Workshop 1

Generative Urban Design

Saturday 21 June 2008, 9:00 - 12:30
# Table of Contents

Workshop goals and scientific committee

**On generation – rule based approach**

**Generating Networks**  
*Jeffrey V. Nickerson, Stevens Institute of Technology*

Design support systems for sustainable development in the Thames Gateway area of London: “Smart Solutions for Spatial Planning (SSSP)  
*Christian Derix, Pablo Miranda & Asmund Gamlesaeter, AEDAS architects, Computational Design Research, Paul Coates, CECA (Centre for Evolutionary Computing in Architecture), University of East London*

A designer-centered shape grammar editor and interpreter  
*Andrew I-kang LI, CHEN Liang, and WANG Yang, Department of Architecture, The Chinese University of Hong Kong, China*

Cities as diachronic models: The spatial logic of growth and its role as a generative design component  
*Kinda Al_Sayed University College London, UK*

City Induction Generation Module - Structuring a generative model for urban design: linking GIS to shape grammars  
*José Beirão, Faculty of Architecture, TU Delft / Faculty of Architecture, TU Lisbon, José Duarte, Faculty of Architecture, TU Lisbon, Rudi Stouffs, Faculty of Architecture, TU Delft*

**On the urban program formulation**

City Induction Formulation Module - Towards a Computational Description of Urban Patterns  
*Nuno C. Montenegro, José P. Duarte*

**On evaluation**

CityZoom: A Visualization Tool for the Assessment of Planning Regulations  
*Benamy Turkienicz, Bárbara Bellaver Gonçalves, Pablo Grazziotin*

City Induction Evaluation Module - Integrating spatial analysis techniques in the parametric urban design process  
*Jorge Gil, Space Syntax, UK*
Generative Urban Design

1. Goals

The workshop aims at bringing together researchers and practitioners in computation and urban design to discuss their views on the future of city planning and design, and to identify key issues, technologies and applications in the development of adaptive, generative urban design processes.

Urban Design is an enduring activity where the dynamics of contemporary society continually introduce unforeseen changes in town development processes.

Traditional planning, in which a master plan is used to respond to all the contextual needs through a formal layout, has been the main approach to urban design, although its limitations are quite well known. In fact, the rigidity of this approach fails to respond to the dynamic evolution of the context.

New technologies can be used to support an alternative approach, in which adaptive design systems are able to respond more accurately to the needs and complexity of the contemporary city. This approach should satisfy, on the one hand, the need for planning and urban management on behalf of public entities, and on the other, the need for responding to the evolving demands of private agents.

The workshop aims at exploring the use of urban patterns, space syntax, shape grammars, parametric design, adaptive systems, and other formalisms, as the basis for developing an alternative approach grounded in the development of generative design systems for urban design.

2. Scope

The workshop scope will include formulation, evaluation, and generation of urban plans. Topics include, but are not limited to:

• generative urban design with shape rules;
• defining pattern languages for urban design;
• shape grammars applied to urban adaptive systems;
• encompassing emergent behavior in town planning;
• interfaces for participative urban design;
• generative tools for urban design based on shape grammars, genetic algorithms, etc.;
• the use of parametric models in urban design;
• urban models for different scales – from city to site planning;
• evaluation models, including space syntax.

José Beirão, José Duarte and Rudi Stouffs, co-chairs

3. Scientific Committee

George Stiny, MIT, USA
Paul Coates, University of East London, UK
Benamy Turkienicz, Universidade Federal de Rio Grande do Sul, Brazil
Sean Hanna, Bartlett School, UCL, UK
Robert Woodbury, Simon Fraser University, Canada
Abstracts

On generation – rule based approach
Generating Networks

Jeffrey V. Nickerson
Stevens Institute of Technology

Introduction

Cities are places where information and material are integrated. This integration takes place on top of a changing infrastructure that is sometimes designed and sometimes organic. We can think of this infrastructure as a network, or, more accurately, as a set of overlapping networks, each with different distance measures between nodes.

For example, there are street networks, in which distance might be measured in the expected time to traverse a block, as distinct from sidewalk networks, in which the time to traverse a path is longer, and in which stores and residences form potential entry and exit points. These networks, which we might measure in terms of time, are of course related to Euclidean space, and our common ways of discussing these networks involve maps.

In contrast, there are also information networks that are based on topological distance. For example, access to an IP network is often thought of as binary – you are connected or you are not. In actuality, there is a nuance to such connections – the ability to communicate is a function of the number of hops – the topological distance – as well as the throughput of the weakest link (c.f. [1]).

These two kinds of distances – Euclidean and topological – define our relationship to urban environments (c.f. [2]). Transportation systems so shorten the time to integrate goods that we are inclined to abstract such networks into graphs. For example, subway system maps emphasize stops, not Euclidean distances, as the stops and transfer points define the time to the destination.
Wired connectivity, from the telegraph to the Internet, as been seen as compressing, and in some cases as annihilating space [3]. But what it really does is create topological spaces that layer on top of the Euclidean spaces we live in.

Wireless connectivity, and especially an ad hoc network, involves a combination of these two spaces. Individual A and B can be walking toward each other, with decreasing Euclidean distance, but with no connectivity. At some point, their radios find each other and they electronically connected.

I have pointed out that, in the wireless world, the topological and the Euclidean can be combined with a measure that can be called the time-to-communicate [4]. Thus, in an urban setting, the time to communicate may involve the time it takes to get to a coffee shop, go online, and send a message to someone, the Euclidean travel time and the electronic transmission time adding together to produce the resulting communication.

In considering urban infrastructure, the forms of networks can involve combinations of wired and wireless electronic communication, along with the existing transportation networks that provide access to electronic hotspots. It is common to take electronic communication for granted, because communication seems ubiquitous, and many appear to always be online. I take a contrary view. I don’t think such a world is feasible. In particular, past history shows that such taken-for-granted urban infrastructure breaks down in emergencies, and responders are reduced to communication improvisation that can be vastly improved on. For example, responses to earthquakes, hurricanes, cyclones, electrical failures, and bombings are often hampered by communication systems failures, regardless of backup systems and service level guarantees.

Here, I present the results of some investigations into the forms of networks. I have made many simplifying assumptions regarding such networks, focusing on one particular structure, sensor networks. Such networks are interesting to study for several reasons. Static sensor networks listen and integrate information. Moving networks involve nodes that have locomotion. These networks often have a purpose, a mission.

There are many applications and analogies to urban design. Aspects of infrastructure often have sensing components – dusk detectors in lights – cameras on traffic embedded road sensors, structural load sensors, etc. In a more general sense, people in a city can be modeled as moving sensors. However, it is not obvious we all have a common goal. Indeed most traffic assumes we move around at random.

I propose, as a simplifying assumption, that city dwellers do have a common goal: the integration of information. Furthermore, that urban
Generating Networks

structures will tend to optimize this integration. To be sure, there is historical contingency - a bad design for public transportation may hobble a city for generations, whereas enlightened choices may speed growth. Still, in general, the systems we evolve maximize integration, while at the same time minimizing costs. Specifically, we can model information integration by assuming that information value degrades exponentially with time, and thus fast integration is more valuable than slow integration [5]. This modeling assumes that information flows through a combination of electronic networks and transportation networks. The transportation networks use couriers to carry information between disconnected electronic networks. For example, I am a courier when travel to a conference to present new research results, and at the point I arrive at the conference, I become part of a highly integrated transportation and electronic network.

Here, I present some visual examples from my research in this area, which draws on a series of related papers on wireless communication ([6]), sensor networks [7, 8], and social networks [9].

**Static Networks**

Sensor network design deals with a tradeoff familiar to all network designers, that between coverage and cost. We will look at this first in static networks, and then in dynamic networks.

We pose the tradeoff of coverage and cost as a multi-objective decision problem. To maximize coverage, we will minimize the average distance from a set of random locations on the plane to the nodes of a tree. We imagine that couriers take information to the network, and thus the integration time can be shortened if the average distance to the network is shortened. To minimize cost, we will measure the amount of material used to build the network. As a simplifying assumption, we will assume that cost is proportional to the total length of the edges between nodes.

This problem is related to the Euclidean Steiner Tree problem [10, 11] – that is, the discovery of trees which minimize the overall path length between all connected nodes, introducing new nodes if doing so will reduce total path length. Steiner trees under most conditions have been shown to be intractable. Therefore, we use evolutionary algorithms, and specifically we use Deb's multi-objective algorithm for simultaneously optimizing more than one criterion [12]. To seed the trees, we start with a set of random recursive tree structures, mutating and crossing over these structures directly.
Figure 1 shows the results of the investigation after 200 generations. On the left, the leftmost cell in the row is numbered. Cell 1 is optimized almost entirely for cost, and cell 100 is optimized almost entirely for coverage. The rest of the cells can be imagined as lying along the Pareto-optimal front – that is, they dominate all other solutions. For every possible solution in the space, one of the cells on the front is both lower in cost and higher in coverage.

The recursive, symmetric structure of the solutions is apparent. As more material is made available, by relaxing the cost restriction, the more branches appear. At cell 21, we can see another set of branches appearing.
Generating Networks

at the extremes of the figure. At cell 47, the extremes of the figure exhibit triangular branching structures. These triangular structures grow in length, overlapping each other and filling the plane, with a mass building in the center, seen strongly in cell 100.

The early cost-minimizing structures are reminiscent of suburban subdivisions, the trees that Alexander pointed out are very unlike cities [13]. The later structures 81-100, look more natural, like brambles. Similar to brambles, which are a protective structure, these networks will sense almost anything moving.

**Dynamic Networks**

Issues of infrastructure often relate to the amount of time it takes for goods or information to travel between two points. We will consider one such situation: in an emergency, with primary communication lost, how long will it take emergency responders to get back in touch with each other? We assume here the use of software-defined radios that can form ad hoc networks (c.f [4]).

We have previously proposed two techniques for insuring contact. In one technique, the responders move toward the center. In the second technique, the responders move toward the center, unless they see someone else already connected, in which case they move toward that someone.
**Fig 2.** Aggregates with the first heuristic

**Fig 3.** Aggregates with the second heuristic
These figures are related to diffusion-related aggregates [14,15]. These structures have been studied before in relation to urban planning (e.g. [16, 17]). In contrast to those models, which build the aggregate from the center out, in this set of experiments, the heuristics are analogous to ballistic aggregates, in which particles are shot toward the center from far away. Here, we begin the movement of particles from within the field, because we are modeling responders scattered at random, and then in an emergency converging on an agreed-upon position. We have demonstrated that the second heuristic is of higher fractal dimension [7], and thus it integrates faster. A set of these aggregates can also be formed in parallel, and then bridged, as in Figure 4: a courier takes a message from one aggregate to another.

![Fig 4. Couriers joining aggregates](image)

Can we combine the organic forms of diffusion-limited aggregates with the discovery process of genetic algorithms? The results are shown in Figures 5 and 6.
Fig 5. Emerging aggregates
Fig 6. Genetically grown aggregates after 200 generations

Aggregates are generated from permutations, and the evolutionary algorithm searches the permutation space, making use of crossover and mutation. Mutation may cause multiple aggregates to build, as in Figure 5. By the end of 200 generations, usually the surviving generations are fully connected networks that look organic, yet subdivide space efficiently, consistent with the patterns of Steiner trees.

Concluding Thoughts

Cities are centers of integration, and urban infrastructure evolves to maximize integration. Multi-objective optimization allows us to create a set of designs for infrastructure that seek to minimize cost while maximizing integration, with varying tradeoffs. Mobile ad hoc networks, useful to emergency responders, can be modeled with simple heuristic algorithms that produce complex tree-like structures akin to diffusion-limited aggregates. These structures can be combined using genetic algorithms to explore a range of curvilinear forms, including settlements connected by courriers or other forms of communication.
References


Design support systems for sustainable development in the Thames Gateway area of London:  
“Smart Solutions for Spatial Planning “(SSSP)

SYNOPSIS

This presentation will describe the methods and approaches used to develop applications for Urban planners for use in masterplanning and scenario building. It was developed using a grant from the Higher Educational Council for England, and the Department for Trade and Industry as part of the “Building Sustainable Communities” project.

BACKGROUND

After many years of inactivity, it seems the field of computational urban modeling has become live once more. The original explorations (Haggett & Chorley 1969, McLaughlin 1969) were left to develop into the more large scale area of GIS, and computational geography, and computational focus on the spatial morphology of settlements did not arise until Bill Hillier's seminal paper (Hillier 1976): ‘Space syntax’ which in its first incarnation was a proposal for a set theoretic syntax for cellular agglomeration models. Batty’s work (Batty 1996) at the regional scale began to explore diffusion limited aggregation models of urban growth, and more recently work on cellular automata and self organizing feature mappings (DLapi 2004) has lead to developments in the emergent systems approach to urban decay and gentrification. Since then the recent work of Koenig (forthcoming) & Mueller(eg 2001) has shown the use of L-systems and other pattern-making systems, many of which are now in use in the games industry for generating ‘realistic looking’ urban space for scenarios.

In most computational work there has been, we suggest, a dichotomy between the study of people in cities and urban systems, and the study of spatial systems as geometrical entities. Hillier’s contribution was to link these two things together. 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.

We suggest that the actual practice of urban design has to some extent reverted from pattern making back to this original cybernetic approach to urban coding where relationships and systems are defined, and the urban morphology emerges from a synthesis of both the site structure and societal data. Our project, then, was to work closely with the regeneration units of Tower Hamlets and Newham (two inner London boroughs) and a team of Urban designers to understand their workflow and strategies so that we could build our simulation models to fit in with their way of working. To his end we built a set of urban design support methods – analytical and generative – that can iteratively be plugged into their workflow.
**SIMULATION STRUCTURE**

The site for this knowledge transfer exercise, sits on the border between two London Boroughs – Tower Hamlet and Newham – within the Lea River valley. The site therefore is subject to two sets of policies Local Area Action Plans and is also topographically divided by the river itself. Those conditions let to the main issue on site, which is the lack of accessibility. Further, the London Borough of Hammersmith and Fulham have developed an accessibility mapping method, called PTAL – Public Transport Access Levels – which serves most urban planners as an initial briefing instrument for density levels, land-use distributions and transport strategies.

Hence, the present approach uses **accessibility** as a backbone, which underpins the overall strategy of building a digital chain from regional data sets, topographical data, social deprivation and access to services. The accessibility network feeds straight into the urban/masterplan scale and the urban block scale.

**Accessibility Levels**

Using a derivative of Dijkstra’s shortest path algorithm, all context paths, routes and access points are integrated to serve as a stimulus for generation of further axes and circulation paths.

Any newly generated network of paths and routes (see urban scale) recursively links into the existing graph and gives properties to the edges of the emergent urban blocks.

**Urban Scale**

While the urban block and its relation to public space is fairly well described and quantifiable, the urban scale structure lacks explicit design approaches. However, the most common heuristics of urban designers/planners pointed towards differentiation of the urban structure by connectivity of ‘activity’ locations including linear spaces (knitted into external location points).

Therefore, a series of studies was undertaken to evaluate computational approaches for urban structure through connectivity (always embedded in the accessibility strategy), which were evaluated with our urban designer and council planner partners.

Initial studies used a Voronoi partitioning algorithm with the centers of the Voronoi cells self-regulating to achieve optimal block areas and block ratios. Further, we tried to implement a random orthogonal partitioning system responsive to the accessibility levels and activation points. Finally, the last of initial studies distorted an underlying grid towards the most integrated shortest path graph through a spring system based on Runge Kutta.

The most appropriate method however, proved to be a more literal transposition of urban design heuristics by implementing a K-minimum spanning tree (KCT) on a grid with a minimum average aspect ratio for urban blocks. The spanning tree calculates the sub-tree through an ant-colony optimization (ACO). The activation locations serve as the K input vertices and produce unpredictable yet rational urban blocks.

![FIG 2 left: relaxation and deformation to shortest path network, right: K-minimum spanning tree](image-url)
**Block definition & Plot Uses**

For the block definitions and land-use allocations, either hand-drawn outline urban blocks or the results from the KCT graph serve as input. Two methods in progress:

**Aggregate Hill-Climber**

According to context conditions, social data and local planning frameworks, a massing is generated dependent on the outline blocks (circulation graph). Single plot units ‘hill-climb’ within an unstructured grid and slowly aggregate towards the desired total area set in the masterplanning brief. The units hill-climb in order to reduce the errors in their adjacency preferences and distance requirement to functions and conditions. Each local change is benchmarked globally and continues until all criteria are satisfied. If the masterplanning brief is un-realistic according to density and accessibility (and other) planning criteria, the applications indicates alternative area schedules.

**FIG 3** two land-use aggregation results with secondary path networks generated

**Pareto Optimization**

The multi-criteria Pareto optimization is developed to optimize the distribution of uses within a given urban block to achieve mix, density and environmental criteria. The target values are taken from policy documents used by the planners, which set out dwelling densities for a range of building typologies. In the example below of a test block the target density is of high density with elevated ratios of retail to residential. Using the Pareto Optimization allows balancing of non-commensurate criteria and targets including individual building typology and open space policies.

**FIG 4** multi criteria optimization for urban blocks: residential target 425 Dwelling per Ha (from Urban Design Compendium), Retail 20% & maximize south facing elevations
SELECT REFERENCES

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A designer-centered shape grammar editor and interpreter

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Introduction

Shape grammars are well known as tools for both design analysis and design synthesis. However, they are not widely used by designers. One reason is that existing interpreters do not give designers the kind of support they need to do their work. Designers using often spend too much attention on the mechanical aspects of grammars and are distracted from the task at hand, namely design. They need an interpreter that shields them from unnecessary grammatical tasks and frees them to concentrate on domain tasks. They would then be able to use grammars to generate and explore large numbers of design alternatives.

To get at such an interpreter, we propose a rough model of what designers do when they use grammars. Based on this model, we then propose criteria for the interpreter. Finally, we implement a prototype of the interpreter.

What designers do and the implications for an interpreter

Designers working with grammars do roughly the following:

- They reason about graphic objects;
- They engage in an open-ended, unpredictable process; and
- They engage in a cyclical process of modifying grammars and evaluating the designs produced by the grammars.

For an interpreter that supports designers working with grammars, the main implications are these:

- It should have a graphical user interface. The designer should manipulate graphic objects directly. For example, the designer should be able to create shapes by drawing shapes, not, say, by typing coordinates in a text file.
- It should support emergence. Otherwise, the designer may not be able to manipulate everything that he or she can see. His or her freedom to explore could be arbitrarily constrained.
It should facilitate the designer’s cycle of work. He or she is editing a grammar and evaluating the designs defined by that grammar. However, he or she is most likely not interested in actually generating the designs; this should be done automatically by the interpreter. This would allow the designer to focus on the domain tasks of editing and evaluation.

The editor-interpreter

Our editor-interpreter is based on a three-dimensional shape grammar engine by Hau Hing Chau at the University of Leeds. This engine does shape arithmetic, tests for shape matching under transformation, and has a minimal user interface. It supports emergence.

To this engine, we have added capabilities as suggested above, resulting in a combined editor-interpreter. These capabilities include:

- An internal graphic editor for creating and editing shapes and rules.
- An Autocad applet for creating and editing shapes and rules in Autocad, and a mechanism to move shapes and rules between the editor-interpreter and Autocad. This allows shapes calculated by the editor-interpreter to be translated into DXF format for downstream processing.
- Labeled points.
- A graphic display of the grammar.
- Automatic calculation and graphic display of next shapes.
- A single environment for both editing and running the grammar.
- Printing and saving grammars and derivations.
Cities as diachronic models: The spatial logic of growth and its role as a generative design component

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Abstract. The research investigates the logic behind the diachronic model of city growth and the rules which govern the emergence of urban spaces. The aim of the research is to implement the generative rules in evolving intelligent spatial grids using combinatorial techniques and learning algorithms. The first approach in this regards would be to study the evolution of existing urban regions or cities and investigate the rules and causes of emergence and growth. The second approach will be to look into the nature of the generative rules themselves. This nature will be defined in terms of several aspects. One of these aspects is the spatial and none spatial nature of the generative rules. Another will examine the rigidness and change in the generative rules. The research will concentrate on the spatial generative rules and investigate their spatial dimensionality whether they are two or three dimensional. In addition to that it will investigate whether the generative rules are merely combinatorial or if they undergo feedback loops. The third approach in investigating the logic of spatial evolution in cities will be to explore ways to implement the generative rules and enhance them through subjecting them to evaluation and optimization techniques. These optimization techniques include methods of minimizing depth in space and maximising spatial intelligibility. The final approach in this research will look into the effectiveness of implementing the generative rules in evolving urban spaces and the benefits obtained by such studies.
City Induction Generation Module - Structuring a generative model for urban design: linking GIS to shape grammars

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Keywords. Patterns, shape grammars, ontology, generative urban design.

Abstract

Urban Design processes need to adopt flexible and adaptive procedures to respond to the evolving demands of the contemporary city. To support such dynamic processes, a specific design methodology and a supporting tool are needed. This design methodology considers the development of a design system rather than a single design solution. It is based on patterns and shape grammars. The idea is to link the descriptions of each pattern to specific shape rules inducing the generation of formal solutions that satisfy the pattern. The methodology explores, from the urban designer point of view, the capacity of a shape grammar to codify and generate urban form (Duarte et al, 2007).

The proposed tool is divided into three parts, a formulation model which formulates the urban program, a generation model which generates designs and a model for evaluation acting at different stages of the design. This paper focuses on the development of the generation model.

The first part of this research aims at defining the ontology that establishes the communication of 3D CAD urban entities within a GIS platform and that will support the implementation of a shape grammar for the generation process. The second part of the research consists in implementing the generation model. In this presentation we show the ontology needed for the implementation of the generation model.

The urban design tool

Figure 1 shows the generic scheme of the urban design tool, which is an extension of the discursive grammar schema to fit urban design. (Duarte, 2005) The design process uses pre-existing data in the form of GIS files as a starting point. The generation of designs involves the application of the rules codified in a shape grammar (Stiny and Gips, 1972) according to the requirements of the urban program codified in a description grammar (Stiny, 1980). From the data analysis the formulation model uses a programming language to extract the urban program defined as a set of urban patterns which will trigger the generation model to produce designs that respect these patterns. The design language is an urban grammar that supports the generation process using design rules organized as patterns. Urban grammars are particular to each designer. The evaluation processes can be applied to all parts of the tool structure and therefore the evaluation model may act upon each part. An ontology of urban entities supports the communication along the entire design process.

Designing with urban grammars

In the envisioned design system, urban design is the result of applying an urban grammar. The urban grammar is a set of urban patterns and shape rules that can be
applied at four different scales or development phases, separately or together (Beirão and Duarte, 2007) (Figure 2): (1) rules based on a territorial scale, through an analysis on existing morphologies, establishing the relevant features for the definition of the plan’s structural geometries; (2) characterization of urban grids or city tissue, lays down the remaining features of the street structure; (3) urban unit characterization, determines the characteristics of the urban units, such as neighbourhoods, city blocks, and plots; and, (4) detailing of the urban space, which defines material aspects, ambiances and other details. An urban grammar encodes a design language and is able to generate urban design solutions within that language. A set of urban patterns defines a vision for a certain scale of the urban design problem. Each urban pattern may yield different shape rules, meaning that each designer will define his own grammar for that pattern based on his preferences. The designer can create an urban design by applying recursively a specific set of rules that translate and define his design language.

<table>
<thead>
<tr>
<th>Pre-existing Data (GIS files)</th>
<th>Formulation model</th>
<th>Urban Program description grammar</th>
<th>Generation model a shape grammar</th>
<th>Designs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programming Language</td>
<td>Patterns</td>
<td>Patterns and shape rules</td>
<td>Design Language</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1- A tool for urban design. Designs are the result of applying an urban design language constrained by an urban program defined by a set of patterns, determined by a programming language from data on a pre-existing site. An ontology of urban entities supports communication throughout the design process.

Figure 2 – Generic structure for an urban grammar

The ontology

Designs result from operations performed on an ontology of entities with attributes to be implemented on a GIS platform. The entities are urban objects with specific
topology and conditioned by attributes. Attributes add specific meaning, hence also specific behaviour to the urban objects. The ontology also relates objects and attributes on a larger topological and semantic level. Basically, all the features commonly present in the urban environment are topologically interrelated and have parametrical behaviour, being able to assume any formal solution while keeping their intrinsic relations and dependences. Design rules operate on this structure.

Table 1 shows an excerpt of the Ontology for the generation model.

In this table we show that the urban environment can be considered as a network of entities (or city components) grouped into object classes on the left column and described topologically through specific object types (and eventually subtypes) on the right. The complete table has the following object classes: TO – Topography; SM - Site morphology; NF – Natural features (includes vegetation, natural and planned, and water features); Z – Zoning; TN - Transportation network; SQm – Squares (main squares / referential squares); UP – Urban plots; SN - Street network; UU - Urban units; BL - Blocks or block types; SQs – Squares; BP – Building plots; SD - Street definitions; BD - Building definitions; UF - Urban furniture; MA – Materials; FC – Façade constraints (façade definitions).

Table 1 – Ontology draft for generation model – a topological structure of city components

| Groups of entities – Object Classes – Entities (components of urban space) – Object types |
|---------------------------------|---------------------------------|
| SN - Street network (grid/urban tissue) | Street types: |
| | B1 – Bicycle Paths (independent from streets) |
| | P2 - Pedestrian Walkways (when independent from streets) |
| SD - Street definitions (street profiles / street junctions) | Sp - Street profiles: |
| | ① - street parking / ② - sidewalks / ③ - bicycle paths / ④ - bus/tram lanes |
| | ⑤ - car lanes / ⑥ - green alley / ⑦ - noise protection / ⑧ - tree alignments |
| | ⑨ - canal big – b / small – s |
| | Sj - Street junctions |

Relationships between the object classes are defined by the partial relations between their object types. These relations are defined through classification attributes. For instance, the profiles for street types within SN – Street Network – are defined through a collection of SD – Street Definitions – object types. As such, a given street type may be a collection of different street profiles as follows:

\[ S1 - (①)②③④⑤[⑥⑦⑧⑨bs] \]

The features on the left are obligatory components of the street type S1, whereas, the features on the right, namely ⑥⑦⑧⑨, are optional parts. Shortly, a street type is a collection of complementary street profiles where a street profile is a parametric model of a part component of a street. Figure 3 shows 2 examples of S1 street types that result from different combinations of street profiles. Each street profile has a minimum and a maximum value based on regulations or other indicators. An ideal value can be used for optimizing results. Every street type may have different appearances depending on the values attributed to parameters of each street profile and on each component’s attributes linking with other object classes, for instance, MA – Materials.

From the geometrical point of view SN objects are a grid of polylines, each one with a corresponding attribute that identifies their street types. Each street type is a collection of various street profiles, each one being a parametric model of the
correspondent basic profile. Further detail can be added through attributes, linking for instance, with material definitions, attributed to sidewalks or even with new parametric models (e.g. consider a profile definition for a stone on the sidewalk border).

BL - Blocks or block types have similar approach defining the internal relationships that characterize the different block types like relations between buildings within the block structure, relations between block and street access, relations between function and building form, function and space, and so on.

![Diagram of two different S1 street types](image)

_**Figure 3** – Two different S1 street types – the left one is asymmetrical and the right one symmetrical resulting from the different combination of street profiles._

Ultimately, each object type is geometrically defined by points, straight lines, polylines, closed lines, surfaces or 3D solids and their topological relations. The ontology is a step from abstract geometrical representations to meaningful representations.

**The presentation of a research quest for more flexible approaches to urban design**

The first section of the presentation gives a short notice on the existing knowledge used to structure the generation model and presents the case studies chosen to support the research. Secondly, we explain the basic structure of the design tool as being an ontology of urban entities with an implicit topology. Finally, we detail the design process and how patterns can be used to explore more efficiently and interactively an urban design.
On the urban program formulation
Towards a Computational Description of Urban Patterns

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Keywords: Urban Formulation; Ontology; Pattern Language; GIS interoperability.

Urban space shelters a wide range of human activities. Due to its complexity, the overall perception of urban phenomena requires an administrative representation based on a taxonomic methodology. This study is concerned with a formulation toward decoding such urban problems. It departs from Alexander’s pattern language theory and urban design guidelines, to create a system for generating specifications or the ingredients of a plan, given a scale, a site and a community. It takes into account strategies, regulations, guidelines, physical features of the site, and furthermore the social, cultural and economic characteristics of the population. This system, sorted by a sequence of events, through stages, categories, methods and agents, describes taxonomic levels and its inner relations. This taxonomic structure is defined through Ontologies (Gruber, 1993). Each ontology encompasses different levels, namely, taxonomy, partonomy, mereology, chronology and topology. Ontology standard relations are expressed through Taxonomy (is a, type of), Partonomy (part of), Mereology (‘part-of-all’ theory), Cronology (time between concepts) and Topology (boundary and limit theory). The heuristic diagram 1 shows an ‘Application Ontology’ describing urban space parameters, through patterns definition.

The urban formulation encompasses a specific chapter of the planning process, regarding the pre-design (PD) phase. PD consists in a phase of analysis that occurs before design begins. Usually, during the pre-design phase, studies are done to analyze requirement issues, the constraints and opportunities of the proposed site. PD seems to comprise a higher amplitude of occurrences than those presented in the Alexander’s pattern language theory. The proposed urban formulation ontology engages an overall process, starting with aims and strategies, and ending with a precise selection of urban patterns. In such ontology, the ingredients of the urban planning process interact and operate within a systematic structure, aiming to assemble rules and classes. This ontology comprises two design stages; pre-design phase I (PD1) and Pre-design phase II (PD2) and it’s organized by categories (strategies, regulations, data, and language), methods and users (the designer’s inner language).
Prior to the final spatial characterization and the urban patterns definition and selection, some support information is required to identify objectives. This characterization corresponds to the PD1 phase.

Although Alexander's Pattern Language embodies the theoretical basis towards the urban design, ruled by patterns, it contains operative limitations such as the lack of a pre-design (PD) and the Preliminary Information (PI) data set. This PI is described herein as; 1) Social, Economic, Cultural and Political Strategies, within Strategic Urban Planning (SUP), enclosed by SWOT (tool used to evaluate the Strengths, Weaknesses, Opportunities, and Threats) and PEST (Political, Economic, Social, and Technological analysis) methods; 2) Regulations, as urban rules, guidelines, requirements and urban standards. The regulations have a precise application, varying according to the site and its context; 3) Site and Population Data, describing the physical features of the site, the social and economic characteristics of the population, within Site Analyses Data Compilation Categories (SADCC which also compris design guidelines, codes, and requirements), among other statistical information.

After the PI classification, an urban design space description is required, through the definition and selection of urban patterns, based on their particular nature and formalization.

This characterization corresponds to the PD2 phase. The development of this phase is centered on the principles described by Alexander’s series of books in the 70s. The Pattern Language provides a language for building and planning that includes detailed patterns for things ranging from rooms to towns. The Timeless Way of Building provides the theory and instructions for the use of the language, which is the discipline that made it possible to use the patterns to create a building or a town. Alexander’s premises address to the linguistics theory, which defines language as a combinatorial and creative method of communication, based on user instructions, through different contexts, within an index of vocabulary and procedures. Thus language allows users a creative mixture and an assorted manipulation of its ingredients. The speech expresses a combinatorial characteristic of the language, which is crucial in the production of concepts. In planning, such characteristics are useful for a creative and flexible process. This speech is structured under syntax rules, defining the way words combine into phrases and sentences (Chomsky, 1957); similar to Alexander’s combination patterns.

The work of Alexander stirred the field but had little practical impact. A set of comparative examples detected debilities into the description of PL sorts: 1) PL taxonomy by scale seems to repeat similar urban solutions (example: patterns 57 and 68); 2) PL lacks some key patterns as structural urban grids; 3) some PL patterns are embedded by a very particular cultural standard background. A large amount of PL patterns have no practical application to the site scale of this specific study (4 to 12 hectares).
Towards a formulation of an urban model it is crucial a prior selection of patterns to apply to a specific context and the exclusion of patterns that are inefficient for that context. An ontology draft defines the first two groups of excluded patterns: scale exclusion, and standard cultural exclusion. A set of new patterns have to be introduced into the language to bring up the recursive data from the new knowledge domain, filling existing lacks.

Within the social knowledge domain, The City Joust (Guterres, 2004), comprises an innovative and overall study within urban planning. The social metrics are enclosed into the ‘experience of the city’, gauging urban social space relations, empathies and social behaviours. This work presents an exhausting study on the social space sizing consequences, implicit on both public and private areas as well as densities. As a conclusion, it describes specific impacts on the quality of the population’s quotidian life. The social urbanimetric indicators and variables provide contributes within a range of sources, namely analyses, critics, recommendations and studies, using data attributed to the variables, namely from: Maslow 1954, Jacobs 1961, Hall 1986, Newman 1972 and 1980, Hiliier 1984, Colleman 1990, and Sustainability Indicators.

Other crucial ‘neological’ patterns are enclosed in the bioclimatic urbanism domain of a pioneering study (Higueras, 2006), which assembles a set of relative studies, focused on data territory, climatic charts and urban environment conditions. The main outcome of this study is expressed into guideline design tools for green or open areas, buildings and volume orientation, etc., supported on energy and environment sustainability criteria. Other central study encompasses the grid generator pattern, conceived by Leslie Martin, critical for the basis of the planning design process.

This Ontological structure provides a pattern encoding structure towards a computational model within the capabilities of the spatial data modeling of GIS (GIS-O). The urban formulation model is conceived to increase qualitative inputs, reducing ambiguities, through a flexible while automate process applied to urban planning.
The critical aim of the study is to define such an ontology for urban patterns allowing their codification into a GIS platform for future use by a system that will formulate urban programs. Future work will be concerned with the definition of a description grammar that encodes the rules for manipulating urban patterns and defining urban programs.

Figure 2 - Ontological diagram based on the Urban Formulation Process

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On evaluation
A city modelled according to planning regulations usually presents a correlation between plots and building dimensions. To simulate the overall impact of building regulations over a large number of plots it is advantageous to use a computational tool to perform the task. Existing software can generate proxies of the would be reality, but do not accurately simulate the impact of alternative urban regulations. CityZoom is a Decision Support System for urban planning which not only provides CAD tools, but also allows users to evaluate and modify the city model according to different constraints such as solar radiation, luminance, terrain’s pervious conditions, etc. . By simulating specific urban regulations and addressing environmental comfort issues, CityZoom helps architects to simultaneously evaluate the different attributes of a particular design. Coupled with GIS tools, CityZoom allows users to perform multiple analyses over the existing database and use the resultant feedback to optimize proposed solutions. Future developments envisage giving CityZoom a more autonomous role, using artificial intelligence to optimize building shapes and dimensions.

Keywords: CityZoom, Urban Planning, Building Simulation
1. Introduction

Throughout the last two decades, cities and buildings have been represented in various ways with the support of computational tools. Sometimes aimed as a replacement for human skills, these tools have reached capabilities far beyond such skills. In fact, some computer programs are now able to shape buildings and cities in much faster and “realistic” ways than the human hand. These programs, mostly CAD, have been designed to enhance the user’s awareness of a particular reality and even to simulate the user presence in different environments (virtual reality). The focus has been adjusted as to furnish a progressively better image of the existent and the would-be realities. Visualization tools have somehow focused on bringing more realistic images, driven to show the visual attributes of urban form. At the same time other graphic computer programs (mostly GIS) have evolved in another direction. These were conceived to retrieve data from urban form, basically 2D data. The main goal of these programs was to offer a better understanding of the overall impact of the different attributes of built form, superimposing a grid in order to visually represent built form attributes. As buildings and cities are usually edited through lines, planes, points, volumes or other geometric features, computer programs have enabled a new combination, associating these features to performance models. Proceeding this way, these features could then be “read” as data which, in turn, are used to feed performance models for the analysis of different attributes of buildings and cities. Object oriented programming has achieved important results in linking the perceptual representation of buildings (what you can see with your eyes), in data form, with the production of information related to various aspects of buildings and cities. This has been the case of many computer programs related to performance models (radiance, luminance, ventilation among others). All these programs are based in the retrieval of particular attributes of built form, calculations and the numerical and graphical representation of the built form (either building or city) performance.

Representation has played a key role as an artifice to simulate future impact of designs in the development of professions such as architecture and urbanism. In the design of cities, the representation of “building types” has been used to anticipate the future configuration of urban spaces. In industrialized countries (North America, Europe and Scandinavia) this kind of representation sufficed for the actual need for the visualization of the impact of future developments. Performance models have been used to model and establish better correlations between the different attributes of chosen building types. In countries situated in South America, Asia and Africa this kind of representation has a very weak value as an anticipation for the future urban configuration. Plots and buildings cannot be pre-figured in their final shape, volume and even land use. In these countries, urban configuration and planning regulations evolve in a much faster way than in
industrialized countries. Countries with rapid growth have as a natural consequence more difficulty using planning tools similar to those used in countries where it is common sense to establish accurate proxies for the urban scene. A common feature in non-industrialized countries is the dissociation of the development of buildings and plots. The expansion of cities involves the implementation of plots and infrastructure sometimes far ahead from the construction of buildings. Planning regulations have worked, in these situations, as feeble tools to control urban form. In countries such as Brazil, planning regulations have been limited to the establishment of very general volumetric rules (building footprint, plot ratio and height limits) usually relating the building shape and size to its plot shape and size.

The correlation between plot and its built form is made through the plot ratio in that there exists a natural proportion between these two elements since large buildings require large plots and small buildings do not. Some regulations may well overemphasize this property and thus the volumetric result will be a byproduct of a non-three-dimensional variable, i.e. the plot size and shape. On the other hand, regulations may well emphasize the streetscape as its most important parameter. In this case, the plot's size and shape will not play a deterministic role. However, in any of these two cases there exists a strong probability that the plot's size and shape will vary, even if the block has had an initial homogeneous subdivision. That being the case, an enormous amount of work is necessary to simultaneously correlate these two variables for large quantities of plots and buildings in order to obtain a model or representation to assess the effect of planning rules. As the idealized occupation of urban blocks is unlikely to occur, the performance of buildings is more and more randomized as the block’s actual occupation occurs. Planning regulations in Brazil are based in frozen pre-figurations of a very dynamic urban configuration. This has led planners and city planning authorities to constantly modify rules as to “adapt” to the upcoming changes. Building shapes which were built according to the new regulations are usually not related to previous ones. This process ends up determining, very often, chaotic images of the urban space. Thus, in cities with rapid growth, such as those existing in Brazil, it is quite clear the need to formulate new ways to adapt and coordinate existent configurations to new ones since they have a strong interface. The impact of the interface between the existent configuration and new urban designs is not sufficiently simulated or analyzed. The environmental comfort of blocks, buildings and public spaces is constantly changed every time a building is added. Existing software has not so far developed any tool to simultaneously represent the effect of planning regulations and environmental comfort over large amounts of plots. This has led to the use of city models only for representing either existent or idealized form, i.e. such models do not take into account the precise correlation between building shapes, plot sizes and the evolving transformations of urban blocks.
The development of a model sensitive to incremental changes is obviously important for the planning of cities similar to those found in Brazil.

The generation of a virtual city model and the simulation of possible future developments is not only craved for, but definitely needed especially when considered that participatory planning in Latin America (and, very likely, in the majority of democratic societies) requires heuristic tools – what, if…- to enable laymen audiences to have a better grip of the rules which will govern the growth of their districts and cities. Although CAD and GIS technologies have given important contributions to the visualization of would-be scenarios, an important gap between the real world and the idealized world still remains. This gap has led to the development of CityZoom, software to be used both by laymen and planners as a visualization tool to level the discussion of themes such as privacy, solar radiation, luminance, environmental comfort, sky lines, view obstruction and other issues constantly raised in public enquiries. This paper describes the main features of this software and is organized in four parts. In the first part, a short review of the available existing tools to represent urban space is made. The second part details CityZoom and its performance models. The third part presents the current research and future envisaged developments. Finally, in part four conclusions are drawn and discussed.

2. Existing Tools

Computer Aided Design (CAD) is defined as the use of computers for creating and editing drawings. In 1982 Autodesk introduced AutoCAD ® (www.autodesk.com; May 2007) software, bringing CAD to the PC. It was initially file based and had the drawings organized in layers, with powerful tools for designing real-world objects and paying full attention to managing data without losing precision.

On the other hand, a Geographic Information System (GIS) is a computer software designed to efficiently capture, store, manipulate, analyze, display and link geographic information with descriptive information. Among the GIS tools one of the leaders is ArcGIS, from ESRI (www.esri.com; May 2007). ArcGIS is an integrated collection of GIS software products that allow you to author, analyze, map, manage, share, and publish geographic information.

Historically, CAD tools have been much closer to “drawing” tools than actual “design” tools as their name imply, since they are not “smart” enough to correlate different parameters and user needs during the process, and do not provide means to validate the results. GIS data is always more reliable when it has CAD precision. Therefore, it is only natural that there is an increasing demand for integrating CAD and GIS software.

ESRI has developed a solution to this integration problem: ArcGIS for AutoCAD is a free application that installs on top of AutoCAD 2007 and
provides access to the results of all of the GIS mapping and geoprocessing capabilities performed by ArcGIS in the form of map service images. This application accesses dynamic georeferenced ArcGIS Server map services and displays them in the AutoCAD drafting environment. The integration between CAD and GIS has also led to the correlation between plots and buildings but in a very shallow mode: buildings can vary their height from existing footprints but planning rules are not applied for each of the building floors.

Virtual reality (VR) solutions made representing cities easier, using 3D modelling based on the real or idealized cities. Cybercity (http://www.cybercity.tv: May 2007) developed the generation, distribution, analysis and visualization of reality-based virtual 3D city and facility models as well as of photo-realistic 3D landmarks, using photos and images of the city to build its 3D model.

A faster method, Virtualised Reality, was proposed by Avideh Zakhor from Berkeley (http://www-video.eecs.berkeley.edu/~frueh/3d/index.html: May 2007); this method involves the scanning of the urban landscape using lasers and digital cameras mounted on a truck or plane thus enabling the modeling of an existing city in a few hours.

It comes to attention that by using either CAD and GIS tools, or virtual reality based models, it is possible to obtain an accurate representation of reality. However, these are models based only on real data. There is no control on how changes in the data set would influence in the city. It is possible to explore and analyze existing scenarios, but the tools do not offer support to help the understanding of the city and what it would become if the urban plans were changed.

To conclude, all the described tools are not active models in that they do not constitute an interactive model for what the city could be. In other words, these tools provide static models which allow planners and laymen to have a frozen picture of what a city could possibly become but without an assessment tool which could shed light on how it could be made better.

3. CityZoom

CityZoom (www.cityzoom.net: May 2007) originated from a challenge raised by Porto Alegre’s (Brazil) Mayor, Tarso Genro, who, in 1994, wanted to implement a bonus policy allowing the exchange of plot ratios between urban plots. In order to assess how much could be transferred, and how beneficial those transfers would actually be, an issue needed to be answered, i.e. how much one could build in a particular urban plot.

To answer this question, the City Hall has asked UFRGS (Federal University of Rio Grande do Sul) through different laboratories led by SimmLab (Laboratory for the Simulation and Modeling in Architecture and Urbanism) to elaborate a study (Turkienicz, 1994) to show the possible impact of the existing and alternative Master Plan Rules over five different
neighborhoods of Porto Alegre as to provide guidelines for the city’s development. The building volumes for this report were manually edited, in a time-consuming and labor-intensive process.

This experience led SimmLab to create its own software, capable of automatically generating buildings according to planning regulations. In 1996, CityZoom’s research project was incubated at UFRGS’ Institute of Informatics. During over ten years of development, many tools were developed to solve problems raised by several different cities in Brazil and abroad and by research partners in different Universities all over the world. All of CityZoom’s modules, functions and libraries were created from scratch by the SimmLab staff. The specification and modeling was done using MagicDraw UML, and several different programming languages were used for the implementation. The interface and performance calculation modules were implemented using Borland Delphi, the 3D visualization was done with Visual C++, and the authentication system (outside of the scope of this paper) was implemented in Java.

At its current development stage, CityZoom is a full Decision Support System for urban planning. It provides a computational environment where different building performance models can operate interactively, aiming to optimize the urban planning process. Each performance model corresponds to an active module in the computational environment.

Starting from a specific built-in object-oriented city model (Figure 1), representing the urban structure (city, blocks, roads, plots, buildings, etc.), information can be retrieved at any required level. Within CityZoom’s environment, each performance model operates within its correspondent part of the computational structure hence affecting all the related objects and models.

CityZoom’s main tool is a graphical editor of urban features (Figure 2). Data can be fed in different ways, such as: freehand drawing, using a background layer such as an aerial picture as reference, importing neutral file types (AutoCAD DXF, ArcView SHP, etc.), or by a direct connection to a spatial database. Once fed, data can then be used by CityZoom’s models, which are described in the following sections.
3.1. BlockMagic

BlockMagic (Turkienicz, 1999) is CityZoom’s model for simulating given urban regulations applied to a set of urban plots. It can swiftly generate large sets of buildings in the most different urban scenarios, or validate designed or already built buildings. The regulations can be inserted and edited with the Urban Regulations Editor (Figure 3), allowing the user to set the Master Plan parameters, such as maximum number of floors, maximum commercial and residential plot ratios, maximum slab area projection and minimum setbacks. Buildings are generated according to the regulations and using the user-input parameters which determine which of the building attributes are to be assessed or optimized, such as number of floors, front or size width, slab area, plot occupation and plot ratio.

BlockMagic also addresses environmental comfort issues, through the use of the Solar Envelope technique (Grazziotin, 2002). The Solar Envelope is a construct of space and time: the physical boundaries of surrounding properties and the period of their assured access to sunshine (Pereira,
The way these measures are set determines the envelope’s final size and shape. Planning for insolation is essential in establishing the visual and thermal comfort, i.e., the benefits to be obtained from the sun in and around the buildings. The introduction of such parameters in the design process can substantially affect the land use, building density and urban land value. Using the Urban Regulations Editor, the user can set the obstruction angles for every possible plot orientation. These angles are then applied to the plot’s edges, generating a set of geometric boundaries. Buildings restrained within this volume will not project undesirable shadows over the neighboring buildings during critical periods of the year.

Any change in the Urban Regulations can impact the final shape of the simulated buildings. Hence, there is a preview window in the Urban Regulations Editor that allows the user to see the effects of the changes to the rules associated to a given plot in real time. Thus, the users can have both an idea of the final result due to the application of that rule or they can change the shape of the buildings (acquiring the correspondent rule) to obtain the desired result.

### 3.2. Visualization of Results

Results from the simulations can be visualized both in quantitative and qualitative ways, i.e., CityZoom can summarize numerical data generated by the performance models in tables and graphs as easily as it can show 3D graphical previews of the city (Figure 4). These allow the user to observe the desired results and navigate through hypothetical scenarios.
Numerical data can be retrieved from the geometric objects in the city (for instance, the area of a block) or simply inferred as, for instance, the population inhabiting a building. Data can be extracted for the whole city, or its specific regions, and subsequently visualized with the Numerical Results Viewer module. Land area, built area, plot ratio, average building height, and other important attributes can be clearly displayed.

CityZoom’s 3D visualization tool, implemented using the OpenGL library, makes it possible to interactively navigate through the three-dimensional scenario which represents the city being modeled, with the blocks, plots, buildings and reconstruction of the 3D terrain. It also supports the generation of realistic shadows in real time, based on the city location, date, and time input by the user, and the display of the Solar Envelope superposed to the existing or simulated city objects. This allows the assessment of relations between buildings such as the overall impact of a building shadow over its neighborhood.

3.3. “Linking CAD to GIS”

CityZoom goes beyond simulation and visualization through its analytical tool, Mosaic. Mosaic (Scheidegger, 2002; Figure 5) is a model correlation...
tool, which allows visual access to the information generated by the performance models. By applying a regular orthogonal grid over the simulated area and dividing it in cells of the same size, attributes such as building footprints or building heights can be represented by assigning to each of these cells a numeric value. The grid will then work as a spatial representation, where each cell holds a value corresponding to the relative intensity of the attribute. In order to determine patterns or clusters of attribute’s density, a color scale is used in each grid.

The information can be retrieved at any required scale (blocks, plots or buildings) or modularly be aggregated or disaggregated in different and progressive steps. This allows a modular grid to be disaggregated into a 10x10 meter grid (the actual size of a small building projection) and to be aggregated up to a 200x200 meter grid (the size of a group of blocks).

From an original grid (primitive map) it is possible to derive new ones, using map algebra (such as sum, multiplication, etc) and image-processing filters, similarly to map operations performed by raster GIS. Mosaic's

▲ Figure 5. Mosaic window.
potential to analyze and correlate different aspects of the city allows the unveiling of underlying structures and patterns which are normally blurred by complex sets of data.

Acknowledging the increasing demand for integrated CAD and GIS, SimmLab has recently collaborated with regional Idrisi Developer, LabGeo, in order to implement CityZoom’s interface with shape files (.SHP), ESRI’s geospatial vector data format. The achieved interface allows now both the importing and exporting of neutral GIS files to and from CityZoom. With the interface, CityZoom can feed data to commercial GIS software, such as ArcMap (Figure 6), enabling a whole new set of analyses to be done over CityZoom generated data. Similarly, GIS files can be edited in CityzZoom, providing a very intuitive and longed user interface, not available in most GIS packages.

3.4 Interface with Other Software

CityZoom can also export data for different types of analyses using free tools and educational software packages, opening the path for a new branch of data analyses and editing. Interesting results have been obtained through the interface with Google Earth, Sketch Up or Apolux (Claro, 2005).

![Figure 6. Visualization of CityZoom data using ArcMap](image)
The visualization of results using Google Earth (Figure 7) allows users to visualize the simulation of a given plan rule as well as to see how the city actually is situated over the existing topography. Using Sketch Up as a final result-editing tool it is possible, for example, to insert 3D objects such as trees, benches, lamps, cars, etc into the simulated city. This results in a model that is very close to reality, thus making it even more intuitive in presentations for laymen.

The interface with Apolux allows the consideration of different daylighting parameters, based on the radiosity method. Apolux can calculate and generate graphics of form factors and illuminance levels. It can also generate luminance distributions of different points of the sky (Figure 8), solar obstruction masks, both inside and outside buildings, as well as semi-realistic images.

4. Ongoing and Future Research

Current Cityzoom development is threefold: Computational Fluids Dynamics (CFD) is being used to develop a new performance model, Shape Grammars are being studied as a way to implement generative design, and Artificial Intelligence techniques are being investigated as a way to simulate the built form evolution.
4.1 Computational Fluids Dynamics modeling

In the Computational Fluids Dynamics laboratory of the University of Nottingham (Nottingham, UK), CFD techniques are being investigated to model wind flows, dispersion of pollutants and heat transfer in urban environments. At present there is no urban planning software that incorporates such physics, although it is required to assess the wind effects (speed, direction) inside and around buildings in particular on the pedestrians. These calculations are also important for pollution dispersion and the effect of wind over snow and rain.

There are several physical models and codes available for CFD calculations; however standard techniques may prove too heavy for the modelling of complex and large urban areas, which will require faster analysis. There are several important input parameters to be considered, such as the ambient wind direction, and speed; the urban geometry, street canyon aspect ratios, sequences of canyons, and effects of street intersections on the flow; the thermal effects caused by solar heating on building walls and street canyon bottoms; the traffic-induced turbulence effects; and the background concentration, and emissions of pollutants. There are also different modelling options for turbulence (Direct Numerical Simulation, Reynolds-averaged Navier-Stokes equations, Detached Eddy Simulation, Large Eddy Simulation), and transport (Eulerian, Lagrangian, Hybrid). Suitable, simplified techniques will therefore need to be investigated and tested, in order to achieve simulation times akin to the CityZoom philosophy.

The current approach being developed involves the creation of an extensive database of normalized flow fields for each possible set of input parameters (individual buildings, canyons, or intersections, coupled with the different wind, heating, etc. conditions) using an existing and validated CFD
package, such as CFX or FLUENT. Since the creation of this database is
done beforehand, complex turbulence models can be used, obtaining more
accurate results, without causing increased simulation times for the end
user. The database can then be used as a starting point for each particular
simulation, searching it for equivalent cases or interpolating two or more
similar ones. The retrieved flow fields will feed the implemented urban scale
CFD model and its own simplified turbulence, and transport models.

The proposed model will need to be validated. First of all simple building
set ups and forms (found in the literature) will be analysed. To validate the
wind behaviour simulations further, it is proposed that wind measurements
will be taken in different locations of a city (Porto Alegre, Brazil), using
sensors on top of buildings, although this is usually very difficult to achieve
as it requires equipment and, more importantly, authorisations from the
owners. Should this second validation be impractical, the team will try to
request wind, and pollutant concentration data obtained from experiments
conducted by colleagues at other Universities, such as the Ecole Centrale
de Lyon in France, or the University of Leeds in the UK, as possible
substitutes. These data will be used to build a wind behaviour database,
which can be compared to the simulation results.

The CFD model will be the third performance model in the CityZoom
framework. Along with the above-mentioned urban regulation, and sunlight
simulation models, this model will improve the software capability to
generate buildings based not only on master plan rules but also on physical
parameters.

4.2 Shape Grammar modeling

Simultaneously, at the SimmLab, Federal University of Rio Grande do Sul
(Porto Alegre, Brazil), a Shape Grammar model is being developed aiming at
the definition of shape rules and a generation engine which could possibly
interact with the performance models already developed. Shape rules define
how an existing shape (or part of) can be transformed. The generation
engine selects and processes rules. A shape grammar minimally consists of
three shape rules: a start rule, necessary to start the shape generation
process; at least one transformation rule; and a termination rule, necessary
to make the shape generation process stop.

Parametric shape grammars are an advanced form of shape grammars.
The new shape is defined by parameters so that it can take into account
more of the context of the already existing shapes. This typically affects
internal proportions of the new shape so that a greater variety of forms can
be created. The idea behind the use of shape grammars in the CityZoom
model is to enable the automatic generation of buildings or families of
building types according to desired or particular architectural languages. This
approach turns out to be much more flexible than the existing one in that it
widens up the field for the creation of a multiplicity of building shapes.
According to the new approach, the prismatic output, which is today featured by CityZoom, will give place to a set of possible shapes, which could be, in turn, submitted to the different performance models.

4.3 Artificial Intelligence

Once further development is achieved on these models, the next step is to study Artificial Intelligence techniques for the simulation of built form evolution. The main focus will be on intelligent agents, autonomous systems that can perceive their environment and take actions to maximize their performance. Agents must be capable of showing flexible behaviour in order to solve individual problems – they must therefore be reactive (capable to answer the changes that occurs in the environment) and even proactive (capable to act anticipating the future objectives).

Modelling an urban environment will require or involve multiple agents, in order to represent the decentralized nature of the problem, and handle multiple or conflicting interests. These agents will need to interact with one another, either to reach individual objectives or to negotiate the dependences caused by being in the same environment. These interactions rely on simple exchanges of information so that certain actions are carried out that lead to cooperation, coordination and negotiation and, ultimately, interdependent activities.

Each building will be considered as an intelligent agent, capable of simulating its own growth (change its own form and attributes) based on a set of rules and conditioning factors. The main evolution rules are the Building Regulations or Shape Grammars. The conditioning factors are sunlight access parameters, the wind effects, and the dispersion of pollutants over and around the buildings and streets. Buildings must be capable of “noticing” their neighbourhood and react to changes around themselves, for instance, avoiding or using the shadows generated by a new neighbour building.

Ultimately, the intelligent agents will be responsible for binding together all the performance models, resulting in a full generative performance-based design system. Using CityZoom, it will be possible to evaluate and better urban environments based on both legal and physical parameters, as well as automatically generate ideal designs (whole cities or just localized solutions) using the same parameters.

5. Conclusions

Beyond described applications, CityZoom and its modules constitute a powerful tool for the evaluation of the impact of urban regulations, showing clear advantages over existing GIS and CAD software. CityZoom is currently helping planners to adjust urban regulations to performance targets so as to anticipate the impact different urban regulations might have on desired environmental goals.
CityZoom is a powerful visualization tool when used in participatory planning processes. Its output allows for an easy understanding of the likely effects of norms and numbers by people whom otherwise would have severe difficulties in understanding complex numerical data. CityZoom has been used in Brazil and abroad in different ways: in technical sessions with planning officers, in decision sessions about planning regulations at municipal councils and in urban design exercises at Architecture and Urban Planning graduate and undergraduate courses.

Acknowledgements

This research has been supported by FAPERGS, CNPq, and Alban.

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http://www.cityzoom.net
City Induction Evaluation Module
Integrating spatial analysis techniques in the parametric urban design process

Jorge Gil, Space Syntax, UK

The “City Induction” research project aims to develop an urban design framework at the scale of site planning consisting of three modules: formulation, generation and evaluation. The evaluation module will be driven by sustainable urban development principles, which determine the design analysis criteria and benchmarks, and it will be structured around selected urban spatial analysis, of which space syntax is the main reference (Hillier and Hanson 1984), and parametric design methodologies. We discuss the challenges of bringing these two domains together, setting criteria for the implementation of the evaluation module as an interactive design support tool.

When we consider a sustainable urban development approach, rather than a purely investment-oriented one, the stress is on establishing a dialogue among the stakeholders to keep the process as transparent as possible, and with mechanisms to ensure that a strategic development vision is defined, an adequate urban programme is laid out, and a matching outcome is then reached that can be both quantitatively and qualitatively evaluated (The Prince’s Foundation 2007). The “City Induction” project proposes an urban design framework that attempts to span between the two goal posts: development vision and successful design outcome. The formulation module defines an ontology of urban patterns that is shared by all modules to ensure a consistent and iterative evaluation during the design process. It produces a site specific program setting the performance criteria and target values to be used by the evaluation module. The user then uses the generation module to produce alternative design solutions. The evaluation module provides constant feedback to ensure that the solution being generated matches the program.

The urban design process is a complex endeavour that poses specific challenges to the designer due to the levels of information that need to be assimilated, the necessary involvement of various stakeholders with different perspectives and often conflicting interests, and the time it takes to develop and implement an urban plan. As such, there is a growing interest among urban planners and architects, and a demand or expectation, from other stakeholders, to incorporate analytical data in the design process in an attempt to guarantee the quality of the outcome at different levels, namely: environmental, structural, infra-structural, visual, social, economic or cultural. It has been shown that such an evidence-based design approach, where an urban designer works closely with a wide range of experts to support his design decisions, can generate more sustainable solutions. But simultaneously, it becomes apparent that the analytical process must intervene earlier in the urban design process and be more tightly integrated in the creative loop.

The proposed computational framework consists of the following ingredients:

- Design programme - requirements, values, urban patterns, subjects
- Design solutions - form, space, relations, objects
- Data and design analysis – properties, profiles, impacts, phenomena
The evaluation module will be looking at spatial analytical methodologies that cover socio-economic (Chiaradia et al. 2008), environmental (Nikolopoulou 2004, Morello and Ratti 2007), and mobility (Chiaradia et al. 2005, 2007, Hillier and Iida 2005, Raford et al. 2005) aspects of urban plans. Special focus will be given to urban layout and public space because these are the first elements to be determined and the most difficult to adapt a posteriori, having great influence on the future development of the city (Hillier 1996).

The main aim of the evaluation framework is to integrate the selected analysis methodologies with simplified models into design tools that are suitable for working with urban design methodologies. Some of the difficulties that need to be addressed:

- **A common language** - a unified urban planning ontology suitable for both analysis and design, which will facilitate the sharing of knowledge between models and tools.
- **CAD Tools ≠ Urban Design tools** - there are many tools for architectural design and drafting, some for parametric design, but none to support parametric urban design processes. The components, parameters, and scale of urban design are very different, in particular, the intangible nature of public space and urban layout must be explicitly incorporated into urban design tools.
- **Analysis Tools ≠ Urban Design tools** - GIS platforms can perform display and analysis of large scale urban developments and be essential aids to the management of the data required for the urban design process. However, GIS tools designed specifically for urban analysis (Gil 2007) are not simple or flexible enough to integrate directly into the design process.
- **Design Models ≠ Analytical models** - Design models can be complex with detailed geometry, rich descriptive representation conventions, and based on generic geometric elements that are independent and non-hierarchical. Analytical models are usually simple in terms of geometry, abstract in what they represent, with a set of domain specific elements and sticking to very specific formats. This framework needs to specify a new set of components and parameters specific to urban design and accommodate the large number of components required for urban simulation. (Wu 2002)

**Analysis ≠ Evaluation** - analytical results are simply numbers that only acquire a value when placed within the whole evaluation framework together with a solution and a program. The same analytical results can have positive or negative interpretations depending on their context. Evaluation requires an interpretation of the analytical results as it tests them against regulations, development targets, and quality and sustainability benchmarks.

The evaluation system should be equipped with a graphical user interface to provide dynamic visualisations of complex urban phenomena to sustain meaningful stimulation of the creative process. How does evaluation provide feedback? How does the designer intervene in the process and respond to this feedback? Design is traditionally a top down process, controlled from a single source and based on individual authorship. To accommodate the complexities of urban design and achieve more sustainable solutions, we need to allow external influences to emerge in a bottom up fashion into the design process. But the designer still needs to play a central role and be able to accommodate these external forces through an intellectual understanding of the subject matter and direct manipulation of the object matter, towards indirect generation of successful and sustainable urban environments.

**References:**
urban layout (i-VALUL): Developing a tool kit for the socio-economic valuation of urban areas, for designers and decision makers”, in Timmermans, H. and de Vries, B. (eds.) 9th International Conference on Design & Decision Support Systems in Architecture and Urban Planning, Eindhoven University of Technology


Hillier, B. and Hanson, J. (1984), The Social Logic of Space, Cambridge University Press.

Hillier, B. (1996), Space is the machine - a configurational theory of architecture, Cambridge University Press, UK.


Workshop 1: Schedule

Generative Urban Design
Saturday 21 June 2008, 9:00 - 12:30

9:00: Introductory note

Chairs

9:10: Session 1: Strict grammar-oriented approach

Moderator: José Duarte, Technical University of Lisbon, Portugal

Generating Networks (15 + 5 min)
Jeffrey V. Nickerson, Stevens Institute of Technology

Design support systems for sustainable development in the Thames Gateway area of London: “Smart Solutions for Spatial Planning (SSSP)" (15 + 5 min)
Christian Derix, Pablo Miranda & Asmund Gamlesaeter, AEDAS architects, Computational Design Research, Paul Coates, CECA (Centre for Evolutionary Computing in Architecture), University of East London

A designer-centered shape grammar editor and interpreter (15 + 5 min)
Andrew I-kang LI, CHEN Liang, and WANG Yang, Department of Architecture, The Chinese University of Hong Kong, China

Cities as diachronic models: The spatial logic of growth and its role as a generative design component (15 + 5 min)
Kinda Al_Sayed University College London, UK

10:30 Coffee Break

10:45 Session 2: Other approaches

Moderator: Rudi Stouffs, Faculty of Architecture, TU Delft

CityZoom: A Visualization Tool for the Assessment of Planning Regulations (15 + 5 min)
Benamy Turkienicz, Bárbara Bellaver Gonçalves, Pablo Grazziotin

City Induction project:
City Induction Formulation Module - Towards a Computational Description of Urban Patterns
Nuno C. Montenegro, José P. Duarte

City Induction Evaluation Module - Integrating spatial analysis techniques in the parametric urban design process
Jorge Gil, Space Syntax, UK

(15 + 5 min)

Structuring a generative model for urban design: linking GIS to shape grammars (15 + 5 min)
José Beirão, Faculty of Architecture, TU Delft / Faculty of Architecture, TU Lisbon, José Duarte, Faculty of Architecture, TU Lisbon, Rudi Stouffs, Faculty of Architecture, TU Delft

12:00 Final Discussion (25 min)

12:30 Closure

Note: Each presentation slot includes paper presentation and software demo (15 min), and discussion (5 min). Presenters without software demos will have their presentations shortened to 8 min.