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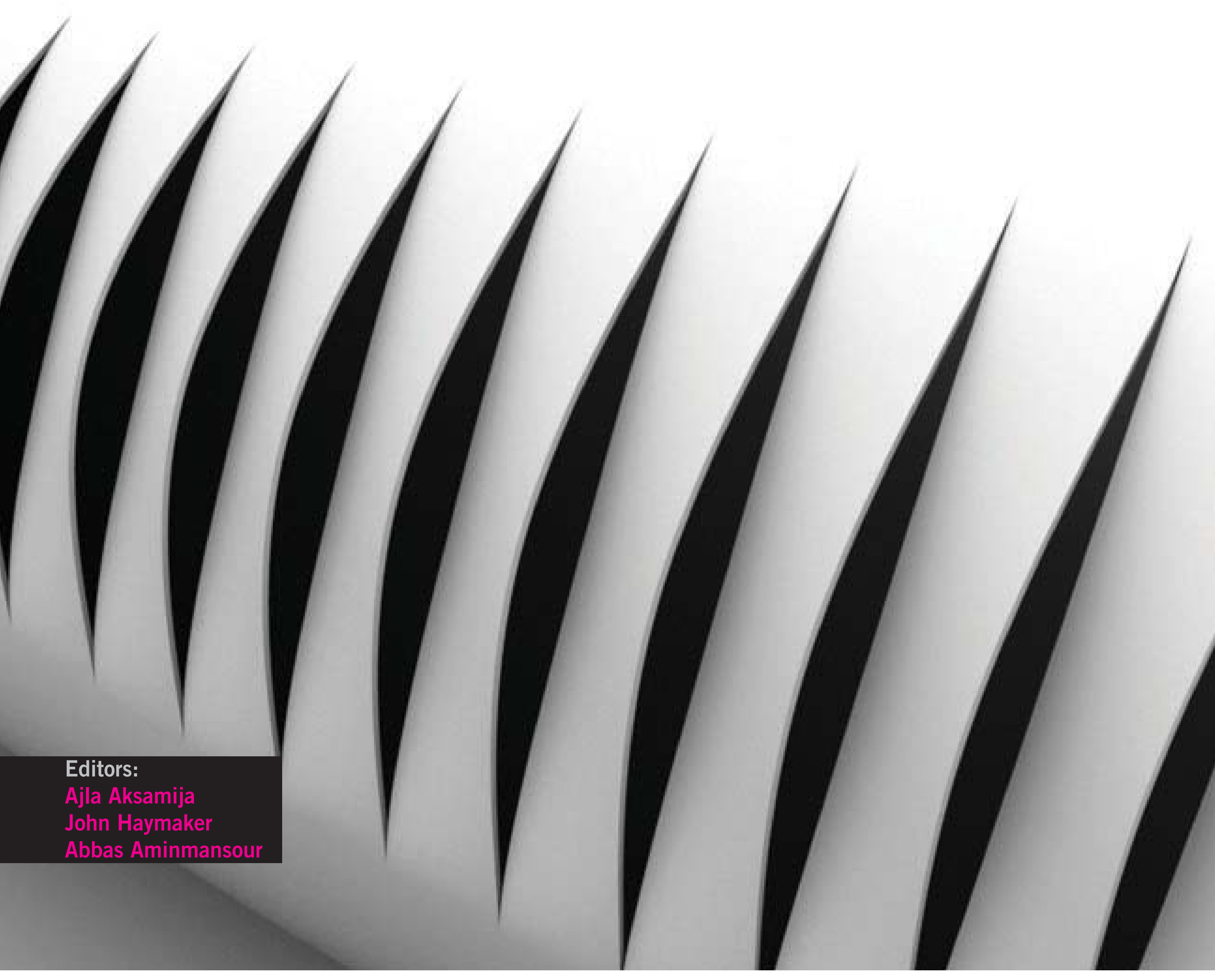

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Computational landscape: Data driven urban modeling with agent-based system

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ABSTRACT: Michael Batty described the property of “Autonomy” and “the embedding of the agent into the environment” as the two key properties of agents in an agent-based system. This paper presents the ongoing research of integrating agent-based methods with bottom-up urban modeling. The paper discusses several research projects and examines approaches where agents are set and interact with a defined environment. The research extends to the agents’ interactions driven by a set of rules and external forces. From the perspective of evaluation and optimization, a hybrid method is investigated by combining movement network, space syntax, and Geographic Information System (GIS).

The paper describes the process of bottom-up design and simulation to generate emergent urban patterns and adaptive urban forms. Starting with movement simulation, agent-based modeling tools are used to decode and recode the spatial complexity within the parametric equation. Computational tools for architects and urban designers such as a minimum path algorithm, spatial accessibility analysis, GIS, and procedural modeling are integrated to build a platform that allows parametric control of the generative outcome. The authors focus on how agent-driven emergent patterns can evolve during the simulation in response to the “hidden hand” of globalized goals. The multi-phase method starts with defining the self-organizing network, which is created by optimizing movement networks with agent-based modeling. Then, an “attraction map” is generated based on spatial accessibility and GIS data. The map is then used to control various urban morphologies and drive the construction of an adaptive urban model.

KEYWORDS: Self-Organizing, Agent-Based System, Space Syntax, Bottom-Up, Emergent

1.0 INTRODUCTION

1.1 Agent-Based System

An agent-based system (ABS) consists of numerous agents, which follow simple localized rules to interact within an environment, thereby formulating a complex system. The concept of the agent-based system has been widely used computer science, biology and social science, such as swarm intelligence, decentralized social networks simulation, and economic growth modeling. ABS consist of interacting rule-based agents which can create real-world-like complexity. In terms of spatial modeling, agents can be defined as autonomous “physical or social” entities or objects that act independently of one another[1] (Batty 2007). Our research only discusses the agent as the physical entity within the field of architecture and urban design. It focuses on the agent’s properties and processes used to respond to external changes, specifically how the agents can “sense” and “act” to form a bottom-up system.

1.2 Agent & Environment

As the basic element in a self-organizing system, the most popular behavior of an agent is movement. The autonomous agent can represent humans, animals, robots, plants or artificial lives. “The agent-based system with motion behavior mechanisms can be influenced by the other steering behaviors, at any moment; this is, to change the agent’s location and orientation” (Baharlou, Menges 2013). The autonomous, bottom-up approach is most effective for movement-related computation. For instance, ABS has been widely used to simulate the behavior of crowds, where the agents’ movements are computed based on the interactions among themselves, as well as the interactions with the environment. Because designers are able to analyze the relationship between the environment and the agents’ movement, design decisions can therefore be made by evaluating the result generated from ABS. There were many computational methods applied to simulate agents involving movement, including “the simple statistical regression, spatial interaction theory, accessibility approach, space syntax approach and fluid-flow analysis” (Batty, 2007). Many research projects have been done to examine how agents “sense” the landscape and “walk” through it, such as the study on shopping malls and pedestrian flows by Sehnaz Genai (Genai 2008), as well as the migration pattern by Batty in the Sugarscape exploitation[2].

1.3 Architectural & Urban Design Application

In recent years, ABS has become an integrated analysis and evaluative process. In architecture, this process is defined as "an interaction between internal components and external" (Kwinter, 2008). Some of the emerging aspects in the practice involve utilizing ABS to generate complex self-organizing systems and geometries that respond to the interactions of elements and external forces. ABS becomes "a computational framework that incorporates its own elements, rules and interactions" (Baharlou, Menges 2013). An agent can represent various architectural entities ranging from panels, volumetric massing, egress, and even abstract building program. ABS allows complex architectural systems to emerge from 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 tessellation pattern across a complex surface. Li Biao used ABS to optimize the location of skyscrapers to maximize their views and solar exposure. The ABS approach can also be found in large urban design projects, such as the context-aware multi-agent system for urban infrastructure by David Gerber (Gerber 2014), and path optimization system in the Kartal Pendik urban design project by Zaha Hadid Architects.

1.4 Preliminary Research

We studied ABS through swarm intelligence, circulation movement, and network optimization. Similar as Batty's "global attraction surface" in his study on the agent's movement, we created an agent system to introduce "external force rules" to influence the agents' movement behavior. (Figure 1) Similar rules were created in the layout planning researched by Hao Hua in the "floating bubbles" project (Hua, Jia. 2010). The external rules also were used to evaluate the purposive movement of agents in Clayton and Yan's panic evacuation simulation (Clayton, Yan, 2013).

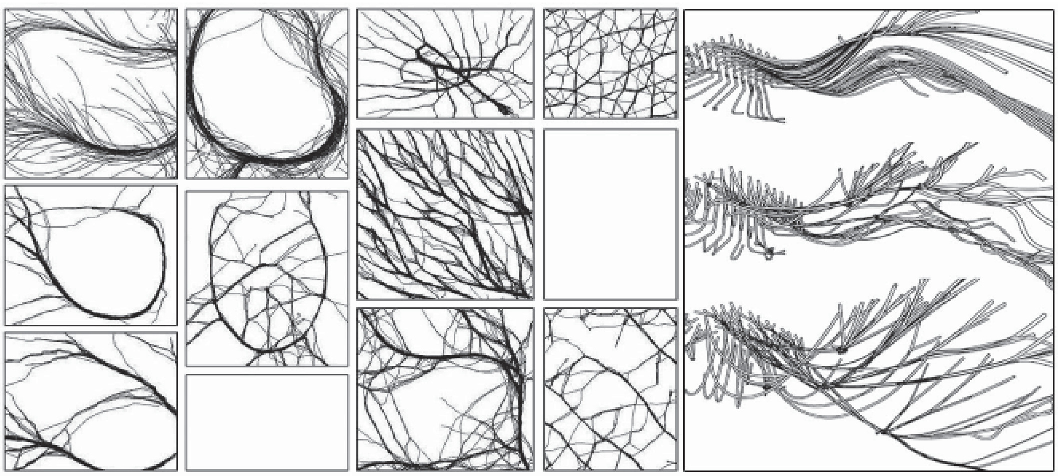

Figure 1: ABS movement network by Processing (2D space) and MEL script (3D space).

2.0 METHODOLOGY: SELF-ORGANIZING URBAN MODELING

Inspired by the parametric urbanism of Patrick Schumacher, shape grammar based procedural modeling by Pascal Mueller, self-organizing behavior research from Kokkugia, agent and cells method by Batty, as well as the wet grid by Frei Otto, we launched several preliminary research projects in 2014. The investigation focused on the movement based urban network, which is simulated through ABS, evaluated by space syntax method. (Figure 2)

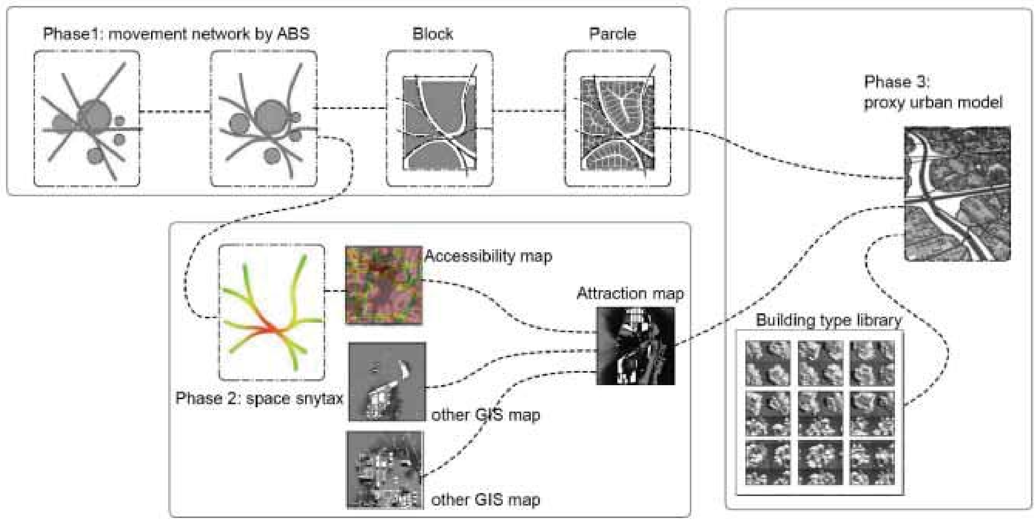

Figure 2: Three-phase process including movement network, attraction map and proxy urban model.

2.1 Phase I: Movement Network

The research began with an abstract city form by creating a movement network across a complex landscape. The goal was to form optimized paths. This approach uses a few simple behaviors of individual agents to interact with environment and other agents, which ultimately increases the complexity of the system as a whole. First, a group of agent-based spatial nodes was woven into an initial, rigid network (Figure 2). Once the two respective nodes are set to represent the start point and destination, a straight line is used to connect two nodes to represent the initial trajectory. A network optimization script is developed to generate the minimum paths using Otto's wool simulation method. Instead of a simple "dumb" static network, each agent along a path becomes an active, moving element and interacts with the neighboring agents and their trails based on rules such as proximity, attraction, alignment, and collision. The external landscape is formed by a series of contextual elements, including existing buildings, land obstacles, and non-destructive topographic boundaries. As reactive agents seek equilibrium between external forces and other agents and their trails, every agent's movement is continually modified within the micro environment by various operations such as attracting, following, repulsing, or keeping distance. The initial, rigid network thus evolves into a complex, self-organizing pattern.

With the external forces and interaction among agents, the autonomous "action" of each agent lies within modifying its own movement based on the repulsion or attraction to neighboring agents in addition to the environment itself. A complex movement organization is automatically formed over time. Visually, the agents' trails appear to be bended, deformed, and merged into one another based on their contextual relationships. Different behaviors can be assigned to form alternate emerging patterns. Designers can even set several conflicting behaviors in the ABS to allow one behavior to compete with other behaviors. (Figure 3).

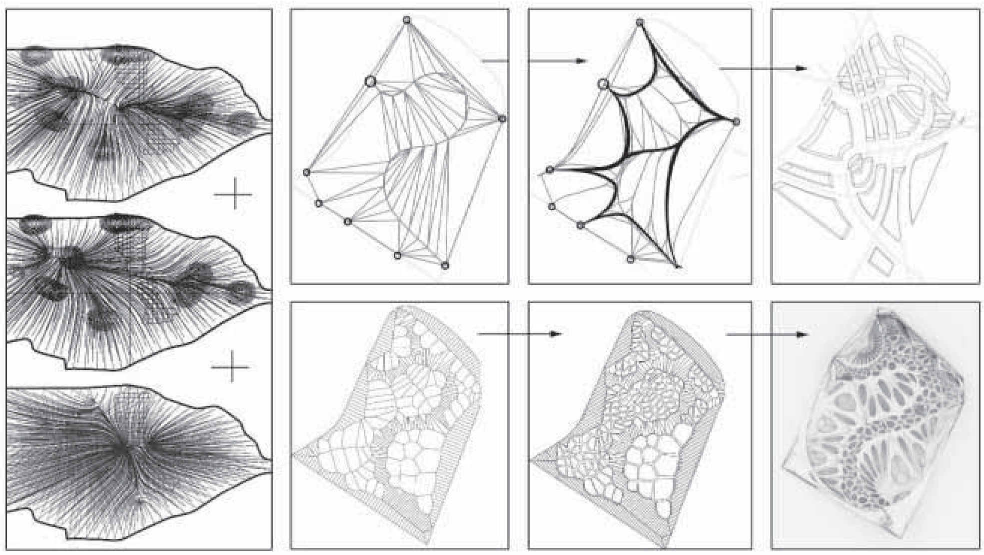

Figure 3: Phase I. A system of agents with unique values and behaviors are calculated and manipulated. The initial grid is optimized similar to Frei Otto's wet grid network[3], which is a physics-based analog method. A movement network is optimized by the computer simulation based on the proximity and interaction among agents and their trails. Projects by Dallas Puckett, Derek Morphew, James DiMeolo, Yiren Weng. University of Cincinnati.

2.2 Phase II: "Attraction map" by Space Syntax

Space syntax is a powerful method to study movement patterns and accessibility of streets based on nodes and network. A street is computed as a line and open environment is computed as a cluster of "cells" in space syntax. By utilizing various spatial analysis tools, the accessibility of cells and lines can be measured. These simulated results were generated to measure spatial integration, accessibility and other circulation related values. The new data associated with the geometry can be extracted and represented as color map and data sheet. In spite of including "agent analysis" tools, space syntax does not examine the interactions between agents. However, space syntax provides a fast analysis for spatial integration and accessibility. These qualitative values extracted from space syntax analysis are then combined with other data for further computation.

Although space syntax only evaluate the relationship between "passive agents" and the environment and does not allow adding agent's behavior, we used it as a quick evaluation method to the self-organizing pattern generated in the first phase. In order to convert the space syntax data into various geometric representations, we created several data processing methods using Geography Information System (GIS) and Grasshopper scripts. The goal of this hybrid approach is to allow geometries (point, lines and shapes) to carry new data representing their spatial accessibility and spatial integration values. The values are translated into a raster image, named "attraction map[4]" representing the overall spatial accessibility. The raster image is combined with other maps and used later in phase III to drive the urban form generation. (Figure 4)

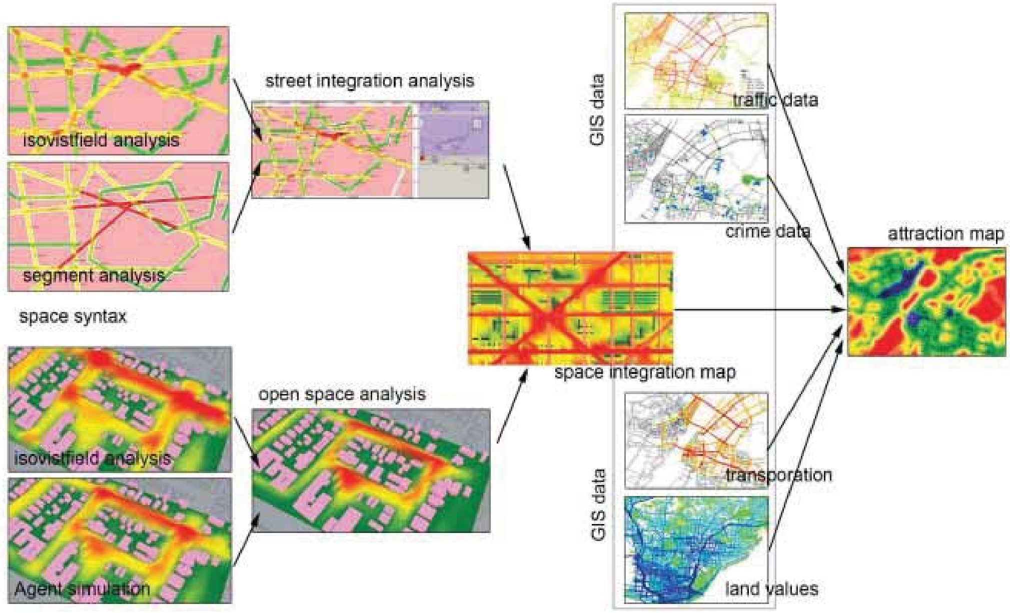

Figure 4: Phase II. The space syntax analysis is primarily used for evaluating the existing movement pattern. Then, it is combined with other GIS map to form the final "attraction map".

2.3. Phase III, Proxy urban model

In this phase, the urban blocks are defined by the self-organizing movement pattern from Phase I. Procedural modeling techniques are used to divide blocks into parcels based on various spatial subdivision algorithm such as voronoi and shape grammar. A parcel is defined as a "place holder" with an index value projected back to the "attraction map, the "hidden hand". Script is used to extract the "attraction" value based on the index of each parcel and populate it with appropriate buildings selected from a large building library. (Figure 5)

Besides the accessibility values from space syntax, extra GIS data were added to the "attraction map" to represent development intensity, Floor Area Ratio (FAR), zoning and other planning related quantitative attributes. These data is mixed together with appropriate weight values. Each parcel can "read" its corresponding data from the "attraction map" and then select the best-fitted building from a building library. For example, a view-shed map was created in GIS to control the building orientation. A family income map was used to control the placement of public housing. An above-60-year-old population density map was used to control the placement of senior housing. A digital elevation model (DEM) was used to highlight the unbuildable zones around steep slopes. The resulting "attraction map" guided the placement of proxy buildings, green space, parks and automatically filled parcels with 3D models. If needed, each proxy building mass can also be substituted by a highly detailed architectural unit from the building library.

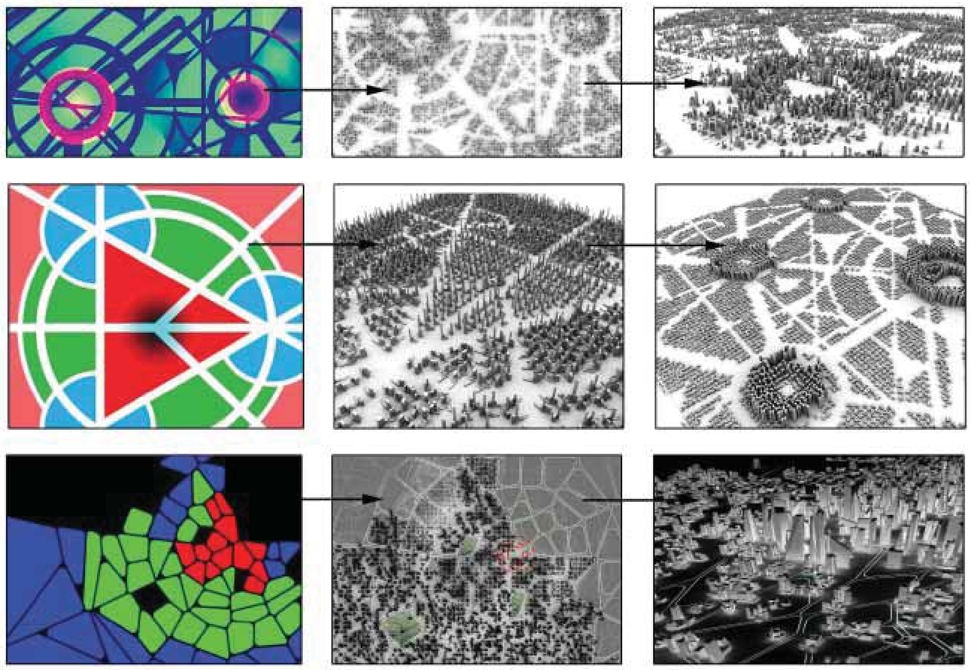

Figure 5. Phase III. Adaptive urban model constructed from "attraction map", using script to populate various building types into the "best-fitted" parcels. Projects by Trey Meyer, Boer Deng, Guande Wu, University of Cincinnati.

3.0 PROJECTS APPLICATION

In order to test this new bottom-up approach, we applied the three-phase method to two urban design projects, sponsored by a Chinese real estate organization and a local municipal planning institute in Dalian, China. The two projects present many challenging problems for our self-organizing approach with ABS.

3.1. Silicon Valley of China

The first commissioned project is called "Silicon Valley of China", a large urban design project in the TJW valley near Zhuhai. The project goal is to create a 6,000,000 square meter sustainable and ecological valley, which includes residential, commercial, cultural and institutional spaces. A new water system is required to improve the existing hydraulic network. We applied the movement optimization in the conceptual design stage. Space syntax was used to create an "attraction map" and combined with other GIS maps in the schematic design stage. Then, we used proxy modeling method to construct a fully detailed 3D urban model at the end. Self-organizing pattern of movement network emerged based on the external rules including the proximity to the existing urban infrastructure, slope of the topography and distance to the water body. The "soft grid" automatically adopted a set of forces that drive movement pattern with various magnitudes. A highly efficient circulation and transportation system for pedestrian, vehicle and bike was achieved by agent based simulation. As the result, neighborhoods, blocks, and parcels were automatically constructed based on the self-organizing pattern to promote the most efficient pedestrian flow and vehicular streamline.

Phase I: The self-organizing pattern was accomplished through an ABS bottom-up approach. Then, the movement network was optimized.

Phase II: space syntax was used to analyse movement network and generated an "attraction map". Two historic villages and the proposed public space are evaluated based on the spatial integration and accessibility values.

Phase III: Proxy urban modelling based on "attraction map". Green corridor, central park, and riverside park system were added into the 2D parcel system. 3D buildings were automatically loaded from a building library and adapted to each parcel based on the "attraction map". The map combined various data such as the proximity to the urban infrastructure, proposed zoning and development intensity. After the automatic modelling process was completed, the skyline along the river and east-west axis were evaluated and modified by designers. (Figure 6)

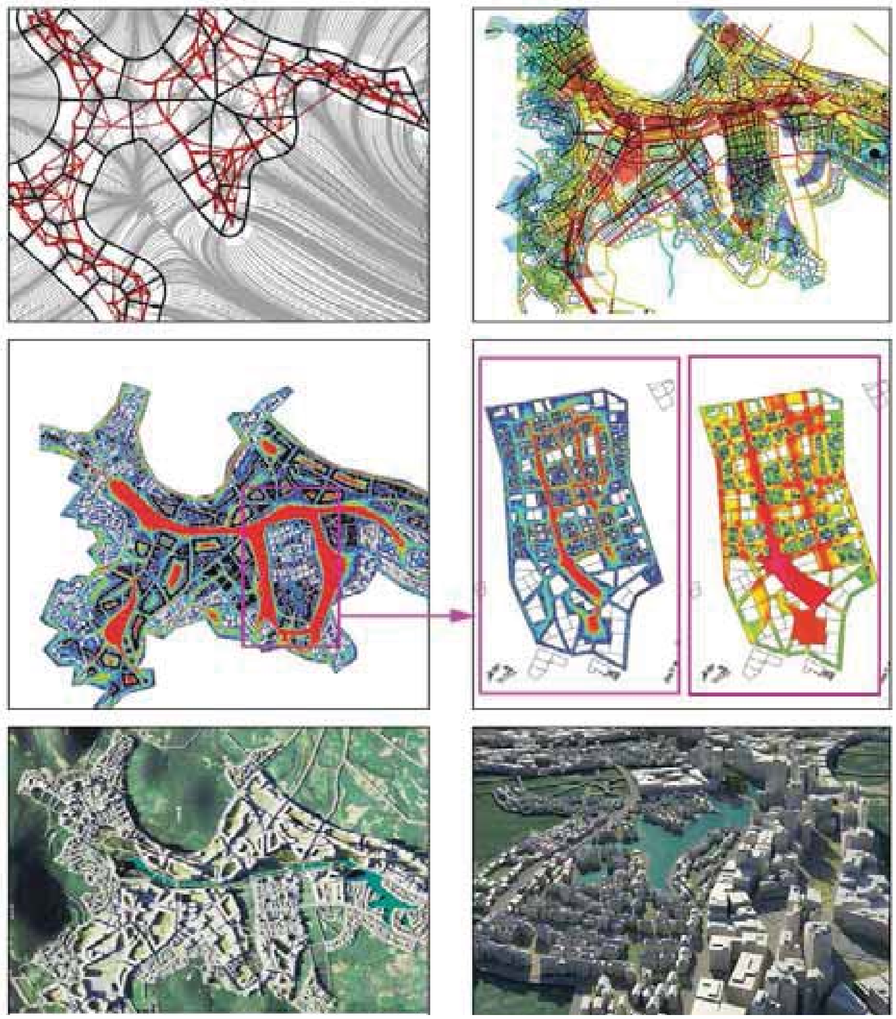

Figure 6. Adaptive urban model, Zhuhai, China.

3.2. Dalian, HYK district

In the second project, 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 surrounded, the project required a mix use CBD blended with residential, commercial, business, tourism and education programs as a whole. In our proposal, the idea of "slow life" and "slow movement" were 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 re-links various green corridors back to the natural landscape. The self-organizing pattern and conceptual model were further developed by architects, urban designers and planers to fit to the local context and program needs. (Figure 7)

Figure 7: HYK district. To investigate the pedestrian movement in a complex spatial configuration, we evaluated and optimized the self-organizing pattern developed in the first phase. Project team: Dalia Dushifazhan Design Institute, Ming Tang, Xinhao Wang, Arefi Mahyar, University of Cincinnati

4.0 CONCLUSION

Both projects demonstrated the bottom-up ABS are capable in generating characteristic movement networks. The generated paths were then analyzed based on the accessibility in space syntax. The result was coded in “attraction map” and drove the construction of a proxy urban model. Additional research interests center around the marriage between the “hidden hand” human supervision and computer-controlled automation. As Li and Xue argued in their multi-agent system “all agents are under controlled by human supervision.” (Li, 2008) There is an apparent need of a solution that integrates the wide variety of agent-based tools available today. It allows designers to generate and evaluate design iterations in a computational way. In conclusion, combining the traditional method of evaluation with ABS, a new relationship of designer and design agent has been forged. Within the bottom-up process of creation, design is now understood as a result of the interaction of agents and their environment, and the modulation of agents’ behaviors to react both physical and social patterns.

However, we do discovered several constraints of our linear three-phase method. First, the ABS movement network was generated as a driving force for the entire urban modeling without consider the proposed building settlements. The movement pattern was isolated from the influence of the later evolved building cluster. In an ideal situation, the building blocks and settlement structure should be able to affect the ABS movement pattern and serve as a feedback loop. Most likely, a minor influence from the building block can impact agent’s behavior and produce a totally different movement pattern.

The second constraint of this method is the creation of “attraction map” using space syntax and other GIS data. How to combine a large number of data generated from various data source and merge them into one single “attraction map”? The map needs encode a large quantity of abstract analytical data, including the accessibility map of space syntax. However, each of the data set only responds to one specific design aspect. How to judge the confliction between these data is a big challenge during the evaluation. When we have many abstract data responding to various geographical, social, political and economic features simultaneously, it is difficult for a designer to find an appropriate middle ground and create one single “abstract map”.

The future development is also focusing on the integration of space syntax into the bottom-up process. To create meaningful urban forms in an ideal ABS environment, designers should be able to continuously feed the analytical result of space syntax into the optimization loop, and guide the self-organizing process with constant modifications. Once this is achieved, the ABS can be used as a truly synthetic assistant.

ACKNOWLEDGEMENTS

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ENDNOTES

[1] Batty defined the environment as a cell-based landscape and agents as “objects or events that are located with respect to cells but can move between cells” (Batty 2007). Agents are objects that do not have fixed locations but act and interact with one another as well as the environment in which they exist according to some purpose.

[2] Batty researched on how the simple movement and resource exploitation actions on heterogeneous landscape can produce various settlement distributions. (Batty 2007)

[3] Frei Otto’s wool-thread machine is a form of an analog computer. Analog computers use a continuously changing aspect of a physical phenomenon to model a problem being solved. Otto’s wool-thread machines change the degree of freedom that water (a physical phenomenon) can act on the wool threads. By changing the degree water acts on the wool threads, Otto solves the problem of path optimization. The end geometry is a result of material interaction, elasticity, and variability.

[4]The name of “attraction map” is from Batty’s “attraction surface” in his urban growth ABS.

Research in architecture, design and the built environment is currently diversifying and reaching new directions. Technological changes, such as new materials, construction techniques and design representations, have accelerated the need for research within design disciplines. Today, research is more important than ever and it is also becoming an integral component in the design practices. The theme of ARCC 2015 Conference, the FUTURE of Architectural Research, addresses these aspects and aims to set the course for the future direction of architectural research. Today, interdisciplinary research approaches that address advanced materials, building technologies, environmental and energy concerns, computational design, automation in construction, design delivery methods, and project management are essential for advancing the state of knowledge relating to the design of built environment.

CONFERENCE THEMES:

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