Growing a City: Individuals, Interactions, and Emergent Behaviour

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Abstract

Individuals and interactions between individuals are key to the evolvement of complex systems. This work harvests the power of individuals and interactions to create a responsive environment, which emulates the growth of Tainan City. Through the study of urban patterns (armatures, enclaves and heterotopias) and their evolutions, a set of individuals and interactions are formulated to represent elements of a city as well as compositional rules for urban patterns. These individuals and interactions are designed into a cellular automation machine to explore their emergent behaviours. The resulting system is a virtual world where a city evolves with the growth and decay of city blocks. This virtual world is presented in a physical space where a video is installed to monitor the changes in this space. Significant changes in the physical space are interpreted as external forces (natural or political events) that trigger massive changes in the virtual world. This system is used by the second- and third-year architectural students to study the growth of cities (the emergent behaviours) by tweaking the individuals (building blocks of the city) and the interactions (generative rules).

1. Introduction

The nature, ant colonies, beehives, human societies, urban developments... are emergent systems where a collection of individuals interact without central control yet achieve an integral whole [1]. In a smaller scale of living organisms, they are formed by a collection of DNAs that interact with proteins to maintain the development and functioning of living organisms. Individuals and interactions between individuals are key to the evolvement of complex systems. This work harvests the power of individuals and interactions to create a responsive environment, which emulates the growth of Tainan City, the most ancient city in Taiwan.

The purpose of this work is not to develop a generative design system, but to train students of computational design thinking. This is part of a research aims to create a new curriculum to train the new architectural designers to all be competent digital designers.

2. City as a complex system

Cities are one of the finest examples of complex systems. Cities display many traits common to complex systems in the biological, physical, and chemical worlds. Experiments with fractal geometry and feedback mechanisms in cellular automata have proposed various cellular models of urban theory [2].

Central to the physics of complex systems is emergence. Emergence refers to the way complex systems and patterns arise out of a multiplicity of relatively simple interactions [1,3]. An emergent behaviour or emergent property can appear when a number of simple entities (individuals) operate in an environment, forming more complex behaviours as a collective. Such emergent behaviour is usually hard to predict because the number of interactions between components of a system increases combinatorially with the number of components, thus potentially allowing for many new and subtle types of behaviour to emerge. Emergent structures appear at many different levels of organization or as spontaneous order. Emergent self-organization appears frequently in cities where no planning or zoning entity predetermines the layout of the city.

The process of genetic recombination allows for change in actors and their responses to altered circumstances, explaining the mutation of traits from one generation to another and the natural selection process. Recombinant DNA technology genetically engineers DNA by cutting up DNA molecules and splicing together specific DNA fragments usually from more than one species of organism. These DNA spiral code is analogous to some sequencing apparatus in the city and architecture. Processes of sorting, layering, overlapping, and combining of disparate elements involved in the recombinant DNA is analogous to the similar process in the field of architecture.

Recombinant Urbanism [4] is a new approach to contemporary practice that proposes urban modelling with enclave, armature, and heterotopias as three DNA elements in the urban context. Enclaves are self-organizing, self-centring and self-regulating systems created by urban actors, and are often governed by a rigid hierarchy with set boundary. Armatures are linear systems for sorting sub-elements in the city and arrange them in sequence. Each armature forms a recognizable topological module aligned in distinct poles. Heterotopias as switching devices control and direct urban growth in times of crisis, like genetic switches that control growth form, size and direction using simple, recombinant codes and sequences... urban actors act as catalysts in this situation, shaping the codes.

Taking the recombinant urbanism approach, at the smallest scale, buildings (individuals) can be considered basic the component of the city as a complex system. Enclaves and armatures are emergent behaviours. At a larger scale, enclaves and armatures are also components of the city, and heterotopias are emergent behaviours. Heterotopias, in turn, become another type of components to interact with enclaves and armatures thus create further emergent behaviours. The work in this paper takes the approach to study the growth of cities through emergence.

3. An analysis of Tainan City

3.1 The history of the city

Tainan, located in the southwestern shore of the Formosa Island [5], is the most ancient city in Taiwan with a history over 300 years.

In the early 17th century, Dutch East India Company built Fort Zeelandia (1624) and Fort Provintia (1654) and established a Dutch colony [6,7]. It is the site of Fort Provintia that gives rise to the Chinese city of Tainan in the following two century. The Dutch town, occupied areas around the between these two forts, did not have fences and its streets were arranged in a chessboard pattern [7]. The Dutch ruled this area for about forty years until the Ming loyalist Koxinga (Cheng Cheng-kung) took over.

Figure 1. An oil painting of Fort Zeelandia area (source:[7])

Koxinga encouraged Chinese settlers to move away from the coast into wilderness inland areas to reclaim new land [6]. The settled area was divided into four sections but no city walls were built. Nevertheless, religious temples were built following traditions from the Mainland Chinese [7]. In 1680s Manchu Ching (Qing) dynasty established official control of Taiwan. Many more military, government, religious and school buildings were built. In 1720s, bamboo city walls and seven city gates were first built. City walls and gates were rebuilt using clay and bricks in late 1780s and early 1790s [7]. In 1820s, floods caused silts altering waterways and shorelines and greatly affected the urban development of Tainan city. In the latter part of the 19th century, the city took shape as a typical Chinese settlement [6,7].

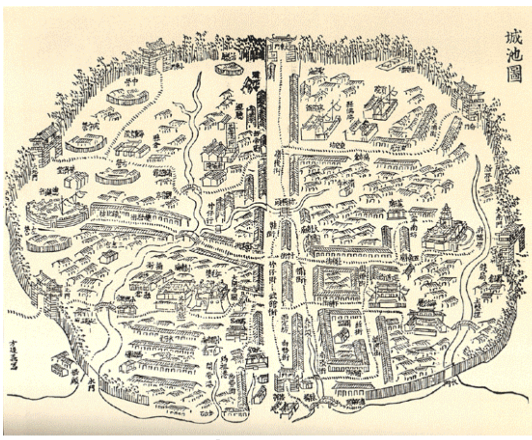

Figure 2. An 18th century map of Tainan

Taiwan was conceded to Japan in 1895. Japanese transplanted the Western models learned abroad to Taiwan. The Japanese plans for the new city completely disregard the pattern of the original city [7]. Old city walls were torn down and gates demolished; new grid roads were built. After World War II up to present day, the city grew according to the Japanese plans even though the Japanese had left.

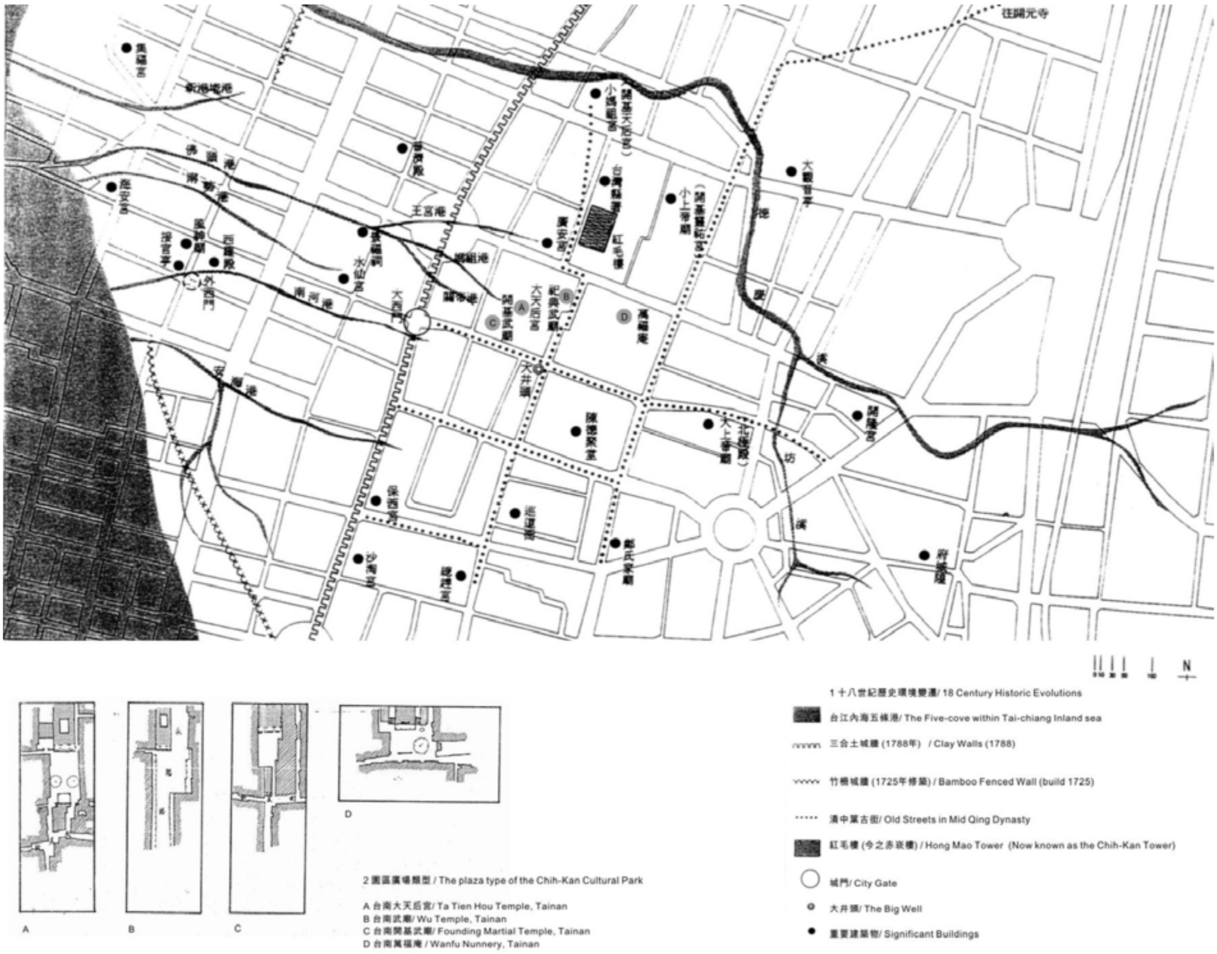

Figure 3. Historic patterns in Tainan (source:[8])

3.2 The evolution of the urban patterns

The development of Tainan City is reviewed based on the urban growth model by Shane [4]. Several urban patterns (armatures, enclaves and heterotopias) are identified throughout the past and present Tainan City.

The very early settlements were established along waterways and formed patterns of armatures. The Dutch colony introduced enclaves of forts and town area in a distinct order. The Chinese immigrants established more enclaves of temples in yet another distinct (heavenly) order. In addition, Chinese military formed enclaves of camps. Chinese farm houses formed yet another type of enclaves. Between these enclaves, armatures formed along natural pathways. The Japanese regime imposed a new order onto the original pattern and thus created heterotopias. Later expansions of the city were heterotopias of armatures and enclaves established on the pre-existing urban context.

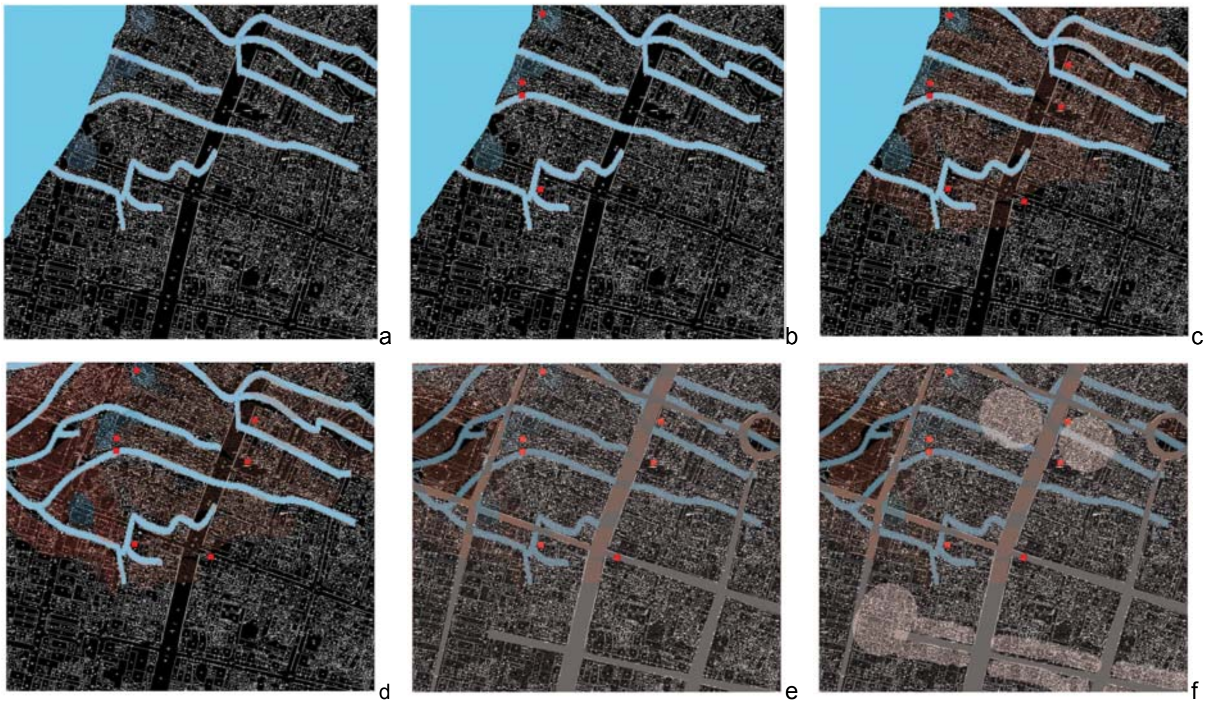

Figure 4. The evolution of urban patterns.
(a) armatures: settlements along waterways; (b) enclaves: temples of heavenly order; (c) armatures and enclaves: increasing expansion; (d) natural changes; (e) heterotopias: Japanese city plan; (f) modern expansion

4. Explorations of virtual cities

Through the study of urban patterns and their evolutions, a set of individuals and interactions are formulated to represent elements of a city as well as compositional rules for urban patterns. These individuals and interactions are designed into a cellular automation machine to explore their emergent behaviours. The system of cellular automation machine based on Conway's Game of Life [9] is implemented in Processing [10]. In it, an individual is a computational representation of city blocks, which is realized as graphical elements on the display screen. Each individual contains a set of compositional rules to react to another individual to generate new forms, a set of rules to react to environmental stresses, and a set of rules to respond to external forces. The environmental stresses are represented as colours or shades of grey, while the external forces are pre-coded into the machine or data taken from input devices such as video camera. The virtual city is a simulated graphical layout presented on a display screen or projected on a vertical or horizontal surface.

A group of second- and third-year architectural students, after studied the history and the urban patterns of Tainan city, begin to explore the growth of virtual cities through various types of interaction rules. The first exploration focuses on the urban pattern of armatures. The set of interaction rules is formulated based on the infant years of Tainan, where settlers gather along waterways. These rules are as the following:

1. Loneliness: any individual with fewer than two live neighbours moves away (basic Game of Life rule);

2. Overcrowding: any individual with more than three live neighbours moves away (basic Game of Life rule);

3. Unchanged: any individual with two or three live neighbours stays (modified Game of Life rule);

4. Move in: any empty city block with exactly three live neighbours has an individual moved in (modified Game of Life rule); and

5. Uninhabitable: any individual situated on the water moves away.

Students use a painting by Miró [11] as the virtual landscape, where colour “black” is interpreted as water. The virtual city is presented in two colours: white as building block and grey as vacant land. This exploration shows that armatures become prevalent in less than 60 generations. As the generation continues, the settlements developed into clusters.

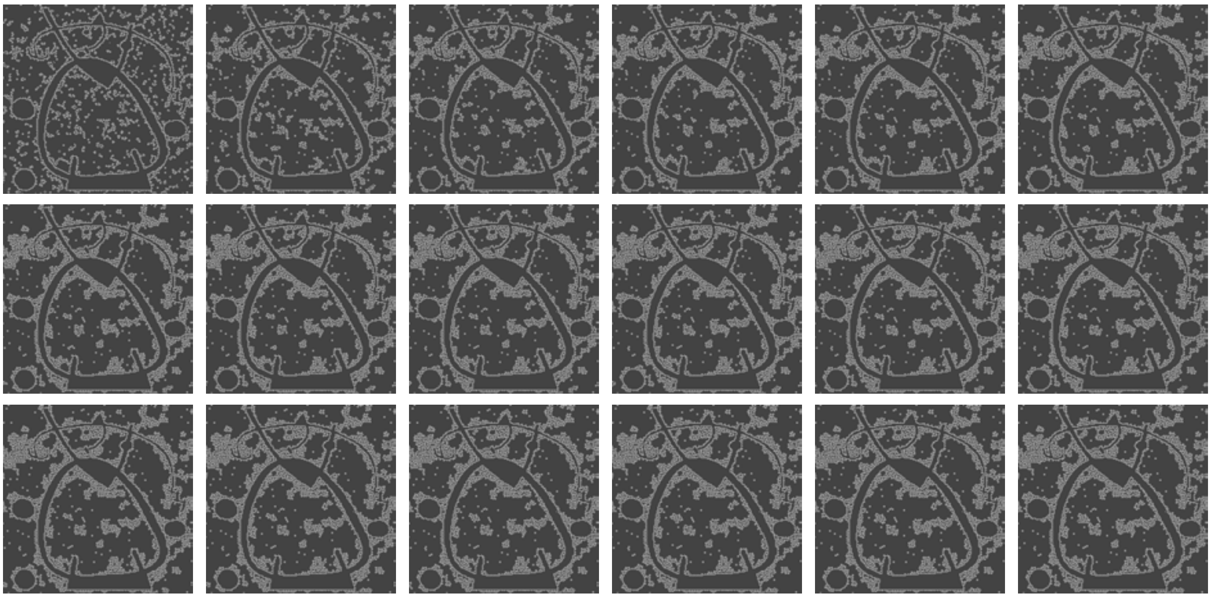

Figure 5. An exploration of armatures.

The second exploration focuses on the urban pattern of enclaves. The set of interaction rules is formulated based on the development in the 18th century of Tainan, where settlers built temples, which are organized according to heavenly orders, of enclaves. These rules are as the following:

1. Settling: an individual picks a suitable land to settle;

2. Decaying: an individual with no neighbours or with more than four neighbours decays gradually and dies in four generations;

3. Clustering: a strong individual attracts another individual to settle in the neighbouring land (probability: 0.4);

4. Longevity: an individual within a cluster of more than five individuals stays; and

5. External Force: an individual dies when its occupied land becomes unsuitable.

In this exploration, the landscape of the virtual city is directly taken from the image captured through a webcam. On the video image, the landscape, the colour lightness (value) of 0.5 or above is interpreted as suitable land. Significant changes in the physical space (captured through the webcam) are interpreted as external forces (natural or political events) to trigger massive changes in the virtual city. This exploration shows that enclaves become prevalent in 10 generations. As the generation continues, the enclaves disintegrate and lose the distinct patterns. External forces trigger the re-generation of enclaves.

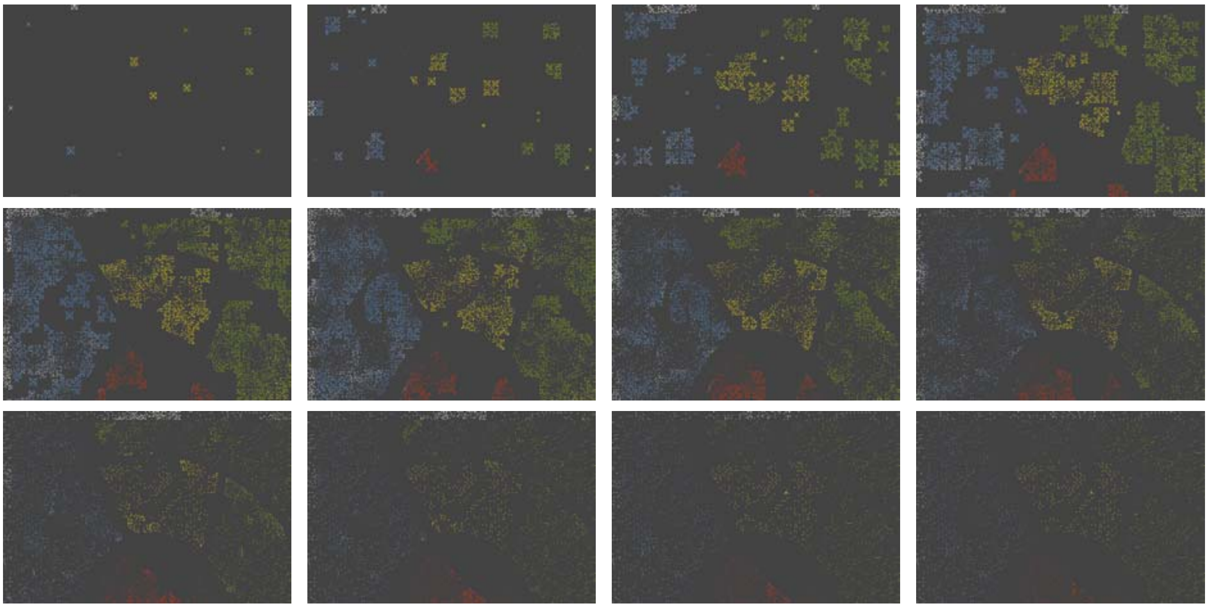

Figure 6. An exploration of enclaves.

The third exploration focuses on the urban pattern of heterotopias. The set of interaction rules is formulated based on the development of Tainan during Japanese occupation, where the western urban plan was imposed on the pre-existing context. Again, a webcam is used and changes in the webcam image are interpreted as natural or political powers, which interrupt the development and created new armatures and enclaves.

Figure 7. An exploration of heterotopias.

The fourth exploration tries to emphasize on the modern heterotopias of vertical armatures (flows in elevation) and enclaves. The set of interaction rules is formulated based not on the historical records of Taiwan but on the urban modelling technique of Shane [4]. These rules are as the following:

1. Loneliness: any individual with fewer than two live neighbours moves away (basic Game of Life rule);
2. Overcrowding: any individual with more than three live neighbours moves away (basic Game of Life rule);
3. Raising: any individual with two or three live neighbours raises one more level (modified Game of Life rule);
4. Move in: any empty city block with exactly three live neighbours has an individual moved in (modified Game of Life rule); and
5. External forces: an individual moves away when its occupied land becomes unsuitable.

In this exploration, the landscape of the virtual city is directly taken from the image captured through a webcam. On the video image, the landscape, the colour lightness (value) of 0.5 or above is interpreted as suitable land. Significant changes in the physical space (captured through the webcam) are interpreted as external forces (natural or political events) to trigger massive changes in the virtual city. After 100 generations, the virtual city becomes forest-like, where pockets of low-rise enclaves spread among high-rise armatures.

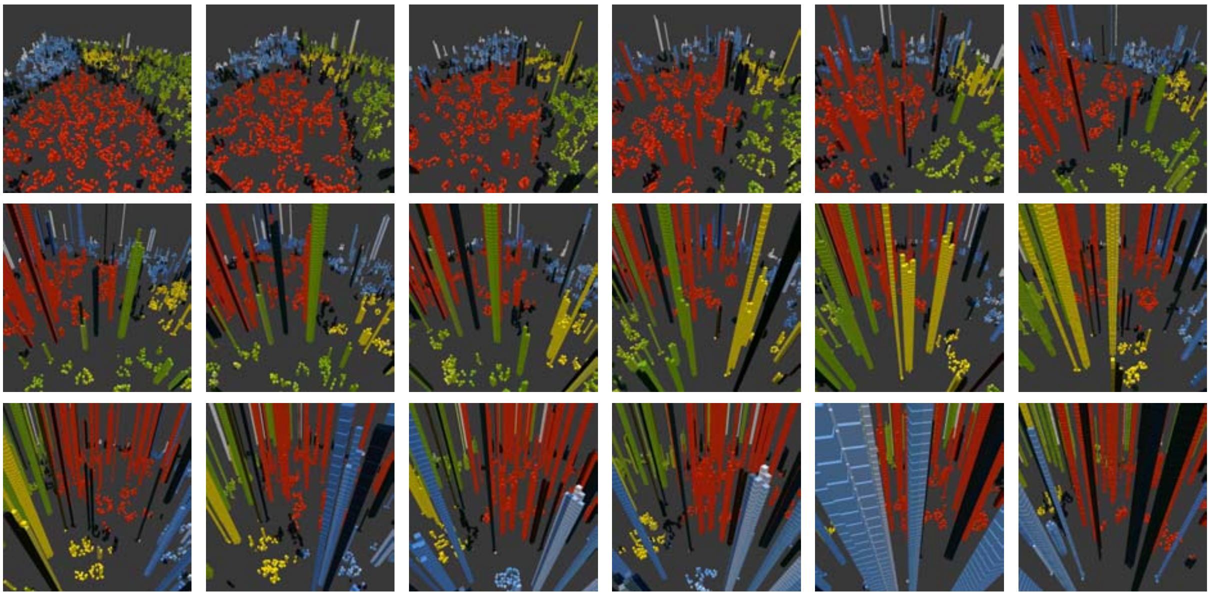

Figure 8. A further exploration of heterotopias.

These explorations create virtual worlds where a city evolves with the growth and decay of city blocks. These student works were exhibited in a workshop where each virtual world was presented, as an installation, in a physical space with a webcam installed to monitor the changes in this space. Significant changes in the physical space are interpreted as external forces (natural or political events) that trigger massive changes in the virtual world. These installations promoted discussions among students, as well as the architecture faculty members, regarding the role of computation in design.

5. Discussions

The works presented in this paper are parts of an on-going effort to train "digital designers" in the field of architecture in Taiwan. Many related works and research projects provided foundations to the trials illustrated in this paper, especially those presented in the past Generative Art conferences, such as [12,13,14]. Digital computational tools have become necessary in architectural design and development processes. These tools, in particular three-dimensional modelling tools, have become very sophisticated and provided users a wide spectrum of operations to create complex three-dimensional models. Using these tools, designers can create a three-dimensional model through direct manipulations on surfaces as if working with digital clay. Furthermore, these tools provide scripting/programming interfaces so that designers may generate models through computer programs. A "competent" designer, therefore, should be able to understand the full spectrum of operations provided by these tools.

I believe the key to a competent designer is "computational design" thinking. My early efforts focused on teaching graduate-level architectural students to write computer programs and recursive computational mechanisms with naïve and unrealistic applications in architectural domain. More recent efforts focused also on training graduate-level architectural students to employ generative methods for conceptual designs [15].

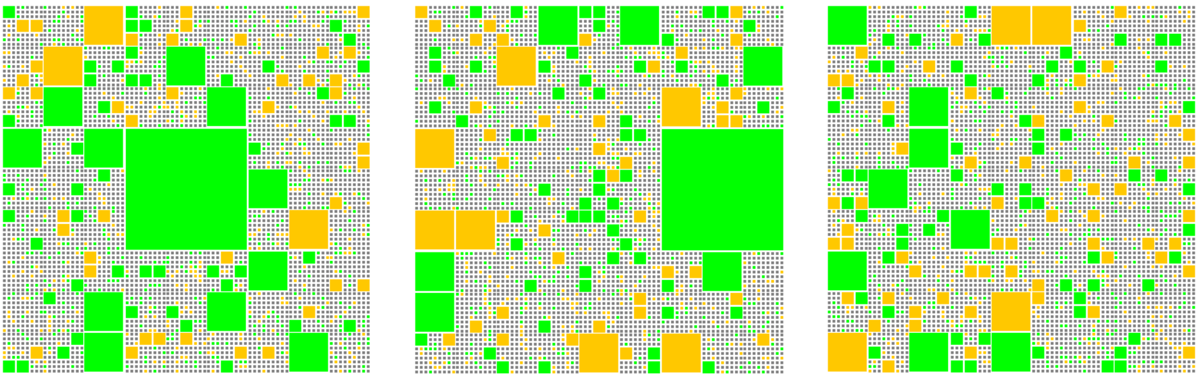

Figure 9. Employing fractal dusts algorithm to generate urban zoning plans

Among various generative mechanisms the ones based on optimization and heuristics (e.g., expert systems, shape grammars) are easily understood by students yet difficult to be implemented and applied by students. The theories of chaos and complex systems explaining emergent behaviours through simple individuals and interactions between individuals are difficult for students to understand yet can be easily implemented and tested by students. This paper shows that second- and third-year students could begin to grasp and appreciate the power of computation through hands-on exercises. A new digital design curriculum is under planning to integrate these generative mechanisms into the undergraduate architectural curriculum.

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