GENERATIVE ARCHITECTURE IN DLA SPACE

JACLYN K. SUN\textsuperscript{1}, GEOFF KIMM\textsuperscript{2} and SULEIMAN ALHADIDI\textsuperscript{3}
\textsuperscript{1,2,3} University of Melbourne, Melbourne, Australia
jaclyns@student.unimelb.edu.au, geoff.kimm@unimelb.edu.au, suleiman.alhadidi@unimelb.edu.au
\textsuperscript{2,3} O(n) Studio, Melbourne, Australia
design@onstudio.co
\textsuperscript{3} HASSELL, Australia

Abstract. In the field of architectural design, Diffusion-limited aggregation (DLA) has been widely adopted in the study of macroscopic urban terrains and structures. If we consider individual habitats as having the same gene as our city, the intrinsic nature of DLA provides interesting insights in emulating local interactions that take place at microscopic level. This paper takes the dynamics of the DLA to the smallest unit of designable space. Whilst Phase I focuses mainly on Euclidean constraints, Phase II looks at how such generative space can add complexity to an open office plan by allowing different physical attributes to interact with one another based on the company’s organizational chart.

Keywords. DLA; generative design; bottom-up design; design computation; cellular automata; fractal geometry

1. Antecedents: Towards a fractal network

Historically, the Vitruvian man signifies the importance of precise proportion and points to an architecture that brings stability through a summation of forces. It is the precursor of a top-down approach in architectural design where an overarching axiom governs the organization of local elements. The prevalence of computer-aided design shakes this concept at its core in which the use of generative and evolutionary computational methods unleashes the potential for a bottom-up approach when engaging with design. No longer depends on a parti that governs the overall architectural composition, micro-scale organizations are translated and aggregated to form a greater whole.
Commonly used agent-based modelling methods such as Cellular Automata (CA), L-systems and Swarm Intelligence are examples of computational models adopted to simulate the interaction of local agents underlay many dynamic complex systems. Particularly, the availability of this technology fuelled the paradigm shift in the understanding of cities where its emergent characteristic can now be reproduced, simulated and analysed in virtual environments. Batty and Xie (1994) use a standard class CA to predict the shapes and sizes of cities resulting from local rules in a hypothetical setting. Likewise, Chan and Chiu (2000) simulate the urban form of the Taipei City by means of fractal geometry, this time with inclusion of generative rules that attract or limit growth based on various economic factors. More recently, Liang, Hu and Sun (2013) relate fractal analysis to future city planning such as the distribution of green space within an urbanized area. Even though it has been a long time coming, the organic nature of city growth that was first put forward by theorists such as Jane Jacobs and Christopher Alexander in the early sixties have now been vindicated. More importantly, the aforementioned computational methodologies translate these complexity theories into design logic and variables that would further empower designers and planners in practice.

2. Diffusion-limited aggregation: Generative process of order and chaos

2.1. BETWEEN SMOOTH AND STRIATED

Whilst the idea of fractal organization and rhizomatic growth is sensitizing for designers, the shift from centralization to decentralization is in reality, less than clear-cut. In fact it is unlikely that a city can remain functional and sustainable if the need for planning and regulations is completely overthrown. In their investigation on the evolution of urban land-use patterns, White and Engelen (1994) reported that the underlying computational logic fails to simulate certain morphological features common in real cities – linear or tentacular structures such as transportation systems – when the degree of stochasticity is high. Fractal form only begins to emerge at a critical value that marks the transition between uniformity and randomness:

“Indeed, much of the economic and political life of cities consists of a constant interplay of order-creating and order-destroying actions. And the result is a balance between the two, constantly shifting, but rarely shifting too far. The city evolves to maintain itself and its evolvability.”

(White and Engelen, 1994, p. 581)

From a philosophical standpoint, the dynamics between the two can be captured by Deleuze and Guattari’s smooth and striated space. Whilst striat-
ed space is stringent, and generally offers little affordance to improvisation, smooth space is delimited and nomadic, a fickle beast that obsoletes even the role of the “designer”. The nomadic however would lose its meaning if there had not been the presence of an envelope in which it were to break out from. In architectural and urban design, perhaps neither a top-down nor bottom-up approach shall be the sole solution, but rather they must exist in mixture:

“What interests us in striation and smoothing are precisely the passageways and combinations: how the forces at work within space continually striate it, and how in the course of its striation it develops other forces and emits new smooth spaces...” (Deleuze and Guattari, 1988, p. 500)

2.2. DLA, THE CITY AND HABITABLE ARCHITECTURE

In the context of computational design, this urges for a computational model that can grapple the tension between the two forces. Although previously discussed generative algorithms are able to simulate bottom-up organizations aggregated to form an architectural entirety, many of them are conducive to an aggregation process without restraints. For instance, fractal geometry exhibited by an L-system constitutes a rewriting of an initial string that could go on indefinitely. In practical situations, designers may better benefit from a mechanism that enables such emergence to happen without having to relinquish all the control over the trajectory of change. The versatility of the diffusion-limited aggregation (DLA) model enables the creation of complex fractal patterns circumscribed by a context or boundary, yet remain reactive within it. In addition, it allows the designer to impose top-down order in mediating the otherwise random aggregation. For example, control can be added to signify topographic characteristics (such as river estuary or a spit of a headland) of the city, which then affect the pattern of the agglomeration (Batty, 2009). The DLA model thus represents a more accurate mode of thinking in reflecting the intrinsic nature of urban growth as well as enriching the organic analogy between design, cities and buildings.

In addressing the interrelated relationship between city and its substrates, Jane Jacobs (1961) has poignantly emphasized the importance of local members, such as the daily interactions of people and their communities, in constructing the organic “whole”. Similarly, Neal (2013) adopts a multi-scalar thinking to the study of urban realm and recognizes the need for a nested level of analysis, linking the city’s structure with micro-networks of collective behaviours in everyday living space. This brought us to the premise of treating architecture as an elemental unit that makes up the greater urban system. Inevitably, its very own anatomy should share a kind of emergent characteristic coherent with the greater urban ecology.
2.3. RESEARCH AIM

In contrast to the ample body of research that focuses on the applicability of DLA as a determinant of various urban morphologies, this paper takes the dynamics of the DLA process to the smallest unit of designable space. In doing so, it aspires to extend the urban analogy into the architecture of spaces at human scale. Just as how a city’s infrastructure networks – streets, sidewalks, buildings and parks – may provoke us to interact in specific ways, the present investigation explores how fractal arrangement of physical layout may influence the way people inhabit and experience space differently. In two phases, we first explore the potential of DLA in organizing and distributing interior programs. Subsequently, we expand this spatial logic to include variables representing the management framework of an organization. In doing so we hope to promote the practicality of DLA in fostering a kind of workspace relationship that favours collaboration and knowledge transfer.

3. Phase I: DLA as informal space generator

3.1. BASELINE DLA PROCESS

DLA, first populated by Witten and Sander in 1981, is a process for generating organic forms with arguably the least number of rules. The process begins with a fixed seed within a defined testing space. A particle is released and wanders through the testing space in random directions. In each subsequent step, it checks to see if it has collided with the seed or another fixed particle. If the particle is within a certain distance, it attaches itself and becomes part of the cluster. If the random walk ever takes a particle past the perimeter of the testing space, the search is restarted with a different initial direction until a particle is hit.

Conventionally, the pattern created by the DLA process is dendritic (or fjord-like). This is because as the process accumulates, it will get more difficult for a random particle to avoid contacting with the periphery branches and arrive at the nuclei of the cluster. A DLA aggregation typically results in patterns that are largely radial (Figure 1) due to the placement of fixed seeds in the centre of the testing space. A gradual percolation effect (Figure 1) can however be achieved when the fixed seeds are placed at the edge of the boundary (i.e. nucleation line). The presented case study takes the most primordial form of DLA in which the movement of the random particle is confined to orthogonal directions, as if the process occurs at a lattice of square cells (Figure 2). The DLA pattern can be geared towards a desired trajectory by altering contextual stimuli, yet the ultimate spatial quality remains unpredictable during creation.
3.2. DESIGN SCENARIO

Phase I of the research explores the use of DLA in generating interior floor space that responds to different programmatic needs. In a hypothetical scenario, DLA is integrated in the design for an office tower. Several initial conditions are set to meet with the circumstantial considerations specific to the site. This includes the program requirement to house a specified amount of office space within the site footprint. In response to this, DLA is adopted as a generator for informal space within a traditional formal workspace environment. DLA particle that accumulates at each collision defines the growth of a unit of physical space. The design aspires to reflect the tension of formality and informality in the process of design that entails both regulated and autonomous spatial configurations.

Fixed seeds are located along the nucleation line L (Figure 2), which demarcates the DLA testing space and the normal floor space. As mentioned previously, the fjord-like pattern is inherent in the generation of DLA clusters. Such pattern, if applied fully to produce interior floor space, can hinder its efficiency to function as an office workspace due to a high degree of po-
osity especially towards the nuclei. The normal floor space is an area excluded from the DLA process with the aim to retain at least a minimum extent of “compactly-filled” Euclidean surface in any given storeys. With this initial condition, the designer anticipates a growth of DLA cluster in a linear front as opposed to a radial geometry. The rules for the DLA process can be summarized as follow:

- **Step 1.** Input the number of fixed seed. Release a random walker and let it wander. At each step, check if the adjacent cell is occupied by a fixed seed or another particle.
- **Step 2.** If so, occupy the space it is in.
- **Step 3.** Repeat Step 1 to 2 and terminate the process when the total gross floor area (GFA) requirement is reached

### 3.3. INFORMAL SPACE PROGRAM COHORTS

Theoretically, the position of the fixed seed only needs to be randomly selected to execute a DLA process. A preliminary experiment reveals that, *ce teris paribus*, the extent of the DLA cluster is more prominent when the number of fixed seeds increases. As more fixed seeds are planted, the likelihood of collision by a random particle increases. In fact, when a single random particle collides with a fixed seed along the nucleation line L, further growth is amplified exponentially because there are now three growth sites open for contact to capture a wandering particle (Figure 3).

![Figure 3. Subsequent growth is amplified after the very first collision with a fixed seed](image)

With this in mind, the placement of the fixed seed provides an opportunity for a contextually informed architectural design in which the designer can gear the DLA pattern towards a particular trajectory by manipulating the initial position of the fixed seed, even though the ultimate form remains unpredictable. By creating three informal space program cohorts (i) Restorative Space; (ii) Common Space; (iii) Collaborative Space within the DLA testing ground, the intensity (and extent) of DLA clusters for each cohort is determined by the number of fixed seeds planted. Controlling only the total area occupied (i.e. Gross Floor Area (GFA) and the given envelope perimeter) and the percentage share of each required program, assemblage of program cohorts depends entirely on the trajectory of random walkers being released during the generative process (Figure 4). By allowing parametric adjustment
on the percentage share of program (as reflected by the number of fixed seeds representative of that specific program cohort), the designer is empowered to manipulate the extent of growth. The initial algorithm is developed in Processing 2.2.1 and subsequently brought to simulation in Rhinoceros 5.0 environment. For the sake of simplicity, the number of fixed seeds is set to three intensity levels prescribed in a Grasshopper script – HIGH, MED and LOW – to which users can easily alter to attain a floor area deemed optimal. The precise location of fixed seeds will however be randomly selected along line L to create novel outcomes. Figure 4 illustrates the process diagrammatically with the simulation result shown in Rhinoceros.

![Figure 4. The creation of informal space using DLA conducted in Rhinoceros 5.0](image)

Finally, the process terminates when the overall GFA requirement is met. In this manner, the way interior space is generated articulates the tension between striation and smoothness: the DLA process begins with a controlled boundary but ends with a high degree of flexibility. Figure 5 illustrates a sample floor plan with different percentage mix of program cohorts. In the case of high-rise buildings where program requirements are often repetitive across storeys, the use of DLA generates multiple variations of layout with only a simple change of initial settings.

![Figure 5. Sample floor plan.](image)
4. Phase II: DLA in the design of fractal organization

4.1. INCUBATOR FOR COLLABORATIVE ORGANIZATION

In Phase I, bottom-up approach to design is considered purely from the Euclidean standpoint, in which the DLA process concerns mainly with floor area, perimeter and so on. There is, however, no apparent local relationship between different program cohorts as to how they may interact with each other.

What is more interesting then is the potential to relate such spatial logic with its implied socio-behavioural consequence: converging physical attributes of DLA with the functional attributes of a workspace. Similar to how a city’s physical quality is intrinsically linked to its underlying social logic and economic forces (Alexiou, Johnson and Zamenopoulos, 2010), Phase II of the research explores how fractal property of DLA-generated space can be a stimulant in fostering a corporate culture that values bottom-up management. In fact, many contemporary workplaces have stepped away from traditional setting and opt for a fractal organization that could better facilitate the exchange of knowledge and trust building among individual employees (Chevez and Aznavoorian, 2014). A fractal network may better resemble the actual hierarchy of a company where both social and functional roles overlap rather than are strictly demarcated.

4.2. WALKER TYPES AND THEIR SOCIAL MEANINGS

Chevez and Aznavoorian (2014) conducted an evidence-based study on physical space in the workspace and found that spatial attributes of informal office space can affect day-to-day interpersonal observations and communication vital to knowledge transfer. In addition, the intensity or the nature of learning changes with physical proximity that renders a space to feel more public or private. To build on this, generative rules from Phase I are further enhanced to include built-in connection between distinct walker types. Random walkers are differentiated into three types signifying informal space with decreasing degree of privacy (P): (i) Mentoring Space (P^1), (ii) Co-working Space (P^2), and (iii) Working Commons (P^3).

It is also useful to overlay the computational logic of the fixed seed with a social meaning relating to managerial ranking. Based on the fact that a manager tends to take up a considerably heavy role in people development, the position of a fixed seed determines the probability for a specific walker type to collide. As an example, the present research has a pre-set rule in which walker type higher in the degree of privacy is more likely to collide with the fixed seed (i.e. a manager is more likely to engage in one-to-one
mentoring). In summary, the DLA process is expanded to encompass the following steps:

- **Step 1.** Input the number of the fixed seed. For every fixed seed, each will have a value $P^0$. Release a random walker and let it wander. At each step, check if the adjacent cell is occupied by a fixed seed or another particle.

- **Step 2.** If so, given that the walker is of $P^N$, check to see if the neighbour is of $P^{N+1}$ or $P^{N-1}$.

- **Step 3.** If so, occupy the space it is in. Otherwise, delete itself and restart the process in half of the time.

- **Step 4.** Repeat Step 1 to 3 and terminate the process when the GFA requirement is reached.

Figure 6 shows the results of the aggregation in which the pattern can serve as an underlying syntax for office space planning. Different from Phase I, DLA testing space now takes up the entire floor plan. DLA clusters agglomerated around the fixed seeds create a kind of interstitial space that permeates through normal individual desk space in a continuous strip. Whilst parametric adjustment on the number the fixed seed and the criteria for collision enables the designer to exert some control over the dynamics of the aggregation, local interactions of walker types remains largely depends upon contextual circumstances. In this particular instance, the emergence of fractal form emphasizes on the location of fixed seeds that is being randomly selected at the start.

![Figure 6. Sample floor plan.](image)

Drawing from the literature on organizational design (Chevez and Aznavoorian, 2014; Raye, 2014), the resulting pattern also closely resembles the circle of influence, where a number of key personnel influence, inspire and stimulate other members within the organization. The architecture of
DLA space enables nested networks of circles of influence to construct an organization that is somewhere in between centralized and decentralized: strategic decisions are centralized at the nuclei whilst information is interchanged among individual agents building from bottom-up (Raye, 2014).

5. Conclusion and discussion

Whilst DLA is commonly adopted in modelling various urban systems, expanding this relationship to the design of space at micro-level yields interesting insights. The research presents ways where DLA can simulate a spatial syntax to house and incubate social relationships that tend to exhibit fractal properties. Whilst Phase I focuses mainly on Euclidean constraints, Phase II looks at how such generative space can add complexity to an open office plan by allowing different physical attributes to interact with one another based on the company’s organizational chart. Whilst the case studies presented are based on hypothetical scenarios, the findings pave ways to bring generative architecture into the broader discourse of adaptive workspace making, linking management frameworks with a design outcome that meet the needs of its users without losing novelty in architectural expressions.

References