

# CloudNets

## *A Workbench for Emergent Urbanism and Architectural Form*

*Tim Schork<sup>1</sup>, Andrew Burrow<sup>2</sup>, Paul Minifie<sup>3</sup>*

*<sup>1,2</sup>Spatial Information Architecture Laboratory, RMIT University, Australia,*

*<sup>3</sup>School of Architecture and Design, RMIT University, Australia*

*<sup>1</sup><http://www.sial.rmit.edu.au/People/tschork.php>,*

*<sup>2</sup><http://www.sial.rmit.edu.au/People/aburrow.php>,*

*<sup>3</sup><http://www.architecture.rmit.edu.au/People/PaulMinifie.php>*

*[tim.schork@rmit.edu.au](mailto:tim.schork@rmit.edu.au), [andrew.burrow@rmit.edu.au](mailto:andrew.burrow@rmit.edu.au), [paul.minifie@rmit.edu.au](mailto:paul.minifie@rmit.edu.au)*

**Abstract:** *This paper reports on the development of the computational tool CloudNets that allows for the modelling and investigation of emergent relational phenomena and provides two worked examples of how the tool was used by architecture students within the context of a computational design seminar taught by the authors at RMIT University.*

**Keywords:** *Design tool development; scripting; urbanism; graph-ca; emergence.*

### Introduction

#### **The formation of clouds and cities**

It is commonplace to talk about the city as a single entity. However, a city is the expression of a complex and dynamic network of constituent parts. The qualities sustained by a city are possible only by virtue of the relationships between parts. These relationships may be effective at a small scale - what is next door – or at a much larger scale – the entire city. Depending on the particular type of program, a specific logic applies. Yet, a city has no author in the sense that other artefacts express the intent of their designer. In this way a city resembles a cloud. It is a spatial manifestation of the dynamic interrelationships across its network of constituent entities and external conditions. This moves the meaning of the city from the individual to the collective.

Let us illustrate this with a modest example, namely the difference in spatial distribution between motorcycle shops and convenience stores.

Motorcycle shops are often clustered. Convenience stores, in contrast, are typically more uniformly distributed. These different spatial arrangements can be explained by considering search cost: shopping for a motorcycle typically involves prior comparison of products and prices, but shopping for a litre of milk does not. So a motorcycle shop does more business if it is adjacent to another, while a convenience store captures the greatest catchment when positioned away from competition. This illustrates how simple rules can describe how programs develop, and thus how complex spatial and organisational orders, such as urban strips and clusters, are derived. Examples like this provide an insight into the organisational logic and ordering principles that underlie our built environment.

While program has been closely examined, there are other attributes such as building type, height and material that promise to reveal similar logics. In this case, what we perceive as “city” is a particular configuration of a large collection of interdependent

entities that are in constant dialogue with each other and their environment. Thus our cities and buildings reveal themselves as an ecosystem that is comprised of a collection of interdependent sub-systems that constantly effect and affect each other. This means firstly that the overall form of a city is neither explicitly prescribed nor fixed, but arises out of the interactions between its constituent parts and its particular context, and secondly that cities evolve over time through constant reconfiguration. In summary, cities are bottom-up phenomena driven by interdependencies from which spatial and organisational patterns and qualities emerge at a multitude of scales.

We believe that the qualities of urban and architectural design emerge through their complex relationships with other objects and material and immaterial systems. Due to the intrinsic complexity of these interdependencies, we can neither predict their behaviour nor anticipate their outcomes without engaging in simulating the processes of these self-organisational systems through computation (Rocker, 2006).

This approach is characterised by an emphasis on formative processes that relate design configurations to the evolution of their performance. Sanford Kwinter describes this conceptual engagement through the difference between form and object, where form is the “ordering action, a logic deployed”, whereas the object is a “manifest variation” or “expression” of this logic (Kwinter, 1994). In this view, form and behaviour emerge from the underlying processes of complex systems.

Kwinter and others (Alexander, 1966; Allen, 1999; Jencks, 1995) contextualise this approach within Complexity Science and the shift from product to process. Namely, they describe the move from singular models of design towards an engagement with the underlying forces of the dynamic and interdependent processes of systems. However, while their analysis offers a powerful way of thinking about design on a conceptual level, it does not provide the required design tools that address architectural designers’ needs for compositional techniques that

allow them to harness and employ these formative processes for the production of architectural space and form.

This paper reports our experience in translating these abstract self-organizing systems of the city into feasible design strategies and propositions. We aim to contribute to this ongoing discourse by providing a computational design workbench that allows architectural and urban designers to set up, capture and explore the above mentioned formative processes across a multitude of scales. In the following section we report on some of the design outcomes rendered possible by our developed workbench that exploits the framework of Graph-cellular automata in a designerly way.

## Modes of representation

We have previously outlined that cities are complex systems that consist of “many basic but interacting units” (Coveney and Highfield, 1995) and are “systems in process that constantly evolve and unfold over time” (Arthur, 1999). Architects and urban designers have long had troubles finding appropriate compositional techniques that allow them to model and simulate the complex interrelationships between entities that exist and those that create the complexity and diversity of our cities and those that incorporate change over time.

### Cellular Automata and the Game of Life

First envisaged by Alan Turing and further developed by the Hungarian-American mathematician John von Neumann in the 1940s, cellular automata (CA) provide an explanatory principle for simulating the dynamics and behaviour of self-organizing systems and allow for the modelling of mutual dependencies between the constituent parts of such a system. Through his research into the underlying rules of evolution and self-replicating systems, von Neumann developed a hypothetical machine, called the *Universal Copier and Constructor*, which proved that a system with life-like behaviour can be

created through a set of simple local instructions or algorithmic procedures. CA are decentralized, rule-based systems that are defined by a series of simple low-level rules that describe local interactions and allow for complex higher level patterns to emerge over time. This means that the global order of a system emerges as a consequence of local, decentralized rules that embody local processes. In their most common form CA comprise a collection of entities (cells) that are arranged on a regular two or three dimensional grid. The state of each entity (cell) responds to the state of all its adjacent entities, its neighbourhood. CA evolve over time and despite their simple make-up allow for unanticipated results to emerge.

An intriguing visual example of how basic rules can generate complex life-like behaviour can be found in the *Game of Life* developed by John Conway in 1970. Conway's work builds upon the foundations of von Neumann's research of the universal constructor and self-replicating systems.

In the early 1980s, the mathematician Stephen Wolfram began to explore the unpredictable and non-linear behaviour of self-organization systems over time through a series of computer experiments, based on CA (Wolfram, 1994, 2002).

Batty has demonstrated in a similar scientific way the flexibility and applicability of generalizing CA to describe the evolution of existing urban settlements (Batty, 1997, 2005).

### **Topological representation: Graphs**

Another way of describing overall relationships of connectedness in a collection of entities is through a graph. At a basic level a graph consists of a collection of nodes and lines (edges) that represent the connectedness of the overall system. While there are other types of graphs, such as non-planar, weighted and directed graphs, the simplest type of graph is a planar graph, which means that the graph is on a plane and none of its edges are crossing, which is similar to the regular grid that traditional CA are based on. A simple example of this type of graph is a

city without any bridges or tunnels. So from a graph point of view, a city is neither a planar graph nor a tree (Alexander, 1966).

A promising new model that enables the development of novel organisational types is described by graph-cellular automata (Graph-CA), where a graph replaces the underlying restrictive organisational structure of the regular grid of CA. While the technical feasibility of this approach has been established by O'Sullivan (O'Sullivan, 2001), there have so far been few attempts within architectural and urban design discourse to explore and test this approach as a compositional technique for design.

### **The workbench**

With this imbalance in mind, we developed CloudNets, a computational design workbench that implements the concept of Graph-CA as a plug-in into the widely used 3D modelling software Rhino™. The workbench provides a design environment for the development, exploration and real-time simulation of the behaviour of complex organisational systems under various conditions and promotes the development of more broadly applicable design propositions derived from a profound understanding of the inherent behaviour of entire systems. Simple scripts developed within Rhino™ give access to the working methods of the plug-in. CloudNets is a means of making a variety of graphs, and a mechanism for deriving emergent properties based on those relationships.

### **Research through design**

The following design projects are worked examples of how the CloudNets plug-in was successfully employed as generative engine in a range of different design scenarios by architecture students within the context of a computational design seminar, taught by the authors at RMIT University. The seminar introduced students to various computational

models and scripting techniques and explored how these effect and are affected by our spatial thinking. Both projects exemplify the proposition that a building is sensibly understood as self-similar to its city, namely enjoying the same logic and attributes of its constituent organisational structure.

### Example 01: Sitegraph

This project investigates the way Graph-CA can be used to generate an organization of program and explores if a Graph-CA based system can generate unexpected spatial and formal organizations through a deterministic process, which is described by a simple set of rules.

The first part of this investigation tests this in the design of an individual nine storey building. The

building volume is broken up into smaller individual volumes (cells) and is represented by a weighted non-planar graph. Each of the 225 spaces within the graph can be filled with either one of the three types of program, residential apartments (green), commercial office spaces (red) and retail shop spaces (gray), or becomes articulated as empty space. At the beginning of the process the entire network is randomly seeded with programs. Throughout the simulation process the type of program for each cell within the building is decided through a set of weighted rules considering the attributes of its neighbours, their orientation and a series of influencing principles and preferences, as well as rules designed to ensure the model stays within the predefined program space quotas. For example

Figure 1  
Varying spatial configurations  
based on weighted rule-set

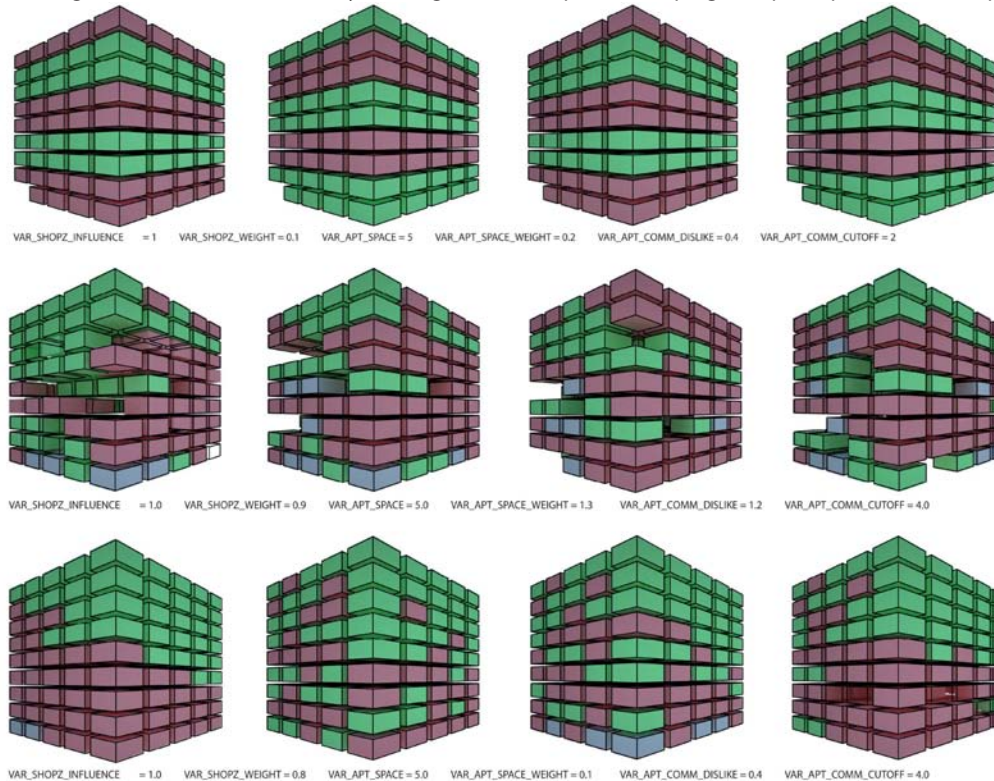
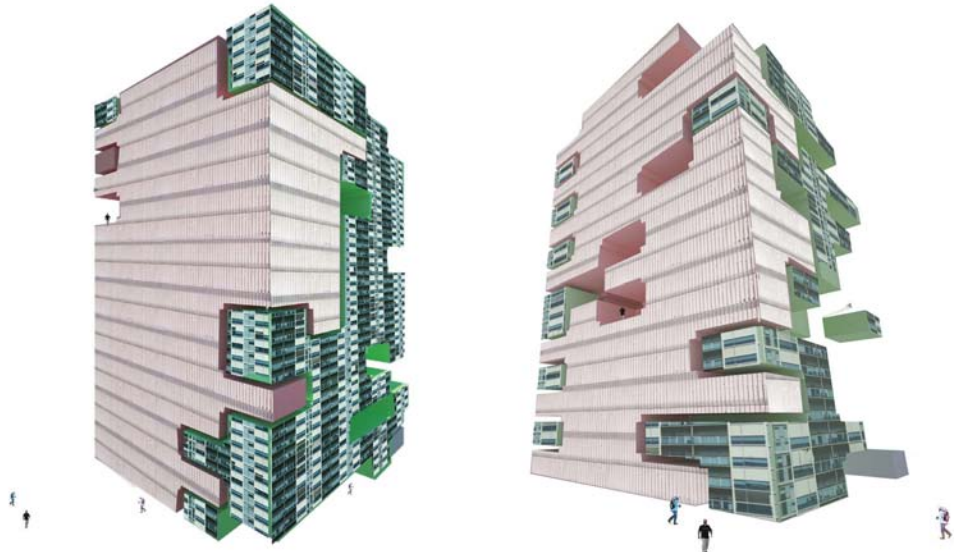


Figure 2  
Architectural interpretations  
of two different equilibrium  
states of the generative system



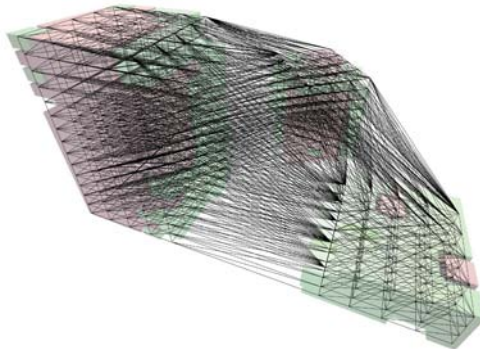
apartments should be orientated to the north and have cross ventilation, while shops prefer to exist at street level and at the periphery of the building in order to have the greatest exposure to pedestrians.

This set of basic rules produces unexpected effects and complexity. Types of spaces cluster together and move apart. In all experiments, a pattern or order becomes identifiable during the iterations, but unexpected results also become apparent. As shown in Figure 1, some of the iterations stabilize and begin to flip between opposite states,

while others form visible ribbons and layers, groups and clusters. The resulting spatial arrangement is differentiated, but embodies coherent order (Figure 2).

The second part of this investigation successfully applies the same process and underlying rule-set to a larger scenario, the design of a small district made up of three individual buildings. The entire site is represented by a single graph, comprising all three buildings and their relationships between each other, creating one interconnected system (Figure 3) that produces unanticipated spatial qualities.

Figure 3  
3-Dimensional graph depicting  
relationships between  
buildings on site



### Example 02: Hito-ga-Hito-Yobu

This project employed the CloudNets workbench in the development of a design strategy for growth and decay around the central area of Shibuya in Tokyo. The investigation first focused on the clustering of people and program in the central area around Shibuya station. The aim was to extract an associative rule-set of local phenomena encompassing urban density, spatial and social diversity and proximity, as well as local property laws and property values. In a second stage, this rule-set was re-coded, based

on architectural intentions, and applied across a graph, representing the entire urban fabric. This set a process in action that allowed for an informed assessment of the resulting transformations in urban development and overall character of the city.

## Conclusion

This paper illustrates through a series of designed projects how the concept of Graph-CA does not only provide a framework for the underlying organisational logic of complex systems, but at the same time

also provides the means and methods to design a multitude of complex organisational systems. The developed computational tool CloudNets provides a design workbench that allows for a designerly engagement with this concept across a multitude of scales. The outlined projects further exemplify how this approach has general application beyond cities and how it can be successfully employed in the development of design strategies across a multitude of scales that not only produce novel spatial configurations, but more importantly develop new architectural and urban design sensibilities.

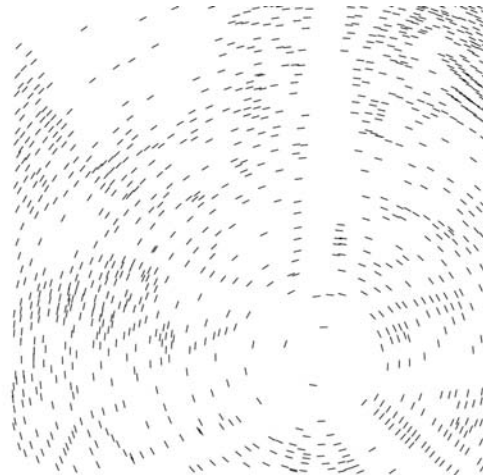
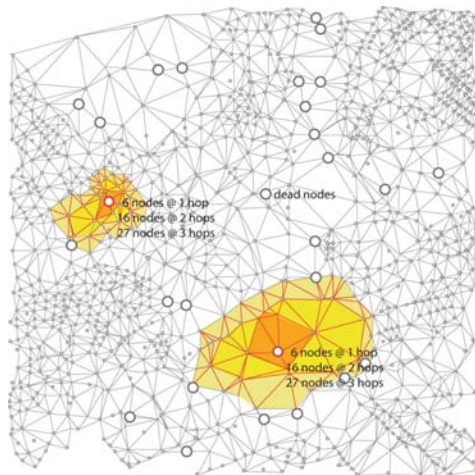


Figure 4  
Graph of nodal connections  
around train stations (left)  
and field of influence (right)

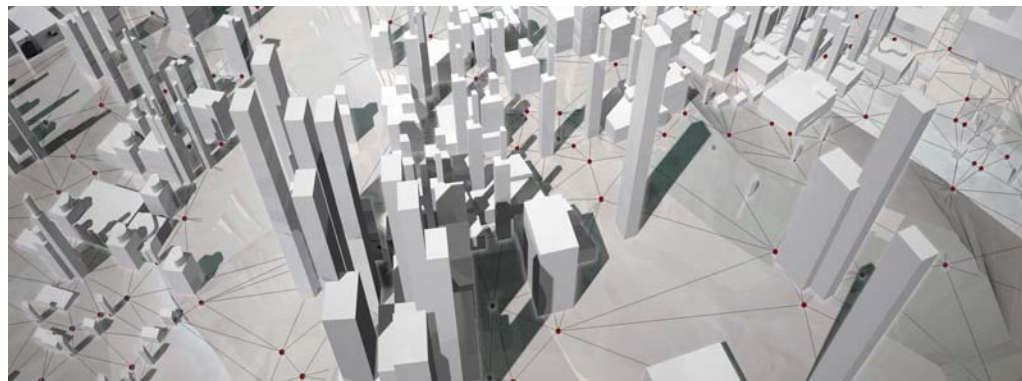


Figure 5  
Birdseye view of a generated  
city with generative graph  
underneath

## Project credits

Sitegraph – W. James Goscinski  
Hito-ga-Hito-Yobu – Peter Charles and Jessica In

## Project links

[www.architecture.rmit.edu.au/Projects/cloudnets.php](http://www.architecture.rmit.edu.au/Projects/cloudnets.php)  
[www.sial.rmit.edu.au/Projects/Cloudnets\\_II.php](http://www.sial.rmit.edu.au/Projects/Cloudnets_II.php)

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