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Exploratory Sequential Data Analysis for Multi-Agent Occupancy Simulation Results

Simon Breslav, Rhys Goldstein, Azam Khan and Kasper Hornbæk

Summary

In this paper we apply the principles of Exploratory Sequential Data Analysis (ESDA) to simulation results analysis. We replicate a resource consumption simulation of occupants in a building and analyze the results using an open-source ESDA tool called UberTagger previously only used in the human-computer interaction (HCI) domain. We demonstrate the usefulness of ESDA by applying it to a hotel occupant simulation involving water and energy consumption. We have found that using a system which implements ESDA principles helps practitioners better understand their simulation models, form hypotheses about simulated behavior, more effectively debug simulation code, and more easily communicate their findings to others.

Capturing an Architectural Knowledge Base Utilizing Rules Engine Integration for Energy and Environmental Simulations

Holly T. Ferguson, Charles F. Vardeman II and Aimee P. C. Buccellato

Summary

The era of "Big Data" presents new challenges and opportunities to impact how the built environment is designed and constructed. Modern design tools and material databases should be more scalable, reliable, and accessible to take full advantage of the quantity of available building data. New approaches providing well-structured information can lead to robust decision support for architectural simulations earlier in the design process; rule-based decision engines and knowledge bases are the link between current data and useful decision frameworks. Integrating distributed API-based systems means that material data silos existing in modern tools can become enriched and extensible for future use with additional data from building documents, other databases, and the minds of design professionals. The PyKE rules engine extension to the Green Scale (GS) Tool improves material searches, creates the opportunity for incorporating additional rules via a REST interface, and enables integration with the Semantic Web via Linked Data principles.

A Digital Design and Fabrication Library

Stylianos Dritsas

Summary

The goal of our system, for lack of better name at moment named as Alpha, is to offer an integrated approach to digital design and fabrication with capabilities beyond computer aided design and manufacturing. We attempt this to identify new modes of digital design thinking and to address the broader picture, that is, the challenge of translating between design and its production. It is to understand the complexity of design and its implications in production, to enable and perform architectural design analysis, rationalization and design performance optimization. We integrate visual: geometric modeling and simulation components; and non-visual: mathematical modeling and numerical optimization techniques. The intended audience at the current early stage of development is the research community in digital design and fabrication and design education with later goal of expanding to production.

Self-Organizing City: Experiments using Multi-Agent Model and Space Syntax

Ming Tang

Summary

This paper describes a process of using local interactions to generate intricate global patterns and emergent urban forms. Starting with network topology optimization, agent-based model (ABM) is used to construct the micro-level complexity within a simulated environment. The authors focus 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 space syntax. The multi-phase approach starts with defining the self-organizing system, which is created by optimizing its topology with ABM. A macro-level “attraction map” is generated based on space syntax analysis. Then the map is used to control various construction operations of an adaptive urban model.

Occupant-Aware Indoor Monitoring for Enhanced Building Analysis

Dimosthenis Ioannidis, Stelios Krinidis, Anastasios Drosou, Dimitrios Tzovaras and Spiridon Likothanassis

Summary

In this paper a novel, cost-effective and robust occupancy monitoring system is presented, which is based on a fuzzy confidence voting algorithm utilizing spatial height histograms. Spatial height histograms are invariant to rotations and translations, providing this way a desirable feature to occupancy measurement systems, and when combined with distance coefficients can fix an occupancy feature vector, which is the main source for the fuzzy confidence voting occupant tracking algorithm. The proposed occupancy extraction system can be efficiently applied to multi-space environments using a privacy preserving multi-camera cloud. Statistics per building, space and occupant can be finally extracted by the system. The experimental results will illustrate its robustness, accuracy and efficiency on occupancy extraction.

Self-Organizing City: Experiments using Multi-Agent Model and Space Syntax

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ABSTRACT

This paper describes a process of using local interactions to generate intricate global patterns and emergent urban forms. Starting with network topology optimization, agent-based model (ABM) is used to construct the micro-level complexity within a simulated environment. The authors focus 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 space syntax. The multi-phase approach starts with defining the self-organizing system, which is created by optimizing its topology with ABM. A macro-level "attraction map" is generated based on space syntax analysis. Then the map is used to control various construction operations of an adaptive urban model.

Author Keywords

Self-organizing, agent-based model, space syntax, urban simulation, urban design.

ACM Classification Keywords

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence

INTRODUCTION

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 model (ABM). An ABM consists of numerous agents, which follow localized rules to interact with a simulated environment, thereby formulating a complex system. Since Craig Reynolds' artificial "bodies" and flock simulation, the concept of ABM has been widely used to study de-centralized system including human social interaction. In urban modeling, agents can be defined as autonomous "physical or social" entities or objects that act independently of one another (Batty 2007). ABM 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. The actions are usually based on simple rules such as separation, alignment, and cohesion. Computer scripts such as Processing can be used to control agent's velocity, maximum force, range of vision and other properties[1].

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). In the early research phase, we compared the bottom-up ABM with the famous Cellular Automation (CA) methods to exam the generation of agents, their spatial properties, and their interactions with the environment.

It is important to understand the distinction between cells and agents. Batty describes agent as "mobile cells, which – objects or events that located with respect to cells but can move between cells." (Batty, 2007) Alternatively, CA calculates cells' changing state through time, based on the state of neighboring cells and context. During preliminary research, formal and spatial explorations concepts of CA allowed us to "grow" forms from seeds[2]. We applied Conway's Game of Life method to create a vertical path of a skyscraper. (Figure 1: Row 1) CA was used as a programmatic layout planner to establish a series of void cells and linked them vertically.

As two famous bottom-up systems, both CA and ABM compute the status of a changing object over time. However, we discovered that the behaviors of CA are often unpredictable and lack purposive planning goals. CA method was abandoned due to the difficulty to add rules and other "purposive goals" to the system beyond context awareness. Similar to Betty's "global attraction surface" in his study on the agent's movement, we need an agent system to introduce "external force rules" to influence the agents' behavior. It became obvious for us to choose ABM method over CA method.

We also tested several other commercial agent-based tools in the gaming and animation industry. One of them is the Maya Miarmy, a powerful plugin for character animation and dynamic behavior simulation. This mass animation tool has been widely used to simulate the behavior of crowds,

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where the agents' movements are computed based on the interactions among themselves, as well as the interactions with the environment. We also explored A* pathfinding in Unity game engine. The promising A* pathfinding algorithm has been used to create the "cognitive agents", which can populate a spatial model and navigate through a "cell" based map. Different from the "reactive" agent in Reynolds' flock simulation, these "cognitive agents" have their pre-programmed goals. The agents have the ability to observe the context and other agents' movement during the game play and modify their behavioral parameters. The computer controlled agents can make decisions while evaluating the result generated in a real time environment.

These tools and methods allowed us to understand the autonomous, bottom-up ABM approach and compare the effectiveness of various agent related computations.

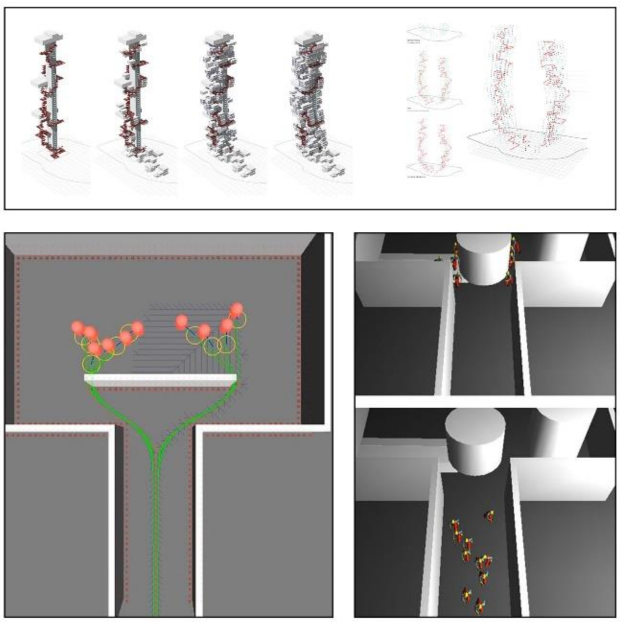

Figure 1. Top: Cellular automation drive vertical path. Miller August. University of Cincinnati (UC). Bottom: ABM simulation using A* pathfinding algorithm. Craig Moyer, UC.

ABM FOR URBAN DESIGN

ABM for urban design is established in the same relational model and computational strategy from the early sociologists' research. Some of the rigorous methods in the urban design practice involve utilizing ABM to generate micro level self-organizing urban forms that respond to the top-down rules and traditional planning methods. ABM allows a complex urban system to emerge from simple interaction among agents. Each agent can "sense" its neighbors and "react" to them by modifying its location, velocity, shape or other attributes. The ABM approach can be found in the Kartal Pendik urban design by Zaha Hadid, Shape grammar based procedural modeling by Pascal Mueller, self-organizing behavior research by Kokkugia, as well as the wet grid by Frei Otto. ABM also inspired Jeff Jones' unconventional computing using the slime mold Physarum polycephalum to construct the natural multi-agent computational model. (Jones 2014) All of these methods modeled the interaction of agents, despite model the macrostructure directly. We may be able to understand the dynamics of urban elements better not by modeling them at the global level but instead simulating the local interactions among these components and automatically construct the global patterns at the relational level.

Path Optimization

Our process began with a straight network, which is constructed based on the desired movement among a group of points. The points are added manually along the property lines representing the connections to the neighboring context, with the goal being to form an initial network. (Figure 2: Row 1) This approach uses bottom-up interaction of individual agents to respond to other agents within the system. First, a group of spatial nodes are woven into a network. Once the respective nodes are identified, the straight paths connect those nodes and form an intersecting network. The initial network is optimized using Frei Otto's wet grid method, which is a physics-based analog method. Instead of a simple 'dumb' static network, each Control Vertex (CV) along a path becomes an active agent. The agent interacts with other CVs from neighboring lines based on their proximity, attraction, and collision. We optimized the movement network by the computer simulation based on the proximity and interaction of agents. The virtual environment is formed by a series of static collision objects, including buildings and none-destructive topographic boundaries. As a reactive agent, every CV along a path is analyzed in its relationship to other CVs within the system.

With ABM, the autonomous "action" of each path lies 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 is automatically formed as the agents stop and remain equilibrium.

We also assigned the Voronoi pattern to each agent (CV) along the path forming its territory, an enclosed cell. The point-to-cell method allowed several new behaviors of agents in the system to interact with each other. For instance, "keep a distance" action was added to enable agents to scatter from the highly concentrated area, but simultaneously make alignment to its neighboring agents. (Figure 2: Row 4). As a result, agents were able to resize its cell/territory and seek a more balanced relationship with its neighboring cells. With a recursive scripting tool named *hoop snake*, agents' behaviors were calculated and manipulated over a period.

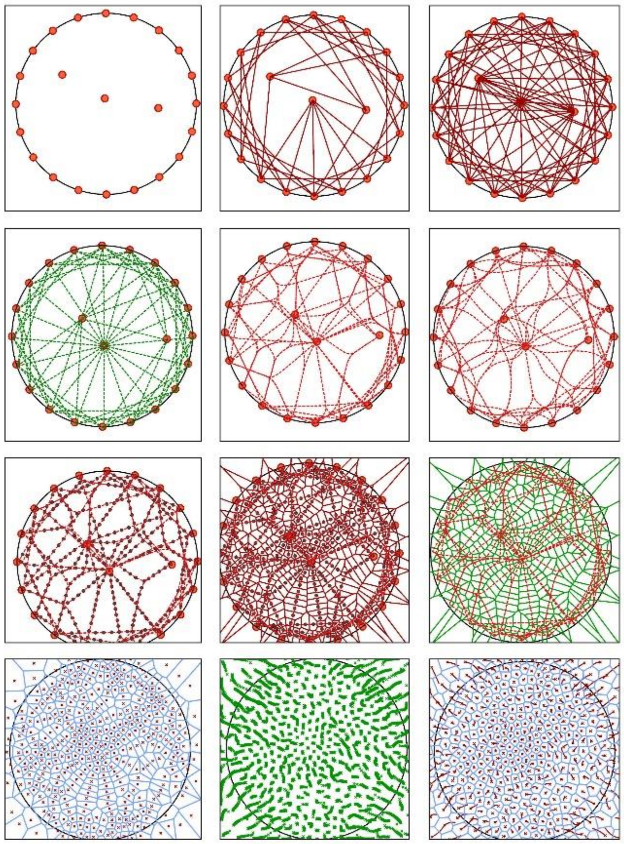

Figure 2. Row-1: Initial straight network. Row-2: Optimized network. Row-3: Voronoi pattern is used to create cells for each agent. Row-4: Agents move away from each other by separation rules. The movement trail is captured to illustrate the "relaxation" process.

Evaluate the AMB with Space Syntax

Space syntax is a method to study movement pattern and accessibility of a network based on lines, nodes and connections. As an "agent analysis" tool, space syntax does not measure the interactions among agents. However, space syntax provides fast feedback between geometric elements and its accessibility value within a network.

We introduced space syntax as an evaluation tool for the network optimized by ABM. Through importing the Otto's wet grid and Voronoi pattern into space syntax analysis tool, we extract spatial values such as accessibility and spatial integration and use them to evaluate the result of ABM. The warmer color represent higher spatial integration values. (Figure 3: Row 1) The centroids of adjacent Voronoi "cells" are connected and form a new network. This network is based on two variables. The first variable is the number of steps a cell take to move from its original status. (Figure 3: Row 2) The second variable is the number of neighboring cells, which are considered "visible" to a particular cell. (Figure 3: Row 3) We computed the integration value of each path by the segment analysis tools in space syntax and visualized the values with colors. The qualitative values extracted from space syntax analysis are imported into Grasshopper for further computing. In order to convert the space syntax result into a heat map representation, we created a data processing method to expand the color values automatically from paths to zones. We named the final image as "attraction map". (Figure 3: Row 4)

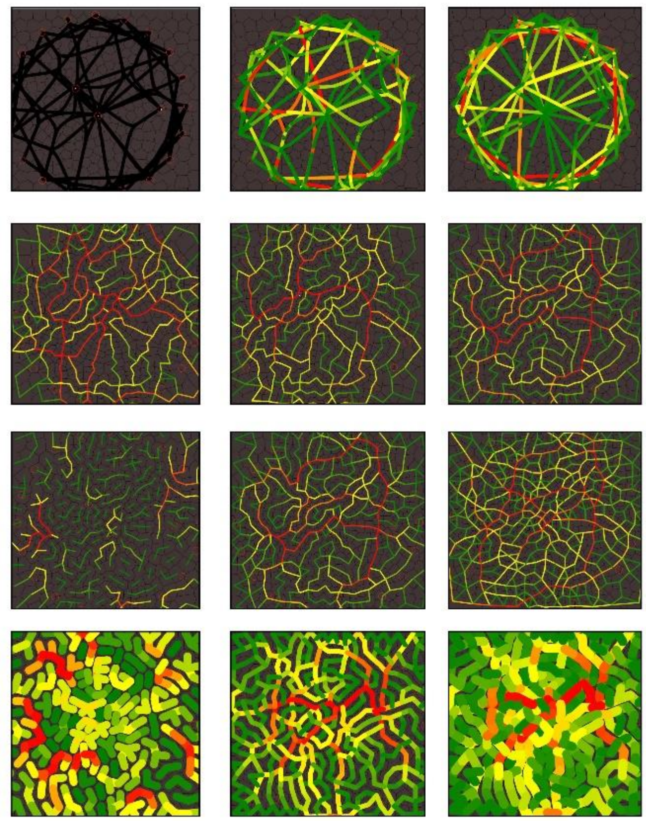

Figure 3. Space syntax analysis is used for evaluating the optimized network from ABM. Row-1. Spatial integration analysis. Row-2. New system is formed by connecting two closest neighbors. Then agents move from their original locations based on separation rules. Left: Initial network. Middle: network after 15 move steps. Right: network after 30 move steps. Row-3. Network by connecting neighbors who are visible to a particular agent. Left: seek one neighbor. Middle: seek two neighbors. Right: Seek 3 neighbors. Row-4. The cells are colored based on the spatial integration values in a heat map.

Attraction Map

In the previous process, each agent is treated as a "cell" with a boundary defined by Voronoi pattern. Then the "attraction map" generated from integration values of space syntax is introduced as the "hidden hand" to control land values and land use on a global scale. The color coded map drives development intensity, floor area ratio (FAR), descriptive zoning code and other spatial attributes. Urban blocks defined by the cells interact with the attraction map and adapt to the best-fitted land use and building topology. We developed script to seek and populate various buildings into the "best-fitted" cells. (Figure 4) This mapping process involves the agent's movement, cell morphing and changing integration values over time. The resulting attraction map is updated by recursive calculations and visualized as a large number of animated "cells" over time.

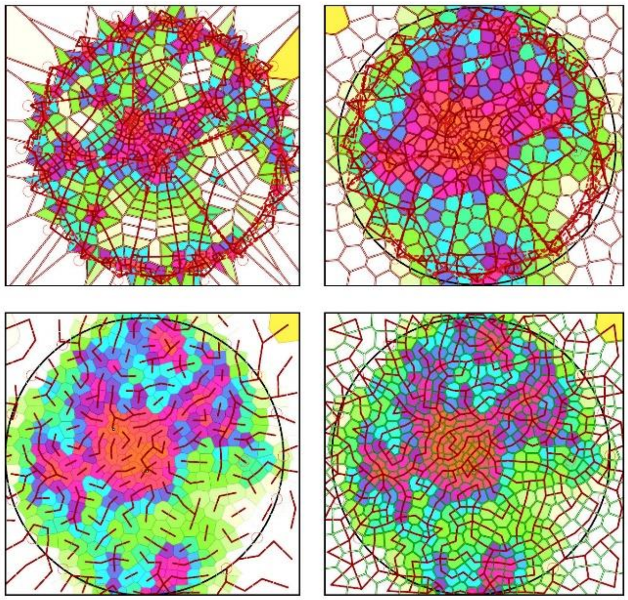

Figure 4. Adaptive urban model constructed from "attraction map". Row-1. Left: Cells concentrate in the "hot" zones of a heat map. Right: Cells move based on separation rules. Cells morph gradually during the move. A bigger well-integrated area evolves from previous smaller area. Row-2. Left: Agent seeks single closest neighbor and makes a connection. Right: Agent finds two closest neighbors and makes connections.

PROJECTS

"Silicon Valley of China" is a large urban design project in the TJW Valley near Zhuhai. The project goal is to create a 6,000,000 square meters 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 network optimization and space syntax to create the attraction map. An intricate order of urban pattern emerged based on the micro-scale interactions among agents. Multiple Voronoi shaped neighborhood automatically adopted a set of rules based on both bottom-up movements, as well as the top-down planning methods. Self-organizing pattern of the movement network emerged based on the connection between proposed neighborhoods and the proximity to the existing natural landscape. A microstructure oriented land use map, as while as a transportation system for pedestrian, vehicle and bike were achieved by ABM and space syntax. Then the traditional planning method was used to drive the further design decisions. (Figure 5).

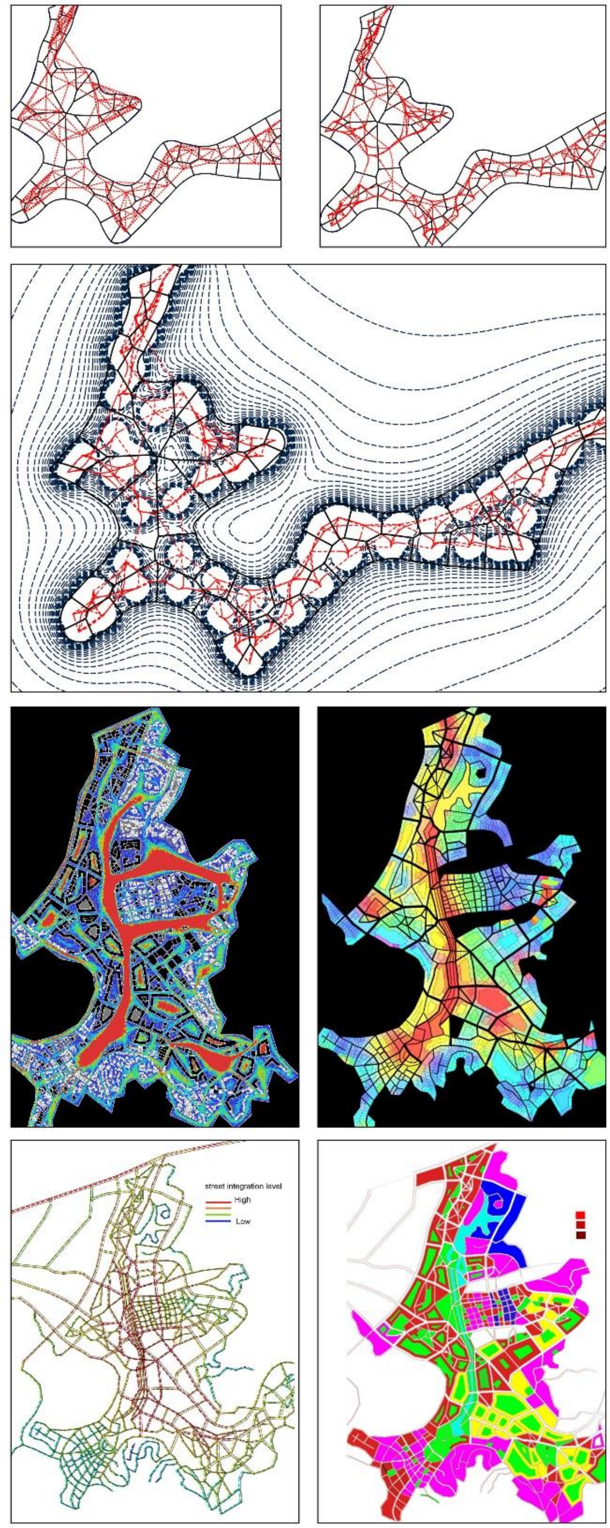

Figure 5. Adaptive urban model, Zhuhai, China. Row-1: The self-organizing pattern was optimized through ABM. Row-2. Voronoi pattern and Metaball method are used to create neighborhoods. Row-3. Space syntax was used to analyze movement network and generated an "attraction map". Row-4. Transportation system and Land use plan were developed based on the attraction map.

HYK economic zone is another project requiring a mixed use CBD blended with residential, commercial, business, tourism and education programs in Dalian, China. We applied the ABM and Space Syntax method and produced organic movement pattern on top of the existing recliner infrastructure. This new superimposed flow network relink various green corridors and left over vacant lots. (Figure 6)

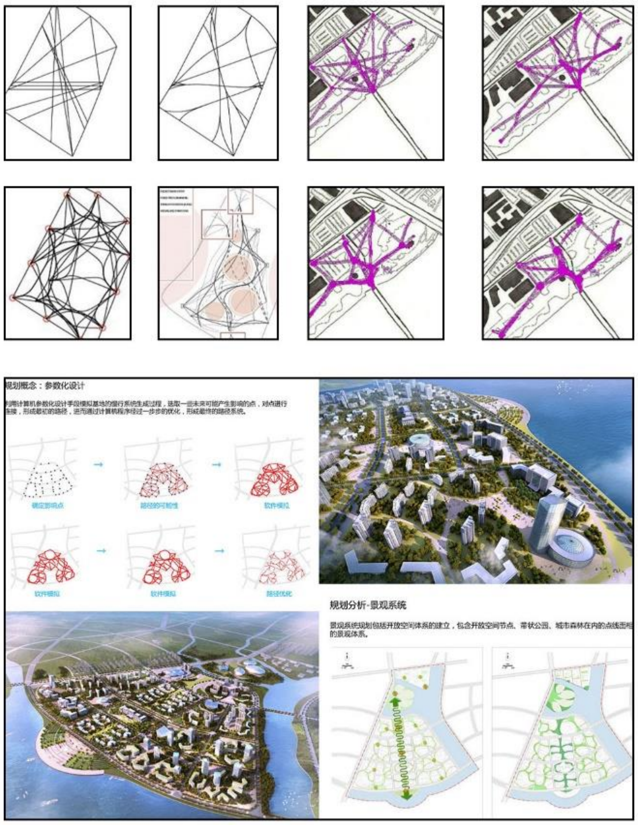

Figure 6: Row-1, 2. Conceptual model to investigate the pedestrian movement in an existing urban context. Benjamin Tamarkin, Andrew Campbell. UC. Row-3, 4. ABM was used to optimize the pedestrian and bike paths in HYK district. Project team: Dalia Dushifazhan Design Institute, Ming Tang, Xinhao Wang, Mahyar Arefi, University of Cincinnati

CONCLUSION

The research investigated how to integrate ABM into the urban design process and evaluate the result with space syntax. Compare 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 ABM, a new relationship of designer and design agent has been forged. Within the process of ABM, design is a result of the interaction between agents and their environment and the modulation of agents' behaviors within external rules. The new ABM can produce measurable improvement in the design. For instance, the ABM optimized curved network increased only 3% of traveling time compare 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%. (Figure 7)

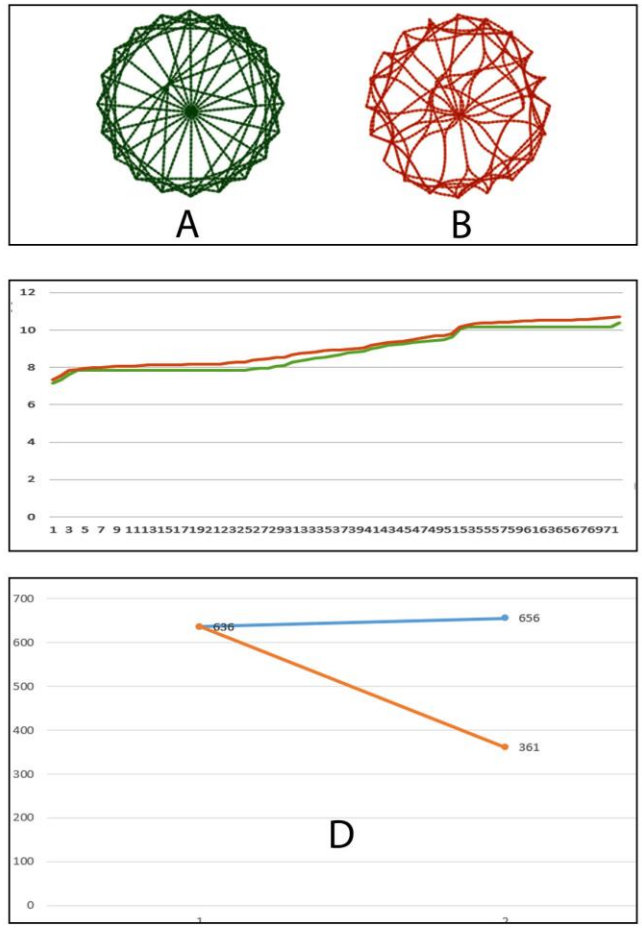

Figure 7. A: initial network. B: optimized network. C: Green: individual travel time of initial paths. Red: individual travel time of optimized paths. D: Compare with the intimal network, the optimized network has 3% increase of overall travel time. (Blue line); 43% decrease in total network length. (Red line)

The optimization is significant for saving construction cost. In the two urban design projects in China, we applied ABM for path optimization. The initial straight network was generated by connecting many existing intersections. We optimized the network to reduce the overall network length. The result of a wet grid is used to suggest the pedestrian paths, bike route, as well as the slow vehicular movement. For individual curved path, the traveling time is increased only 3% compare to the original straight path. The overall network construction length is reduced 35%-45% compare 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 very different from the typical urban grid. Because the ABM is generated as a highly abstract in the micro level, we have to combine ABM with other transportation planning methods to construct a realistic 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 ABM and self-organizing solution might be undermined.

We found another limitation of this method. The new network is evaluated by space syntax to facilitate design decisions such as land use, FAR, and development intensity. The one-way linear data flow is ABM →Space Syntax-→ Land Values -→ Development Intensity→Land use & FAR. The early stage micro level ABM was isolated from the influence of space syntax evaluation. In an ideal situation, the space syntax analysis should be able to affect the ABM 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 to 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.

ACKNOWLEDGMENTS

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REFERENCES

1. Batty, Michael. *Cities and Complexity, Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. MIT Press. 2007
2. Jeff Jones, Andrew Adamatzky. Computation of the traveling salesman problem by a shrinking blob. *Nat Comput*. 2014. 12:1-16.
3. Ehsan Baharlou1, Achim Menges. Generative Agent-Based Design Computation, Integrating material formation and construction constraints. e*CAADe* 2013.
4. Gideon Aschwanden. Agent-Based Social Pedestrian Simulation for the Validation of Urban Planning Recommendations, *SIGraDI* 2012.
5. Li Biao, Li Rong, Xue Kai, Liu Chang, and Gao Qin. A generative Tool Based on Multi-agent system: Algorithm of "HighFAR" and Its Computer Programming. *CAADRIA* 2008.
6. Peter Buš. Emergence as a Design Strategy in Urban Development Using agent-oriented modeling in simulation of reconfiguration of the urban structure e*CAADe* 2012
7. Hao Hua and Ting-Li Jia. Floating Bubbles, An agent-based system for layout planning, *CAADRIA* 2010
8. Ben Coorey, Scalability. Parametric studies from exoskeletons to the city. New Frontiers: Proceedings of the 15th *CAADRIA* 2010.
9. David Gerber. Rorigo Shiordia Lopex. Context-aware multi-agent systems. *ACADIA conference proceeding*. 2014.
10. Tom Verebes. *Masterplaning the adaptive city. Computational urbanism in the Twenty-First Century*. Routledge. London. 2014.
11. Batty, Michael. c1983, *Environment and Planning B: Planning and Design*, London: Pion Lt. 1983

ENDNOTES

[1] Processing language can be used to construct agent-based system. For example, using the agent class from kokkugia and toxic Processing library, the script can control agent's behavior.

[2] http://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

Any live cell with fewer than two live neighbors dies as if caused by under-population. Any live cell with two or three live neighbor's lives on to the next generation. Any live cell with more than three live neighbors dies, as if by overcrowding. Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.