, 2007). It consists of a suite of spatial analytical functions, which can deal with data in raster and vector formats. The topological function allows GIS to conduct network analysis and overlay, which are the most useful functions of GIS. Network analysis allows connectivity between features to be identified and when applied to a town plan will reveal how planners design the street patterns. Smeed (1968) developed an index to compare the efficiency of the road networks. For example, a coarse grid pattern is more efficient than a dense grid pattern, and a grid pattern is more efficient than an irregular pattern. The network analysis approach has also been modified to produce a space syntax measure. This has been employed to study street patterns and pedestrian flows, characterizing the form of the city by the topology of its street network (Batty, 2004; Jiang and Claramunt, 2002).

The overlay function in GIS through the application of intersect and union logics has been used to combine different spatial layers together to pinpoint a specific location, such as an ideal site to develop a residential estate in the city. In this way, different elements of the city can also be separated. In a three-dimensional city, a polygon overlay can be used to represent different layers of the buildings in the city, as is demonstrated by the work of Holtier *et al.* (2000), who used a GIS software known as Smallworld GIS to represent the 3-D built forms of buildings in four English towns: Manchester, Swindon,

Tamworth, and Bury St Edmunds. All non-domestic buildings were surveyed within a defined sample area for this research. Ordnance Survey base maps were also used. The buildings were broken down into 'floor polygons' with attribute information on floor level and storey height. Once this was set up in GIS, a number of data could be computed for each floor polygon: size data and topological data. The topological data refer to the spatial relations among the floor polygons: such as, adjacency, around, above, and below. Therefore, the 3-D model of the city so developed displays both form and function as well as their spatial relationships.

The addition of the 3-D display function to GIS allows height data to be effectively displayed. This is an especially important use in urban morphology of DEM data and the building height data obtained from digital photogrammetry or from LIDAR. Figure 5 illustrates a 3-D model of the campus of the University of Georgia, generated using the following types of geospatial technology: (1) digital photogrammetry with stereocorrelation to extract the heights of the buildings from a pair of stereophotographs (in digital form); (2) a DEM of the campus (also produced from stereocorrelation) to provide the topography of the terrain; (3) the creation of a 3-D model using the 3-D Analyst extension in the ArcView GIS program; and (4) image draping of DEM over the aerial photographic image. The 3-D Analyst also allows the whole 3-D scene to be rotated for viewing at different perspective angles. This example illustrates that different types of geospatial technology can be usefully utilized in combination to produce a realistic three-dimensional map of the city for research. When compared to Figure 3, this example illustrates the great technological advance there has been in producing a 3-D map of a city. Much of this advance can be credited to the automation brought about in digital photogrammetry in terrain data (X, Y and Z) extraction as well as GIS software development that makes visualization in 3-D possible.

## Urban simulation

The availability of powerful computers and digital geospatial data on cities facilitates the use of simulation to study city growth and explore theories on how cities work and change over time. One of the most popular models used for this purpose is the cellular automata (CA). A cellular automaton, as originally introduced by von Neumann and Ulam in the 1960s to model biological self-reproduction, consists of a lattice of cells, a finite set of states for the cells, a finite neighbourhood, and a local transition function (Wolfram, 1994, p. 5). The cells in the lattice determine the state of a CA, which evolves in discrete time steps. The value of the variable in each cell is affected by the values of variables in neighbouring cells on the previous time step. The values of these variables are continuously updated according to a definite set of local transition rules. This original conceptualization of CA has been adapted and modified for use in urban growth modelling by geographers, notably in the works of Clarke *et al.* (1997) and Batty *et al.* (1999). The CA model needs to be calibrated using historical urban maps to show changes, and a set of transition rules is developed to explain the processes that have driven the change. The CA model is capable of dealing with changes in the form and function of the city. As such, it is particularly useful in urban morphological research on how the city evolves with time. The transition rules developed will be based on an understanding of settlement geography, notably site and situation and economic activities. Once the calibration of the CA model is complete, the growth of the city can then be simulated into the future. CA model software is freely available. One of the most popular software packages is called SLEUTH, developed by Clarke (Clarke *et al.*, 1997) with the funding support of the USGS. SLEUTH derives its name from the six types of data inputs: Slope, Land cover, Exclusion, Urban extent, Transportation, and Hillshade, all of which are geospatial data obtainable from satellite image data, with the aid of GIS. The results of the simulation can be stored in a GIS

database and displayed as a series of time-sequential maps, which can be shown as a form of movie (animation). CA simulation has been applied to many cities in different parts of the world, including cities in the United States (Baltimore-Washington DC by Jantz *et al.* (2003), Atlanta by Yang and Lo (2003), Sioux Falls (Goldstein, 2004), and Houston (Oguz *et al.*, 2004)), Portugal (Lisbon and Porto by Silva and Clarke (2002)), Australia (Sydney by Liu and Phinn (2004) and China (Dongguan by Yeh and Li (2001) and Wuhan by Cheng and Masser (2003)).

## Conclusions

This brief survey has illustrated the types of geospatial technology that can be applied in urban morphological research. The transformation of maps into digital form has opened up new areas of research on town-plan analysis, such as the use of GIS to carry out network analysis of the street pattern. It also facilitates metrological analysis. The three-dimensional form of a town or city as well as the various functions of buildings can be readily studied by the use of GIS. The ability of GIS to display maps and perform spatial analysis makes it an indispensable tool for research in urban morphology. All these advances in geospatial technology have been stimulated by the advances in computer technology in the past decade, notably increasingly powerful PCs at lower costs in recent years. Geospatial technology now provides data that allow urban simulations to be carried out, and the popular CA model is particularly appropriate for use by urban morphologists to simulate urban growth. Geospatial technology, in combination with computers, is transforming the techniques that are available for research in urban morphology.

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## References

- Batty, M. (2004) 'A new theory of space syntax', Working Paper Series, Centre for Advanced Spatial Analysis, University College London.
- Batty, M., Xie, Y. and Sun, Z. (1999) 'Modeling urban dynamics through GIS-based cellular automata', *Computers, Environment and Urban Systems* 23, 205-33.
- Cheng, J. and Masser, I. (2003) 'Urban growth modeling: a case study of Wuhan city, PR China', *Landscape and Urban Planning* 62, 199-217.
- Clarke, K. C., Hoppen, S. and Gaydos, L. (1997) 'A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area', *Environment and Planning B: Planning and Design* 24, 247-61.
- Conzen, M. R. G. (1960) *Alnwick, Northumberland: a study in town-plan analysis* Institute of British Geographers, Publication 27 (George Philip, London).
- Gauthiez, B. (2004) 'The history of urban morphology', *Urban Morphology* 8, 71-89.
- Goldstein, N. C. (2004) 'Brains versus brawn – comparative strategies for the calibration of a cellular automata-based urban growth model', in Atkinson, P., Foody, G., Darby, S. and Wu, F. (eds) *GeoDynamics* (CRC Press, Boca Raton, FL) 249-72.
- Hirano, A., Welch, R. and Lang, H. (2003) 'Mapping from ASTER stereo image data: DEM validation and accuracy assessment', *ISPRS Journal of Photogrammetry and Remote Sensing* 57, 356-70.
- Holtier, S., Steadman, J. P. and Smith, M. G. (2000) 'Three-dimensional representation of urban built form in a GIS', *Environment and Planning B: Planning and Design* 27, 51-72.
- Hudson, F. S. (1970) *A geography of settlements* (MacDonald and Evans, London).
- Jantz, C. A., Goetz, S. J. and Shelley, M. K. (2003) 'Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area', *Environment and Planning B: Planning and Design* 30, 251-71.
- Jiang, B. and Claramunt, C. (2002) 'Integration of space syntax into GIS: new perspectives for urban morphology', *Transactions in GIS* 6, 295-309.
- Larkham, P. J. (2006) 'The study of urban form in Great Britain', *Urban Morphology* 10, 117-41.
- Lilley, K., Lloyd, C., Trick, S. and Graham, C. (2005) 'Mapping and analysing medieval built form using GPS and GIS', *Urban Morphology* 9, 5-15.
- Liu, Y. and Phinn, S. R. (2004) 'Mapping the urban development of Sydney (1971-1996) with cellular automata in a GIS environment', *Journal of Spatial Science* 49, 57-74.
- Lo, C. P. (1970) 'Determining and presenting the third dimension of a city center: a photogrammetric approach', *Photogrammetric Record* 6, 625-39.
- Lo, C. P. and Yeung, A. K. W. (2007) *Concepts and techniques of geographic information systems* 2nd edn (Prentice Hall, Upper Saddle River, NJ).
- Madhavan, B. B., Wang, C., Tanahashi, H., Hirayu, H., Niwa, Y., Kamamoto, K., Tachibana, K., and Sasagawa, T. (2005) 'A computer vision based approach for 3D building modeling of airborne laser scanner DSM data', *Computers, Environment and Urban Systems* 30, 54-77.
- Mesev, V. (2005) 'Identification and characterization of urban building patterns using IKONOS imagery and point-based postal data', *Computers, Environment and Urban Systems* 29, 541-57.
- Oguz, H., Klein, A. and Srinivasan, R. (2004) 'Modeling urban growth and landuse and landcover change in the Houston metropolitan area from 2002 to 2030', *Proceedings of the ASPRS 2004 Fall Conference, Kansas City, MO.* (American Society for Photogrammetry and Remote Sensing, Bethesda, MD).
- Silva, E. A. and Clarke, K. C. (2002) 'Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal', *Computers, Environment and Urban System* 26, 525-52.
- Vogtle, T. and Steinle, E. (2005) 'Fusion of 3D building models derived from first and last pulse laserscanning data', *Information Fusion* 6, 275-81.
- Welch, R., Jordan, T., Lang, H. and Murakami, H. (1998) 'ASTER as a source for topographic data in the late 1900s', *IEEE Transactions on Geoscience and Remote Sensing* 36, 1282-9.
- Whitehand, J. W. R. (2001) 'British urban morphology: the Conzenian tradition', *Urban Morphology* 5, 103-9.
- Wolfram, S. (1994) *Cellular automata and complexity: collected papers* (Addison-Wesley Publishing, Reading, MA).
- Yang, X. and Lo, C. P. (2003) 'Modelling urban

growth and landscape change in the Atlanta metropolitan area', *International Journal of Geographical Information Science* 17, 463-88.

Yeh, A. G. O. and Li, X. (2001) 'A constrained CA

model for the simulation and planning of sustainable urban forms by using GIS', *Environment and Planning B: Planning and Design* 28, 733-53.

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## Urban morphological research at SCUT

The Urban Morphology Research Group (UMRG) at South China University of Technology in Guangzhou was established in September 2006. Professor Yinsheng Tian, three Associate Professors and four Lecturers in the Department of Architecture are the principal members of the Group, which is located in the new Liwu Science Building. The principal funding sources are government agencies. With the support of the Chinese National Natural Science Foundation, the UMRG has completed two research projects: on 'The theory and practice of traditional development

in urban residential environments' and 'The development of the spatial structure of the urban recreational system'. Researchers from both China and overseas have contributed to the regular seminar series. The UMRG has established a close research relationship with its namesake in the School of Geography, Earth and Environmental Sciences in the University of Birmingham, UK. A research student will be spending 2 years in the UMRG at Birmingham, starting in November 2007. The UMRG at SCUT will be hosting ISUF 2009 in Guangzhou.

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## Society of Architectural Historians

The Society of Architectural Historians will hold its Sixty-First Annual Meeting from 23 to 27 April 2008, in Cincinnati, Ohio, USA. Among the topics on which seminars will be held are:

- Identities in Greek and Roman architecture
- Inter-disciplinary challenges in pre-modern architectural history
- Architecture and engineering: inter-disciplinary contributions to architecture, 1946-2006
- Entwined perspectives for the construction of the colonized land: Asia before the Second

World War

- The Muslim city: continuity and change
- Spanish and Portuguese colonial architecture and urbanism on the fringes
- Modernist architecture in Africa
- Bourgeois and middle-class Modernism in German architecture, c. 1900 to 1940
- Italian Modernism and the persistence of tradition
- Third World Modernism

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## *Journal of Urbanism*

The new *Journal of Urbanism: International Research on Placemaking and Urban Sustainability* is being launched by Taylor & Francis in April 2008. This multi-disciplinary journal will focus on research on the design of the built environment within social, economic and environmental contexts. It is concerned with not only the form, pattern and design of human settlements but their relation to notions of sustainability, social justice and cultural understanding. There will be three

issues per year, consisting of peer-reviewed articles only. The co-editors are Charles C. Bohl, School of Architecture, University of Miami; Matthew Hardy, Secretary of INTBAU; and Emily Talen, School of Public Affairs, Arizona State University. Papers and enquiries should be submitted to [journalofurbanism@asu.edu](mailto:journalofurbanism@asu.edu). The personal subscription is 74\$ ( £38 or 59 Euros) per year. The institutional subscription is 417\$ (£214 or 334 Euros) per year.

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