Bottom-up Design Inspired by Evolutionary Dynamics

Adaptable Growth Model for Architecture

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Abstract: Development of flexible and adaptable architecture has been a perennial theme among practitioners. Design of universal subunits that could tolerate technological, environmental, and circumstantial changes over time is a challenge. In this paper, I would like to introduce several generative design strategies inspired by ideas from evolutionary dynamics and discuss potential benefits of the methods for designs of emerging future building types.

Keywords: Evolutionary dynamics; bottom-up design; DLA.

Introduction

In today’s building design methodologies, we thoroughly study all kinds of future requirements and potential changes for the buildings before construction. For some building types we expect fewer future changes but some require more. Besides seeking to minimize the need for few possible future alterations or maintenance work, the design methods aim at producing completed buildings that can tolerate as many future conditions as possible from the outset of their design. I will call this type of design approach “Top-down.”

On the other hand, some buildings do not include a comprehensive solution for all the potential scenarios of the future from the beginning, “as is.” Instead, some of those buildings possess systems that allow them to adapt to future changes over time by altering their designs spontaneously based on simultaneous feedback from a number of simple entities (or agents) inside the system. These feedback systems can be effectively distributed to formulate globally working solutions as a collective result. These methods do not always guarantee the best solution in a deterministic sense; however, they could be effective where there is no deterministic and analytical means to derive solution. As a natural consequence of adapting to radical population growth, sometimes these characteristics can be seen in low-cost housing developments in less regulated zones with no supervision by professionals. I will call this type of design approach “bottom-up.” The bottom-up approach is appropriate for the design of any system that is required to change over time and where there is no adequate total control of the entire structure due to its quantities or complexity.

Gradual growth and adaptation overtime

I would like to start this paper by introducing one intriguing example of architecture that displayed radical mutation over its lifetime. Kowloon walled city in Hong Kong was neither a beautiful nor successful building in our standard sense of perception; however, this is one of the rare synthetic examples of emergence in building construction process which had achieved within a less than a lifetime of single generation. Political situations between China and...
Britain during the last century had made Kowloon area in Hong Kong a political and diplomatic black hall which had been free from any laws or regulations from neither government. As a consequence, Kowloon had become an asylum for many refugees escaping from the civil war and political prosecutions by the Communist government at the time, and had formed a rare model of an anarchist city. Only the regulations for the growth of this monstrous structure were height restriction above fourteen stories high due to the nearby airport, and the requirement for electricity in order to avoid the occurrences of fire.

The structure was not planned for the residents of more than 35,000 from the beginning; they had displayed incredible tolerance and adaptability for accepting radical increase of their population over relatively short periods of time. They might not have been the most efficient building in terms of circulation. Labyrinthine interior networks were far from efficient compared to ideals of conventional axial building planning of modern architecture planning, and the same construction or design methodology cannot be directly applied to our contemporary social environments. However, each resident’s needs for basic livings were mostly satisfied at some degree by constantly altering its morphology. In other words, scarcity in some functionality had triggered motivation for another new construction to adapt new features, such that the structure as a whole, it displayed incredible robustness and flexibility.

We have witnessed self-organizational qualities in formations of many historical cities such as Mouray Idriss in Morocco. But this example had been accomplished within relatively short period of time and in a scale of several building complex. This self-organizational structure actively adapted and regenerated itself into a working model of metabolic system in architecture by accommodating everlasting incoming refugees. Unprecedented adaptability exhibited in this project was achieved by relatively unsophisticated and nonprofessional carpentry works by local residents using low quality reinforced concrete constructions. Their crudeness in construction qualities might have contributed to their spontaneous growth of the structure. In exchange for construction precision and qualities, they gained extremely unique, almost organic, plasticity in erection sequences, and these seemingly primitive construction methods led them to achieve the unprecedented adaptability in their architecture. They also resolved many individualistic needs among local neighborhood area, and many residual spaces emerged during the process were heuristically morphed into different programmatic elements such as schools and common spaces in the courtyard. I believe that the type of growth model that Kowloon represented showed us a potential existence of completely different methods in building design compared to our relatively top-down conventional design strategies. We may find some potential benefits by learning from fundamental design principles unique to Kowloon walled city.
**Diffusion-limited aggregation (DLA)**

Diffusion-limited Aggregation (DLA) is a process of accretion over time and observed in many systems such as electrodeposition, mineral deposits, snowflakes, dielectric breakdown (lightening path), and even in living organism such as growth pattern of coral. Witten and Sander (1981) proposed a theory that explains DLA growth, and their idea is that randomly walking particles launched from distant points stick to the surface of the growing cluster when they arrive at a site adjacent to the aggregate. The DLA-cluster can be also interpreted as aggregates where the formation is controlled by the probability of particles to reach the cluster. They provided the mathematical explanation that the random-walk DLA model can be rewritten as the Laplace form of the diffusion equation based on the probability of a particle at \( x \) at time \( t \) as \( u(x, t) \) where \( d \) is the dimension of the lattice. (Witten, 1981)

\[
\frac{1}{2d} \sum_{i=0}^{d-1} u(\overline{x} + \Delta \overline{x}, t) - 2u(\overline{x}, t) + u(\overline{x} - \Delta \overline{x}, t) = \frac{1}{2d} \sum_{i=0}^{d-1} \frac{\partial^2 u(\Delta x, t)}{\partial x_i^2}
\]

(1)

Solving the above equation (1) with the boundary conditions \( u(x, t) = 0 \) where \( x \) is inside the DLA cluster and \( u(x, t) = \text{constant} \) where \( x \) is infinite distance away from the center will provide the probabilistic growth model of DLA, and we can gain the same results from random walk DLA (Witten, 1981).

Theoretically, this probability for potential growth area can be assigned based on more complex information relating to architectural constraints such as light, view, circulation, structure, and so on. In this paper, I start by measuring views and distances among the each unit cells within 10 units’ distances around the potential next deposition locations in order to maintain a certain level of privacy among the units. As a result, growth of thin diagonal branches is observed and they all keep a certain distances among others. By biasing the probability in South-North orientation, I could direct the growth toward a certain orientation as well based on a specific condition of solar radiation. Then, I constrained the growth within a bounded zone. This time, instead of branches, I start to observe formations of parallel layers of strata.

In addition to aggregation, reductive process can be used by introducing a predator that eats the units which have lower values among the existing cells. This process will maintain better overall value for cluster by replacing old cells with new ones as if it were metabolizing it.

In principle, beyond physical/environmental constraints, programmatic/social issues relating to occupancy types, social issues, programs, and code/zoning constraints can be implemented by assigning proper probability field over the site under the considerations.

The probability based DLA model has a remarkable resemblance to a construction sequence of housing developments such as Kowloon where people build additions at the most probable and likable locations at each time step. This seemingly
momentary and transient attitude toward construction is definitely not proper for a design of a single residence with limited site area. However, here is a question, “what if the system is under a constant demand for growth and alteration in relatively short sequence of time?” If the demand for growth, additions or renovations, are once or twice in a life time of the structure, precise and deterministic planning for optimal results is far more reliable. However, responding to constantly changing and unpredictable demands for expansions or possibly alterations and contractions probably requires completely different systems’ behaviors.

A DLA model can derive better cell locations in every discrete step. If the search space for the problem is relatively small, it is suggested that the conventional design strategy can still analytically derive more deterministic and reliable solutions. What is more intriguing about this process is that the system can provide quite robust solutions for constant and endless changes, and the system is designed to maintain its balance as a whole. For instance, accretive growth patterns of corals appear to be quite transient during their developments, though their systems of growth are known to maintain effective forms to absorb nutrients in the fluid.

Finding scenarios that require gradual growth over time in architecture is practically a challenge. Besides some urban scale developments, a scale of physical size and a magnitude of time that it takes to grow for buildings have not reached a stage where we require such a design method. In most cases, practitioners can forecast sufficient solutions analytically, and it is very unlikely to find any kinds of building development that requires step by step constant improvements in shorter segments of time like Kowloon walled City. All that said, I would like to anticipate the emergence of architectural type that takes advantages of metabolic adaptation seen in accretive growth model by continually adapting itself to new conditions as if it were an organic entity.

**Tectonic implementation using multi-body dynamics**

The experiments in this paper so far have least consideration to physical balance of generated structures, and now, I would like to explain my strategy

![Figure 3](image)

*Figure 3*

Three dimensional clusters created by Diffusion Limited Aggregation. DLA cluster with 10,000 cells. Approximately 350% more opening areas than the structure using simple 10x10x100 tower configuration
to implement physical properties to the structures and to evaluate overall geometrical balances in schematic level.

This system resolves all forces into axial-ones in order to carry out Finite Different Method (Euler Method) to approximate and visualize structural behaviors. The structures are divided into a finite set of grids composed of masses and weightless elastic connections (bracings). This network of mass and spring will form a three dimensional truss to approximate overall geometries. The springs’ coefficient is provided based on the materiality of the structure (density and elastic property are considered to be homogeneous throughout the structures.), and modal equations are formulated based on stresses inside members using Hook’s law. I animated the
Figure 5
Auto-generated Design Instances using DLA-based methods and Animated Dynamic Structural Deflections. Example of unsuccessful implementation: Failing Structure (bottom)
displacements in each member by using finite difference methods (explicit time stepping), and my program can display stresses inside the members by color gradients. (Further, solving the modal equations (by using method such as Gauss-Jordan elimination algorithm) will provide strains in each member. (Finite Element Method) Only the dead load (its own weight) and boundary conditions (whether fixed or free, and stressed or not) are considered this time, though more complex conditions such as wind load or materiality for members can be programmed for more detailed analysis.

This structural evaluation can be inserted within the generative processes’ selection sequence; however, speed of computation in the program need to be optimized for the future study. The animated real-time deflections of the structure are also quite effective for communicating a physical stress and a behavior of the structure to users. This experiment’s another objective is to propose visualization of animated physical reactions to CAD systems. By using above techniques, structural feasibilities of computationally generated DLA clusters can be analyzed at the level of schematic design. (Figure 4, 5)

In addition to the analytical capability for static structures, the software allows users to design Kinetic components. Users can assign actuators that can vary their lengths in a certain frequency. These actuators works as pistons within a structure, and users can design periods of gait cycle, amplitudes of actuation, phases, and original length of segment for each kinetic member. Kinetic Architecture can be generated from this platform. (Figure 6)

**Conclusion**

The research in this paper is not at the stage of providing a direct application to existing architecture. They are, rather, at the stage of finding the right instances for applications in architecture. Practical and functional needs of current structures may be yet to reach the stage where evolutionary processes can be fully effectively utilized. However, the quantity of information and the level of complexity involved in many building projects have started to arise at unprecedented levels, and our design processes may well be on the brink of a necessary transition from conventional methods to methods that requires evolutionary processes.

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**References**

Nowak, M. A.:2006, Evolutionary Dynamics: exploring