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URBAN MODELING WITH AGENT-BASED SYSTEM:
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ABSTRACT
This article describes research on using local interactions to generate intricate global patterns and emergent urban forms. An agent-based system (ABS) is used to optimize an urban network and construct the micro-level complexity within a simulated urban environment. The author focuses on how agent-driven emergent patterns can evolve during the simulation in response to the "hidden hand" of macro-level goals. The research extends to the agents' interactions driven by a set of rules and external forces. An evaluation method is investigated by combining network optimization with the space syntax. The multi-phase approach starts with defining the self-organizing system, which is created by optimizing its topology with ABS. A macro-level "attraction map" is generated based on the space syntax analysis, where the map is used to control various construction operations of an urban model.

KEYWORDS: self-organizing, agent-based system, space syntax, bottom-up, emergent

1.0 INTRODUCTION: AGENT-BASED SYSTEM

An agent-based system (ABS) consists of numerous agents, which follow simple localized rules to interact with an environment, thereby formulating a complex system. Since Craig Reynolds' artificial "bodies" and flock simulation, the concept of the ABS has been widely used in computer science, biology, and social science, such as swarm intelligence, decentralized social networks simulation, and economic growth modeling. ABS consists of interacting rule-based agents that can create real-world-like complexity. In urban modeling, agents can be defined as autonomous "physical or social" entities or objects that act independently of one another[1]. The autonomous agent can represent humans, animals, robots, plants or artificial lives. As the essential element in an ABS, the most popular behavior of an agent is movement. The movements are usually based on simple rules, such as separation, alignment, and cohesion. Computer scripts can be used to simulate agent's velocity, maximum force, the range of vision, and other properties (Figure 1). This autonomous, bottom-up approach is most practical for movement-related analysis. For instance, ABS has been widely used to simulate the behavior of crowds, where the agents' movements are computed based on the interactions between them as well as the interactions with the environment.

In recent years, ABS has become an integrated analysis and evaluative process to assist architectural and urban design. Some of the emerging aspects in practice involve using ABS to generate complex self-organizing systems and geometries that respond to the interactions of elements and external forces. An agent can represent various architectural entities ranging from panels, rooms, and even abstract building program. ABS allows complex systems to emerge from the simple interaction among agents. Each agent can "sense" its neighbors and "react" to them by modifying its location, shape or other attributes. For instance, Ehsan Baharlou and Achim Menges used ABS to compute the topology of a tessellated pattern across a complex surface[2]. Li Biao used ABS to optimize the locations of skyscrapers to maximize their views and solar exposure[3]. ABS for urban design is also established in the same relational model and computational strategy. Some of the rigorous methods in the urban design practice involve using ABS to generate micro level self-organizing urban forms that respond to the top-down rules and traditional planning methods. The ABS approach can be found in large urban design projects, such as the context-aware multi-agent system for urban infrastructure by David Gerber[4], and path optimization system in the Kartal Pendik urban design project by Zaha Hadid Architects. ABS also inspired Jeff Jones' unconventional computing using the slime mold Physarum polycephalum to construct the natural multi-agent computational model[5].

2.0 METHOD

Our research investigated the agent as the physical entity within the field of urban design. It focused on the agent's properties used to respond to external changes, specifically how the agents can "sense" and "act" to form a bottom-up system. We studied the self-organizing behavior research from Kokkugia, agent and cells method by Batty as well as the wet grid by Frei Otto. The investigation focused on the movement based urban network, which was simulated through ABS and evaluated by the space syntax method.

2.1 Phase I: Movement Network

Our process began with a straight network, which was constructed based on the desired movement among a group of spatial nodes. This approach used the bottom-up interaction of individual agents to respond to other agents within the system. First, a group of spatial nodes were woven into a network in Autodesk Maya program.

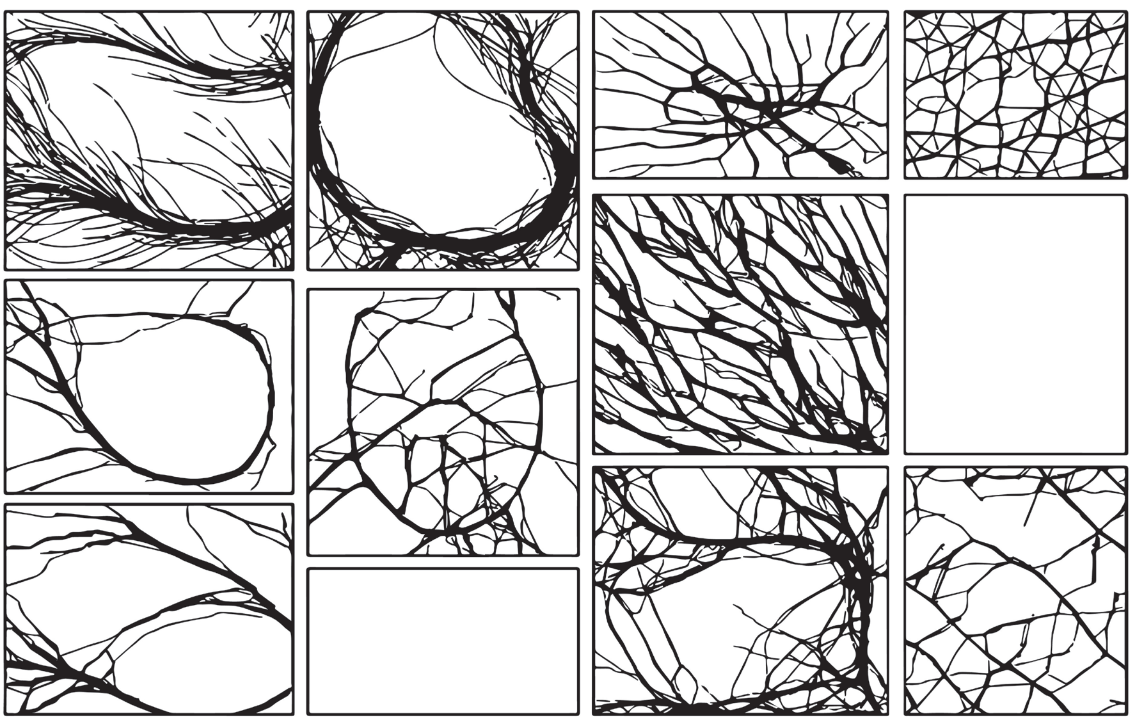

Figure 1: ABS movement network by processing.

Once the respective nodes were identified, the straight paths connected those nodes and formed an intersecting network (Figure 2: Row 1). The initial network was optimized using Frei Otto's wet grid method, which is a physics-based analog model. Instead of a simple "dumb" static network, each Control Vertex (CV) along a path became an active agent driven by the physics engine in Maya. The agent interacted with other CVs from neighboring lines based on the proximity, attraction, and collision. Maya Nucleus engine optimized the movement network based on the proximity and interaction of agents. The virtual environment was formed by a series of static collision objects including buildings and none-destructive topographic boundaries. As a reactive agent, every CV along a path was analyzed in its relationship to other CVs within the system. With ABS, the autonomous "action" of each path lied within modifying its CV point based on the repulsion or attraction to neighboring agents in addition to the environment itself. Over a period, a path organization was automatically formed as the agents stop and remain their positions.

With the external forces and interaction among agents, the autonomous "action" of each agent lied within modifying its movement based on the repulsion or attraction to neighboring agents in addition to the environment itself. A complex movement organization was automatically formed over time. Visually, the agents' trails appeared to be bent, deformed, and merged into one another based on their contextual relationships.

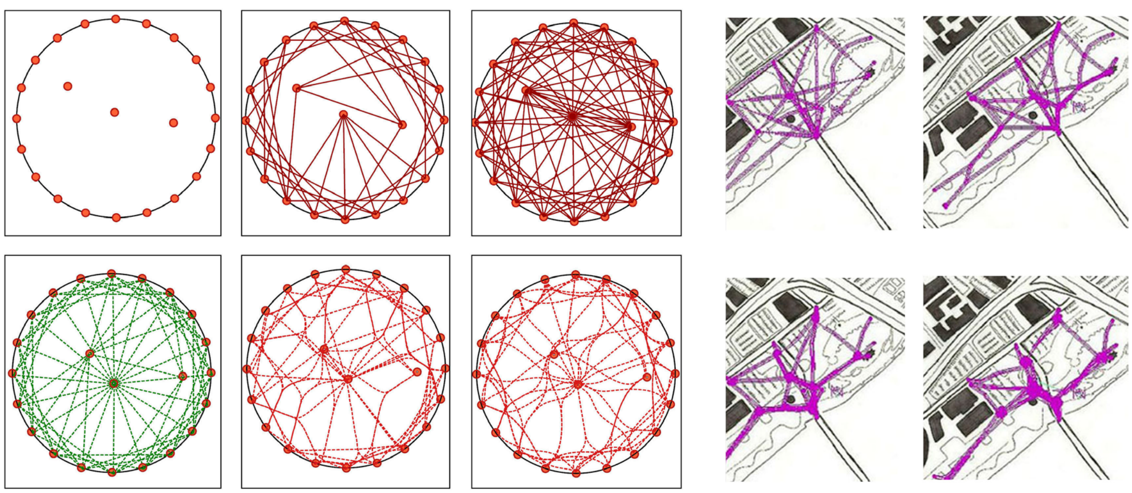

Figure 2: Row-1: Initial straight network. Row-2: Optimized Network.

2.2 Phase II: Blocks and Spatial Accessibility

Space syntax is a powerful method to study movement patterns and accessibility. A street is computed as a line, and open environment is calculated as a cluster of "cells" in space syntax. By using various spatial analysis tools, the accessibility of cells and lines can be measured. These simulated results are generated to measure spatial integration, accessibility, and other circulation related values. These qualitative values extracted from space syntax analysis can be combined with other data for further computation. We used Grasshopper script to apply the space syntax as a quick evaluation method to the self-organizing pattern generated in the first phase. The result was then translated into a raster image, named "attraction map" representing the overall spatial accessibility. The raster image was combined with other maps and used later in Phase III to drive the urban form generation (Figure 3).

In this stage, the urban blocks were generated by the abstract self-organizing movement pattern from Phase I. We defined a block as a "placeholder" with an index value projected back to the attraction map. A Grasshopper script was used to extract the "attraction" value based on the index of each block.

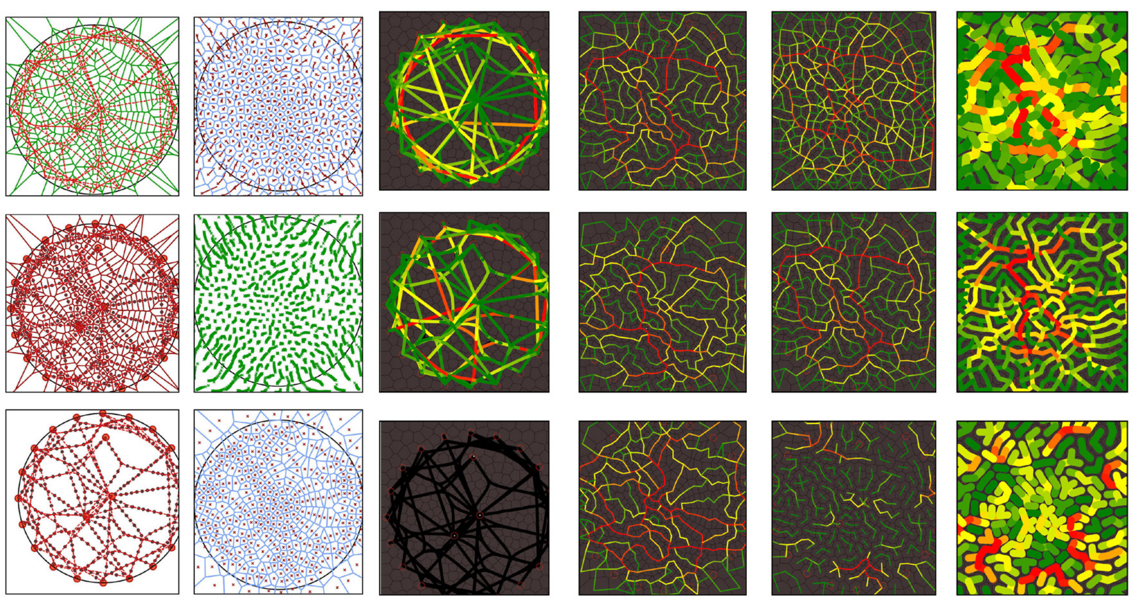

Figure 2: Row-3: Phase II. The space syntax analysis was primarily used for evaluating the existing movement pattern. Then, it was transformed into the final "attraction map" and applied to urban blocks.

2.3 Phase III: Urban Modeling

Besides the accessibility values from space syntax, various assumption data were added to the "attraction map" to represent development intensity, Floor Area Ratio (FAR), zoning, and other planning related quantitative attributes. These data were represented as various maps and combined with appropriate weight values. Each block can "read" its corresponding data from a particular map and use the values to construct an urban model. For example, a building type map was created to control the building type. A building height map was used to control the levels of each building. A means-of-transit map was used to indicate the car usage. These maps guided the placement of buildings, green space, parks, and automatically filled blocks. The overlaid external data were understood as the changing

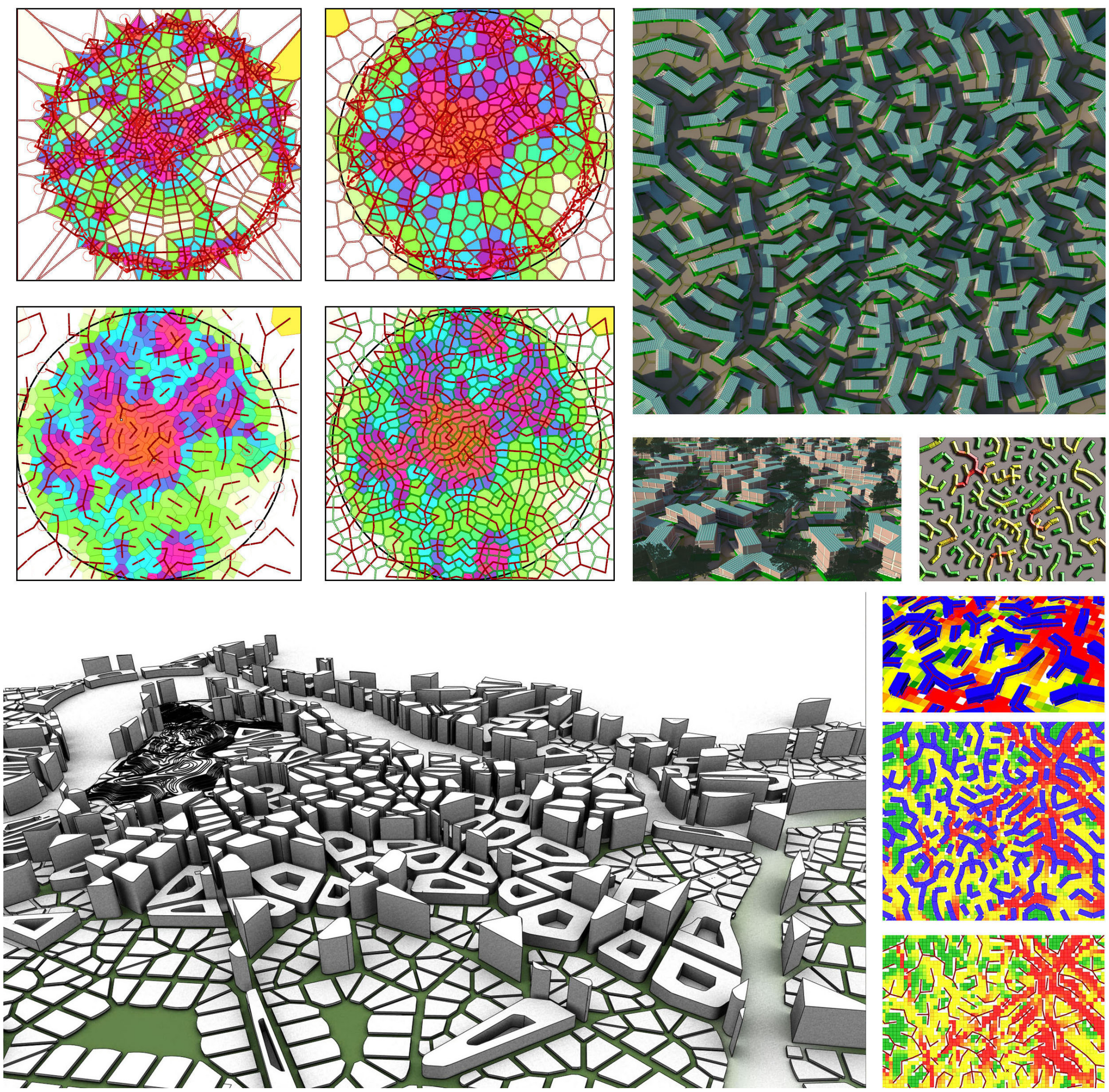

Figure 4: Phase III. An urban model constructed from 2D maps. Grasshopper script was used to populate various building types into the blocks.

scenarios over time. Similar to the design iterations, a large-scale urban model was constructed with flexible parameters of operation. Each scenario includes a set of changing variables. By changing values through a slider, an urban model simulated the growth from one scenario to another scenario.

3.0 PROJECTS APPLICATION

We applied the three-phase method to an urban design project sponsored by the municipal planning institute in Huanyuankou (HYK), Dalian, China. We were commissioned to design a 2,000,000 square meter district as a central hub and public space in the HYK economic zone, Dalian, China. Together with the multi-purpose buildings, the project required a mixed-use central business district blend with residential, commercial, business, tourism, and education programs. In our proposal, the idea of “slow life” and “slow movement” was realized by introducing bottom-up, self-organizing pedestrian network based on the existing attractions such as natural landscape, landmarks, and commercial centers. The three-phase ABS method was executed and produced organic movement pattern on top of the existing recliner infrastructure. This new superimposed movement network serves as the stimuli to rebuilt vacant lots and relinks various green corridors back to the natural landscape. The self-organizing pattern and conceptual model were further developed by architects, urban designers, and planners to fit the local context and program needs.

We applied the network optimization and space syntax to create the attraction map. An intricate order of urban pattern emerged based on the microscale interactions among agents. Multiple Voronoi shaped blocks automatically adopted a set of rules based on both bottom-up movements as well as the top-down planning methods. The self-organizing pattern of the movement network emerged based on the connection between proposed landmarks and the proximity to the existing natural landscape. A microstructure oriented land use map as well as a transportation system for pedestrian and bike were achieved through ABS and space syntax. Then the traditional planning method was used to drive the further design decisions (Figure 5).

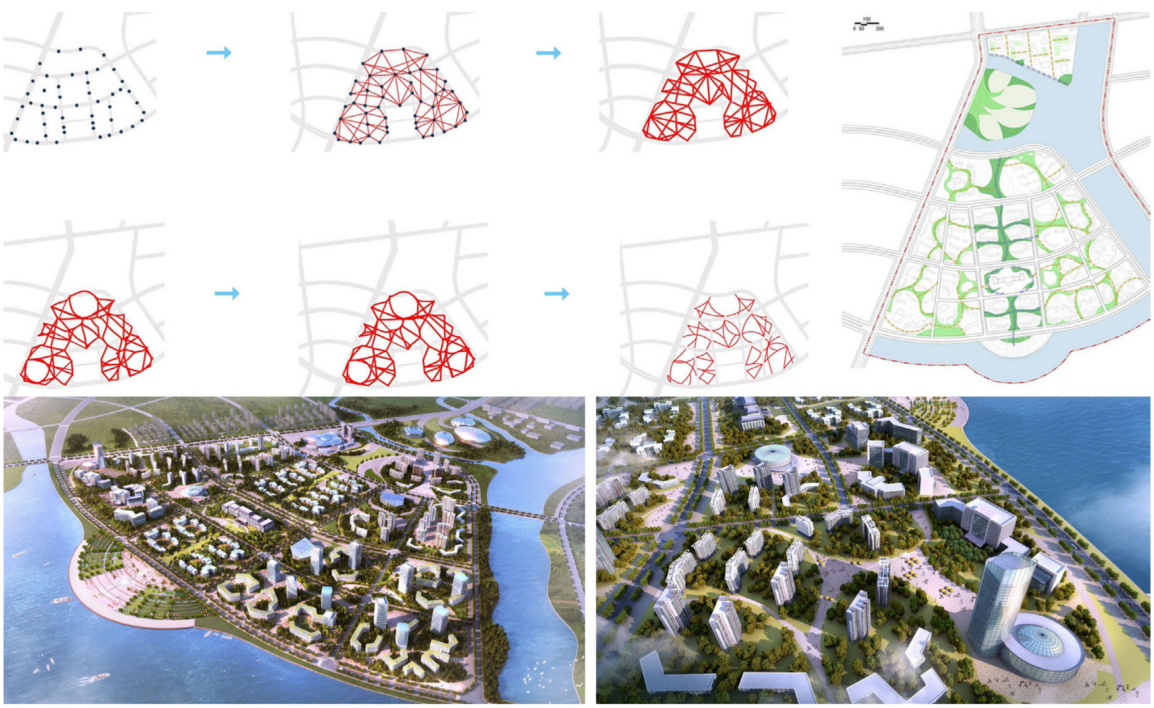

Figure 5: HYK district. To investigate the pedestrian movement in a complex spatial configuration, we evaluated and optimized the self-organizing pattern developed in ABS.

4.0 CONCLUSION

The research investigated how to integrate ABS into the urban design process and evaluate the result with space syntax. Compared with traditional top-down planning, this new method does not operate at the global level. It relies on the emergent properties and local interactions among agents. Together with traditional humanistic evaluation and ABS, a new relationship of designer and design agent has been forged. Within the process of ABS, the design is a result of the interaction between agents and their environment and the modulation of agents' behaviors within external rules. Our new ABS produced measurable improvement in the design. For instance, the ABS optimized curved network increased only three percent of traveling time compared to the original straight network. However, by joining and modifying paths into a new network, the overall length of the network was reduced by 43 percent. The optimization is significant for saving construction cost. In the HYK project in China, we applied ABS for path optimization. The initial straight network was generated by connecting existing urban nodes. We optimized the network to reduce the overall network length. The wet grid was used to create the pedestrian paths, bike route as well as the recreational areas. For the individual curved path, the traveling time was increased only three percent compared to the original straight path. The overall network construction length was reduced 35 percent - 45 percent compared to the straight network.

However, this method is not appropriate for the vehicular-based transportation design due to the small intersection angles. The optimized network is often irregular and different from the typical urban grid. Because the ABS is generated as a highly abstract in the micro level, we have to combine ABS with other transportation planning methods to construct a practical urban model in the later process. This post process can lead to confusion of the design logic and violate the early abstract model. The value of early ABS and the self-organizing solution was undermined.

There are other limitations in this method. The optimized network was evaluated by space syntax to facilitate design decisions such as land use, FAR, and development intensity. The one-way linear data flow was from ABS to space syntax, and eventually to the development intensity and land use. The early stage micro level ABS was isolated from the influence of space syntax evaluation. In an ideal situation, the space syntax analysis should be able to affect the ABS and serve as a feedback loop in a non-linear fashion. We are currently experimenting the genetic algorithm in Galapagos to integrate space syntax into the path optimization process. We are also investigating on importing geographic information system (GIS) data and other geospatial related "big data" into the "attraction map." The goal is to create a virtual urban laboratory allowing designers to manipulate environmental conditions and behaviors of artificial agents and test various design theories in both micro and macro levels.

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