Parsimonious Models of Urban Space

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This paper sets out an approach to urban modelling derived from early work with cellular automata and agglomeration models. In these cases the models are an example of distributed representation, where the rules built in to the model are replicated in all the discrete components of the model be they cells or agents. This is the classic AI. / AL paradigm of emergent systems. The paper describes the main structure of the models, and presents examples of the use of this modelling process in design education, pointing out the way dynamic models allow mapping on to interesting speculations about the dynamic of the city, and its social systems. The paper ends with a report on the use of such models as a design decision support system and how they will be used in planned work in master planning in the London Thames gateway area under the UK govt. sustainable communities initiative.

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1. Why parsimonious models?

1.1 Spatial models: geometry vs. topology.
Urban modelling as opposed to urban design could be said to owe its origins to the econometric and traffic models of the 1960s. These models took account of legal issues, employment and transport determinants both local and regional. Complex rulesets built on models of the economy on the one hand and traffic engineering models on the other sought to describe the formative pressures that would lead to the position of various types of land use on the surface of the planet, the most important of which was industry and employment generally.

This seems to have been especially popular in America rather than Europe, I would suggest, because of the laissez faire mind set of the US economists and transport thinkers. In a continent devoted to personal mobility and individual entrepreneurship the aim was to study the dynamics of emerging systems rather than design ideal cities. The use of gaming and other simulations (cf the community land use game COGS (Feldt 1972) was to lead eventually to such toys as sim city and other generated urban spaces. These models were the very opposite of parsimonious, the needed huge amounts of complex feedbacks and datasets to be able to handle the relationships between transport and zoning. The role of the social actors in such systems was overwhelmingly statistical – probabilities of desires and needs to be satisfied in economic terms. The models had a spatial output, but this was a gross topology rather than geometrical pattern of space, streets squares and so on which the old urban designers would have seen as their main goal.
Early work in computational geography such as Christaller lattices\(^1\) (Haggert & Chorley 1969) and Zipf’s law\(^2\) applied (in the context of spatial measurements) to settlement size ranking and distribution, started a conversation where the morphology of the outcome was an object of study in itself rather than the arbitrary outcome of elaborate econometric / transportation models. This work (which has developed into a mature field covering all aspects of geospatial information) is firmly focussed on mathematical models of shape and distribution ‘as found’ rather than the development of dynamic models that generate such distributions.

1.2 Durkheim vs Palladio the classic polarities of sociology and architecture
Bill Hillier’s paper *space syntax* (Hillier & Leaman 1976) was an early attempt to link the study of society with the study of topology and morphology. Up to then one could characterise the world of social studies as a-spatial – consisting of aggregated data on people, social classifications and so on, while morphology was exclusively about geometry – people without geometry and geometry without people as it were.

After a description of the basics of the syntactic description of spatial arrangements he points out

“However, as the model became better and better defined, it became clear that it might also be possible to associate with the *space syntax model* a social theory of the production and use of space patterns, by using similar concepts and methods to describe society as we had used to describe space. Almost as soon as this was attempted a clear, if somewhat complex, ‘inverse law’ began to suggest itself as the relation between social and spatial structure. Furthermore, the theory as we developed it appeared to make sense and relate a significant proportion of the conclusions of other researchers, including architectural researchers, anthropologists, and even an economic anthropologist“... (ibid p174).

Thus the development of models of urban structure can be seen as both simple descriptions of the spatial consequences of aggregation in the plane, and also a way of describing social relations. Because the syntax is related by what Hillier calls an ‘inverse law’ (space constitutes society and society constitutes space) then it becomes a simple but powerful descriptor that welds together the over elaborate a-spatial models of society and non-social models of space and form, hence parsimonious.

1.3 Architecture vs regional planning
The other aspect of the original space syntax article which is relevant is to do with the kind of space in terms of scale and morphology. Unlike the standard planning models of the 20th century which had a resolution at best of 1km square, and often much bigger, the focus was on architectural scales of 10 M square or so, the spatial arena for social interaction at the level of encounter, rather than the trans continental business trip. In this way the new models while borrowing the technology of the heroic super simulations (after all the Soviets developed economic input output models\(^3\) for the whole Union) also looked towards the urban scale of the 19th century town planners. 30 years after space syntax and its generative models were born we are now seeing (under the guise of the new urbanism) a renewed interest in ‘urban design’ at the architectural scale.

In order to structure the discussion of the models presented in this paper we can maybe use two flavours of model as constructs along which to place different approaches.

- **Syntactic**: where the model concerns non metrics of space such as configurational measures, and graph theoretic and other techniques to establish abstract classes of organisations of space. This is the base case for the space syntax approach, but such models can be extended by:

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\(^1\) Part of the central place theory Christaller 1933
\(^2\) George Kingsley Zipf (1902-1950)
\(^3\) Wassily Leontief (1906-1999) although a soviet citizen did all his best work in america, where a number of econometric models of planned economies were developed using the advanced computing facilities available in the USA, possibly for strategic reasons (eg SOVMOD I – III)
Semantic: where the model uses notions of space that have ‘meanings’ attached to them from the social or topological realm, such as labels (commercial, residential) or other characteristics (river-side, sunny).

Overlaid on this classification are the two most common technologies for executing such models

Agent based modelling (ABM), which uses autonomous computational entities able to define and alter their position in metric (parametric) space at discrete time steps, traditionally 2d or 3d (though n dimension solution spaces can also be used (Miranda 200). Their actions are undertaken in Euclidian space so that distances and other metrics are significant.

Cellular based computation (CA / Diffusion models) are based on a discrete tessellation of space and time. They are usually based on topological measures of spatial organisation such as networks grids etc.

In both cases the global operation of these models is an example of distributed representation, that is, all the components of the model work simultaneously using the same rules to produce a global emergent result. It is also vitally important that to be any use as a description it is vital not to over specify the problem, otherwise the results will be tautologous - already containing the instructions required to produce the outcome, rather than letting the outcome emerge from the interaction of simpler, more general rules. Gordon Pask (1962) set out this idea as the principle of “epistemic autonomy” for the simulation, in order to generate “structural autonomy”.

2. The pedagogy of urban modeling

The general idea of using computer simulation is to get students to understand basic ideas in systems modeling, in particular:

- Using parallel simulations to explore dynamic systems
- Experiments with feedback and emergence of spatial systems in urban models
- Teaching ideas about systems modelling in urbanism

2.1 Sana

The Sana model derives directly from the early alpha syntax work. As part of the Msc Computing and design at UEL we use parallel computation exercises to explore ideas about unplanned settlements and other emergent spatial organizations, as part of the overall studies of morphogenesis. In 1998-9 one of the students (who was fluent in Arabic) decided to model Sana the capital of the Yemen as an example of a very simple (he hoped) process of agglomeration. The old city's history was available in Arabic, (Varanda, Sallma, Kaizer 84) and some work had been done in the 1920's by German ethnologists and archaeologists (Rathjens & Wissmann) which allowed him to set out the main features of the development. The most important aspect of the development process was that, as a result of the usual agglomeration, specific areas developed as communal market gardens or other set aside open spaces called Bostans. This resulted in the development of an alpha syntax model with three rather than 2 space types:

1. open Y space – the permeable matrix of the morphology - the rule for y space is that y space must be connected to existing y space, and can have connection to x space
2. closed x space – the ‘houses’ of the system: the rule is that x space must have connection to y space and can have connection to x space
3. garden (G space) which must be connected to x space and g space.

Emergent properties

Because he was using the then new Starlogo (Resnic 1994) parallel processing development environment the original one-at a-time agglomeration process written in Fortran for a variety of ancient mainframes in the ‘70s by Coates was not just inappropriate but impossible. The model was implemented as a cellular automaton with state change rules (see fig 1) but instead of turn-taking, a probabilistic approach was taken to the state change rules which determined if an x or y was to be tested for.
This lead to interesting outcomes as the morphology was very responsive to alterations in these probabilities (see fig 2). The closest match to the situation of Sana was 40% (top row 3rd along).

The general notion of using such software as Starlogo (and now Netlogo) is, in direct descent from Seymour Papert and Alan Kay's attempt to harness the computer to develop a new epistemology in the thinking of the student (see Coates et al 2006 for an extended review of their significance in design education). By attempting to model Sana using Starlogo, with its insistence on parallelism and simultaneity, one is forced to recast ones approach from the top down designer thought to the bottom up dynamic systems position, which can more easily map onto ideas about the social dynamics of the place being studied. The way in which particular morphologies emerge with changes in parameters can lead to speculation about the social dynamics of the situation which Ali Khudair (Khudair 1999) was able to research, in various texts on Yemeni ethnology and social systems; in particular how single buildings become seeds for further agglomerative development based on the family relations and marriage systems of those societies.
2.2 Developing dynamic simulations of economic models of urban growth with spatial simulations

The Netlogo model (below) was first introduced as way of discussing the various dynamics of the systems to be studied. While the Sana model is based exclusively on a cellular representation, which means that the structure developed is a topology – the metrics of the system are arbitrarily constrained by the orthogonal grid of the Cellular Automaton -, the Milan model includes agents who can take account of metrics in their decision making. This model was used in the Laboratorio Di Sintesi Finale pre-diploma orientation programme at the Politechnico Di Milano in the department of architecture and planning urbanism course run by Prof. Lydia Di Appi.

Di Appi is interested in developing economic models of urban space formation – linking morphology to the economic and regional scale, making the conventional outcomes of econometric models feedback into the simulation of land values. Her work in the more traditional realm of regional planning (eg DiAppi 2004) uses cellular automata with Artificial neural nets (ANN) to describe and predict land use zoning at the regional scale, but her collaboration with Christian Derix came out of an attempt to take such models (much simplified) and link them to generators of architectural space. The students are at a point in their architectural education between the final exams and their theses, and the idea was that architects may have some morphological understanding that would allow them to provide ideas about shapes and effects in the city. The original simulation was written in Netlogo and consisted of:

A diffusion reaction surface which partitioned the plane into usetypes (residential and commercial in the first simple model).

Agents who reacted to this service by hillclimbing on the diffusion surface thus created, and at the

Figure 2
Effect of varying the house (x) placement probability from 20% (top left) to 90% (bottom right)

Figure 3
System diagram for Milan model
same time acting on the surface by defining particular points in space that were seen as transport nodes. (see system diagram fig 3).

The main purpose of this system was to teach the general idea of simulation and to provide the students subsequently with a test bed for experiments. With a range of global variables (represented by sliders – see interface shot fig 4) the students were able to propose scenarios and observe the outcomes.

Building on this work, a more detailed generative model was developed to allow students to experiment with models of new urbanism, with rules derived from (Katz 1994) to generate urban structures in a more architectural way, with 3d geometry of blocks rather than 2d patches as in the diffusion model. The main components of the new urbanism were taken to mean:

- Densification of poorly structured existing areas of cities
- Insertion of new building into the existing urban fabric
- Greater reliance on pedestrian movement (the 10 minute walk cf Alexander (1965))
- Replacing large scale zoning with mixed uses

Di Appi and Derix were using this series of experiments to introduce students to principles of urban design and simulation. The course was discussing notions of ‘sprawl’ and ‘shrinking cities’ and thus used the theoretical framework of New Urbanism to construct the simulation models. In this model the relationship between the agents and their environment was firmly embedded in a metrically defined environment, though the 3d structures also had topological constraints.

The project was defined as one where, using a site in Pavia current planning rules were plugged in. Students used existing theory to test in what way they can be used to generate urban form and structure, and to modify the rules/simulation system to explore a range of outcomes.

This model then, contained distinct layers, the underlying simulation based on diappis work on regional pressures on land uses, with the morphology

Figure 4
Experimenting with the netlogo model

Figure 5
Agents defining dense locations.

Figure 6
Emergent structure of transportation nodes
of the emergent structures using existing and proposed urban codes and planning rules.

The driver of this second model is based on a “morphogenetic” deviation amplifying feedback model (fig 5) (Milsum 68) between growing ‘buildings’ and traveling agents with urban pedestrian type constraints. Buildings will proliferate and grow in value in the presence of agents visiting, and agents will be attracted towards ‘popular’ buildings.

In this model the building rules are chosen to lead to a system of rectangular blocks of building with internal courtyards (fig 6). This was chosen as a nod to the existing urban structure of pavia; other morphologies could of course be used, including Sana type syntaxes.

Agents are also responsible for a superstructure system over the pedestrian spatial system by defining transport nodes. This is done by agents identifying high density areas (fig 5) that are not served by a transport node. This leads to a network of middle distance transport which can be thought of as tram, bus or other transport systems so familiar in the old European cities beloved of the new urbanists. The presence of these nodes reinforces the building values, thus starting a further feedback loop.

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*Figure 7*

*Smart Solutions for Spatial Planning workflow*

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System Diagram for **Smart Solutions for Spatial Planning** project.
3. Using generative urban modeling as a design support system

In January 2007 CECA was awarded a grant towards using these models and others in partnership with Aedas Architects, the London boroughs of Tower Hamlets and Newham to build a modelling system to allow scenario building in urban areas, which we called “Smart solutions in Spatial Planning”. The role of the project is to take data, including planning applications, from the Local Authority regeneration departments, and to use this to build a number of ‘what if’ scenarios to test the outcomes of different policy decisions. The aim is to show that by generating urban structures that can be tested against various sustainability measures we can iterate towards better solutions for redeveloping the area. Typical applications would be to take a proposed mix of uses and house types in a particular site, and build a generative model to explore pedestrian access, connections with neighboring sites and effect of development in measures of transport and daylight and many other parameters.

The project aims to exploit the currently under-used GIS resources of the boroughs, to provide a digital chain from regional and local planning, through master-planning, on to architectural solutions 3d models and detailed design, back to the initial data. Currently, although this process of course does occur, it is broken in many places with lack of coordination on data formats, reliance on paper documents and gulfs of understanding and policy between the boroughs, developers, the local community and architects. We hope to show that with a generative urban modelling system at the centre of the process, we can speed up the evaluation cycle and demonstrate the benefits of a well integrated appraisal system could work. The ultimate aim is to show that such a responsive system can help to develop and test a wide range of measures of “sustainability” hence to lead to better working urban structures.

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