Chapter X. Data-driven Landscape

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Introduction

This chapter presents a study investigating the emerging data-driven processing related to urban design and landscape design. Unlike convention design procedural, the new data-driven model considers quantifiable geospatial and time-based data as input parameters. A data-driven design is defined as a hybrid method, which seeks logical landscape forms and analyzes its importance through various advanced computational methods including scripting, mathematical models, and quantitative analysis. We extended these methods by exploring, collecting, analyzing, and visualizing geospatial data and representing it through 2D, 3D, 4D, fabrication and various simulation technologies.

1. Geospatial data set

For architects, urban designers, and landscape designers, a design process usually starts with data mining. It is essential to collect geospatial information and visualize it in a meaningful way to stimulate design process. Although the data format might be different, the nature of various geospatial data at this stage is usually a statistical distribution across a physical environment. The statistical features such as mean, median and outliers can be computed on the associated elements such as parcel, block, and county. Typically multiple possible distributions are compared by graphing quantities against each other and then studying the generated patterns. For instance, the Geography Information System (GIS) allows the viewers to measure whether the plot values are similar and if the two distributions are related in a map format. (Figure 1)

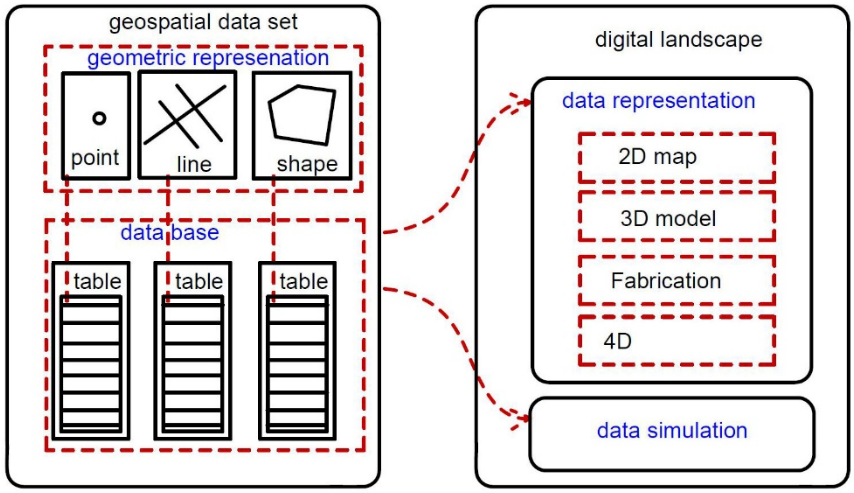

Figure 1. Left: data set contains geometric representation (point, line, shape) as well as the database.

Right: various data representation and simulation methods.

There is a variety of conventional methods for data representation and infographics techniques such as tables, histograms, pie charts and bar graphs. However, designers are always interested in finding alternative ways to visualize data from a designers' mindset. But at first, we must understand that two primary components of a geospatial data set are geometric representations, and the associated information stored in the database.

Geometric representation

Point, line, shape are the basic geometries represent geospatial features such as the landmark, river, parcels, blocks, county, and land use in GIS. There many methods can be used to visualize landscape data within a geometric representation. For instance, point, lines, and shapes can be used to generate a diagrammatic map. These thematic maps contain GIS data such as zoning, population, transportation, and other spatial information. Emerging parametric modeling tools can read the geometries extracted from the GIS data set and execute corresponding modeling operation to analysis and manipulate the geometries. The resultant model inherits all the geometric information from the initial GIS data set.

Database

Other new emerging methods involves using scripts to connect to the database directly. The imported values from a database can dictate geometric operations automatically and thus replacing the most labor-intensive modeling. Designers can stream values from the Excel or dbf format database, and generate new values by combining some existing values.

There are more creative and design related methods to integrate space-time data with the emerging parametric modeling tools in the design industry today. Many of these new data collections, representations and analysis methods are established by directly feeding the statistical data into the emerging digital modeling process to produce 2D, 3D, 4D, and simulations.

2. Digital landscape

Inspired by the data-driven modeling techniques, many new computational methods have been developed in recent years. Digital modeling is increasingly implemented in computing to create digital landscape with a high degree of complexity, such as the agent-based urban modeling by Michael Batty, parametric urbanism by Patrick Schumacher, and City Engine by Pascal Mueller. These methods utilize a set of computational principles to generate diagrammatic landscape models driven by a variety of data sets. One of the objectives of connecting abstract data to a geometric form is to create an engaging experience that allows designers to investigate the data in a dynamically changing interface. The new process permits designers to create a large numbers of representation options and explore unique design concepts. It is advantageous for the designers to be aware of the following essential categories of a data-driven process. We defined digital landscape into two categories, data representation and data simulation, based on its objective and computational techniques.

2.1 Data Representation

Data representation as 2D map

Geospatial data can be organized into point-based, polygon-based or line-based hierarchies. For instance, states, counties, tracts, blocks, and parcels are typically represented as polygons. Streams and transportation networks are typically represented as lines. Simple lines with added values can be interpreted as many spatial features such as transportation network or social connections, depending on their representations in the context. In GIS, a standard map uses point, lines, shape, color, symbols and space-filling variants to represent the geospatial data. Instead of simply represent the physical environment, the abstract analytical data can be projected and superimposed on the map. For instance, a color map can be constructed based on the circulation analysis and spatial integration values with space syntax technique. The new data can then be added on top of the existing streetnetwork to represent their spatial linkages. Spatial integration values associated with the streets can be perceived visually by color. (Figure 2).

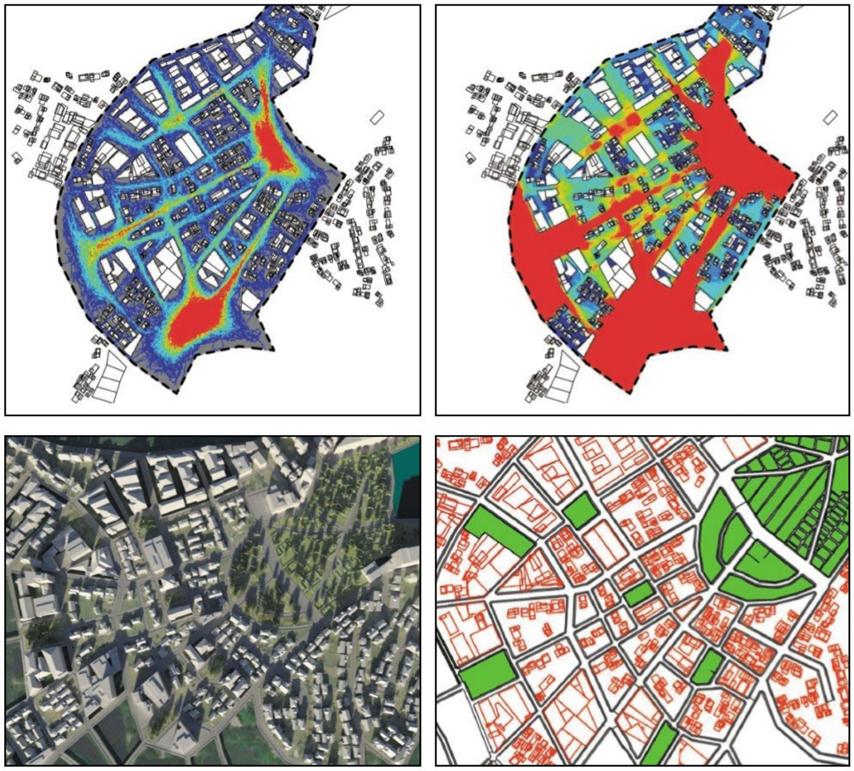

Figure 2. The color value is projected onto a 2D map to represent the spatial integration value. Silicon Valley of China. Tools: Space Syntax, ESRI City Engine. Autodesk Maya. By Ming Tang. 2014

Data Representation as 3D model

One of the goals of constructing a 3D landscape is to represent the statistical information, such as demographic data from the Census of Bureau. This process can explore the relationships among landscape elements and other social and economic parameters. For instance, the spatial integration values can be defined as the rule to control the height of a 3D surface. Although the generated model does not reflect any real typology in this area due to its singular parameter, it does allow the viewers to observe complex 3D urban patterns that communicate the information clearly. This process is similar to how contour lines and digital elevation image are used to represent 3D topography. These types of translations deliver meanings by manipulating data in various formats and structures, which allow points, lines, surfaces and masses to be interpreted as the diagrammatic objects. (Figure 3)

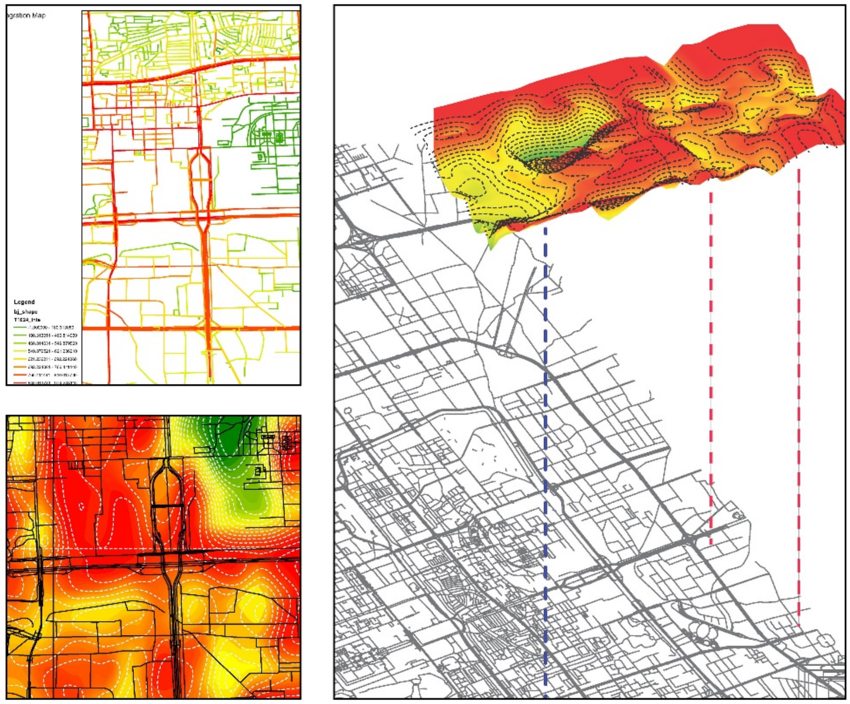

Figure 3: In order to integrate space syntax into parametric modeling tools, the spatial integration value is visualized by the height of digital landscape in the DSL district of Beijing, China. Tools: Space Syntax, Rhino, Grasshopper, ESRI ArcMap, By Ming Tang.

Project. 3D diagramic urban model. Yizhuang, Beijing.

The 3D data represenatation is also a powerful tool as an adaptable method of large-scale site design that can work to produce a responsive working system of distributed site programs and activities. The Yizhuang Industrial district in Beijing was used as a target area to test the capabilities of this data driven system. Developed in the digital 3D modeling programs Rhinoceros and Grasshopper, the data driven system applies measurable parameters such as population density, residential population, means of travel to a set of modeled building footprints. The goal is establishing the corresponding programmatic volumes.

A group of variables and parameters formed the responsive 3D model. A set of values worked together to integrate flexibility into the design process. Driving this flexibility were adjustable Grasshopper parameters that related calculated values back to the 3D program and adjusted building heights based on the proportion of programmatic volume required. The most important parameter of this process was the population density as it was the first parameter of the script that could be adjusted. Subsequent parameters were based on population percentage and the space needed per person for specific design focuses. Based on these two variables in the script, Grasshopper was able to calculate the total residential program square footage needed. Furthermore, this square footage was related back to the 3D model in that the required square footage was divided over the total building footprints allocated towards residential programming producing corresponding building heights.

Ultimately, this allowed the design team to update and model the entire urban model based on changing assumptions and calculations. After the 3D building mass were made in Rhino, they could be adjusted and moved around. If a building were unrealistically tall, the building floor print could be multiplied, lowering the height because the necessary space could be distributed among more buildings. The buildings were then moved to appropriately zoned blocks and monitored by the Floor Area Ratio (FAR) of the blocks.

Throughout the 15 weeks work, the parameters were adjusted contently, and more parameters were added based on the interaction with local planners. Using this type of parametric design process made updating the urban model very efficient. Below is a figure depicting the possible layout of various buildings and green space. (Figure 4)

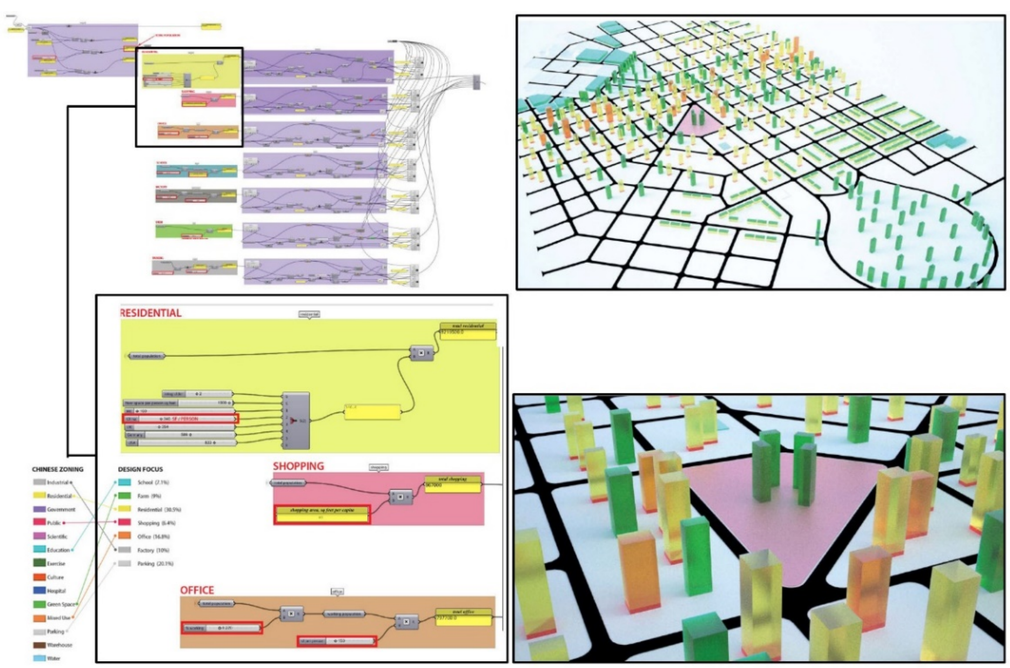

Figure 4. Parametric urban model of Yizhuang District, Beijing, China. Students: Ellen Crawford, Kelsey Reichenbach, Connor Borchardt, David Schaengold, Yinan Wu, Kyle Zook, Lydia Yen. University of Cincinnati.

The process was robust and easily adjusted when changes of the urban model were desired. The design team focused on the 3D modeling and scripting process, the relationship between various building types and their occupancy, parking, as well as the agricultural options. The types of agricultural options described included a brief mention of traditional field crops in the periphery of the site. The research on agriculture focused more so on vertical farming and green roofs. The vertical farms are represented as 3D building blocks. The final urban model became an interactive system controlled by the complex relationship between population, land use, FAR, agriculture infrastructure and other parameters.

Data representation with digital fabrication

With the newly generated data, the creation of physical models through 3D printing, CNC milling, and laser cutting is a powerful representation method. Designers can stream geospatial data into 3D modeling program, which allowed them to manipulate and control the representational geometry and generate the appropriate file for digital fabrication. As a result, designers can translate the abstract information into cutting patterns, tool paths, and 3d forms for digital fabrication. These artifacts were informed by the none-geometric data and not designed arbitrarily by the fabricators. While doing this process, designers had to take into account material property and machine processes. Fabricating, assembling, and interacting with a 3D physical model are the unique experiences that designers will never be able to achieve by viewing an abstract data set or thematic map. The physical model became a representation of the dynamic relationship between various data sets. The marriage between abstract data and fabrication technologies stimulates a different mindset and design thinking process. The dimensional and physical model becomes an object that represents the combination of various geospatial data sets. The model also displays the hidden spatial pattern and sparked the unique design solutions. (Figure 5)

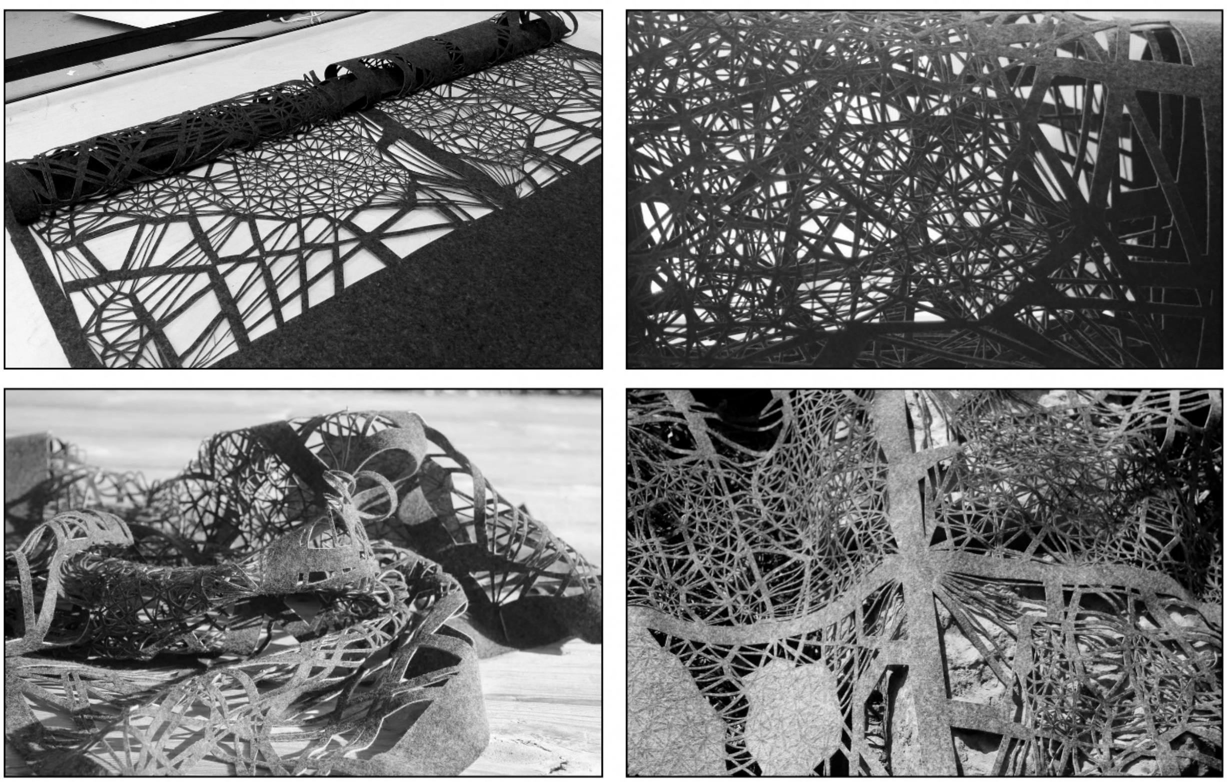

Figure 5. A tessellated city pattern is laser cut on a felt and deformed based on various operations. By Enrique Sanchez. University of Cincinnati.

Data representation with animation and scenario (4D)

The computational method is extended by exploring and visualizing time-based data and scenario-based data and interactively representing data through digital technologies. A sequence of static models allows complex conditions to be described in the animated sequence so that it might be more easily understood and managed. For instance, by constructing an animated digital landscape, the designers would be able to read certain correlation patterns over a period. Time-series data is frequently used in data processing. Index charts and stacked graphs are the conventional ways to illustrate the relative changes over time. However, it is hard to interpret trends graphically over a complex spatial pattern. An alternative way is to use morphing 3D forms, and the overall trends are more easily interpreted. The 3D animation can become very powerful when it is used to illustrate geospatial data within a defined coordination system. The animated objects can be constructed based on the geographical geometries such as parcels, blocks, counties or states. Animation becomes a natural way to represent the changing data. Designers can depict time and space through the use of lines, shapes, colors and other visual elements. For instance, the animated geometry encodes crime related data through its changing location, size, color or shape. (Figure 6) Using a variety of data, either from a map sequence or multi-column Excel database, the resulting animation allows for a larger number of changing values to be represented.

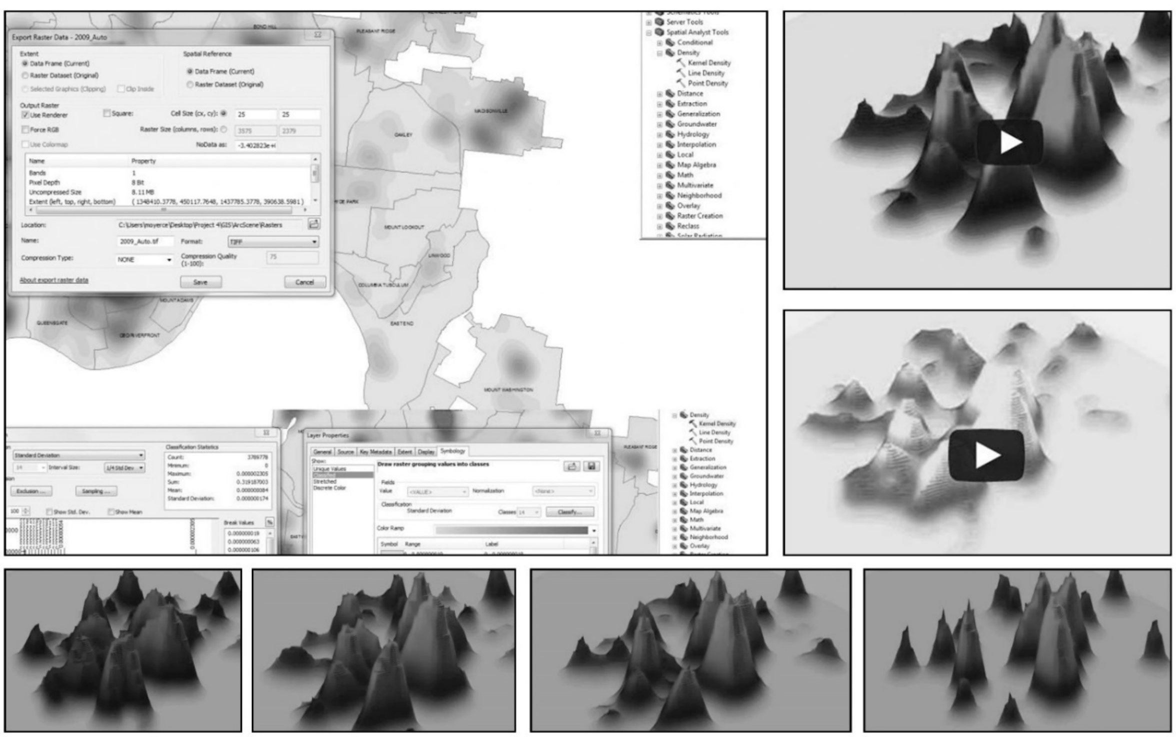

Figure 6: Animation based on urban crime data 2007-2009. City of Cincinnati. By Craig Moyer. Tools: ESRI ArcMap, Rhino, Grasshopper. By Craig Moyer. University of Cincinnati. We first collected point-based crime data for the city of Cincinnati. Data from 2007, 2008, and 2009 at the Hamilton County was downloaded as Excel files. Once the data

was compiled and prepared to be geocoded in Excel. Geocoding is the process of assigning each instance of reported crime to a point in space. This was done through a custom address locator, based on the GIS street grid layer, which matches the street, house number, city and zip code in the original crime table with a physical, real address existing in the Hamilton County. After only the points occurring within the city had been plotted, their respective crimes and densities of occurrence were analyzed. We chose to perform an essential kernel density analysis. This process examined and charted statistically significant clustering patterns of point-based data. To ensure an accurate and unbiased analysis of the clustering patterns, the ¼ standard deviations settings were used, which resulted in 14 classes of clustering. The resulting raster images were exported and brought into Rhino and Grasshopper program to construct a 3D morphing surface to represent changes in crime over time and space. This 3D surface was animated and effectively displayed spatial changes in crime over the years. The final result was rendered as several videos.

4D data representation can also be understand as the changing scenarios over time. Similar to the 4D representation in building construction sequence, a large scale urban model can be constructed with flexible parameters of operation. By changing values through the slider, an urban model can simulate the growth from a low density scenario to a high density scenario.

Project: Scenario based 4D model, Low Carbon City, Shenzhen, China.

PINGDI, the low carbon city's project area, is located 30 Km east of Shenzhen. It is part of the strategic Ping-Qing-Xin ECO-2-ZONE. It is surrounded by mountains at three sides and has much more land reserve than Shenzhen. The industry and services have been less developed and, therefore, offers ample opportunity for transformation into low carbon technologies/practices. While developing the vision of low carbon city, various entities (government, research institutes, and companies) in Shenzhen have done a very thorough review of low carbon cities around the world.

Based on the already established research, the goal of this research is to construct a relationship model, a "3d model + changing senarios". The model allows developers to understand the complex relationships among various urban parameters such as population, density, carbon emission, car usage, development intensity, zoning and energy consumption. The focus of Shenzhen Low Carbon City project is to formulate relational dynamic variables and parameters of which a low carbon city would be comprised. Within our 4D model, those formulae area attached to three scenario variables, named low density, medium density and high density development. A shift in any of the scenarios will result in a change in connected parameters. The use of dynamic modeling has allowed us to compare the advantages and disadvantages of underground, surface, and vertical development, as well as different transportation and building densities and coverages. The model helps us to propose an optimal strategy for new infrastructure development and land use. We believe the great challenge for the low carbon city project is to create evaluation systems that can quantify various parameters of the urban built environment, and ensure a low carbon life to all residents though various scenarios including iterative proposals on urban infrastructure, land use, building programs, waste management, renewable energy and transportation systems.

Step 1: Construct measurable Low carbon indicators

Low carbon indicators from various aspects were proposed. These indicators are very helpful in establishing an eco-city performance monitoring system for the low carbon city.

- Building-based
- Transportation-based
- Infrastructure
- Greenspace
- Electric power/Renewable energy
- Recycling

Step 2: Construct Assumptions

Quantifiable Relationships were established based on the following assumptions of the PINGDI low carbon city starting zone.

Population density

Industrial space requirement

Carbon emission per employee by industry (ton/person)

Energy consumption rates per area by industry sector (J/sq.m.)

Commercial/office space requirement (square meters per employee):

Residential

Energy consumption rate per residential area (J/sq.m.)

Carbon emission rate per residential area (ton/sq.m)

Water consumption

Waste water generation

Municipal waste generation

Storm water runoff

Proportion impervious area

Automobile carbon emission rate (ton/km)

Assumption of surface parking

Transit carbon emission rate (ton/km)

Percentage by travel modes

Total distance travelled per person (km)

Carbon sequestration rates (ton/sq.m)

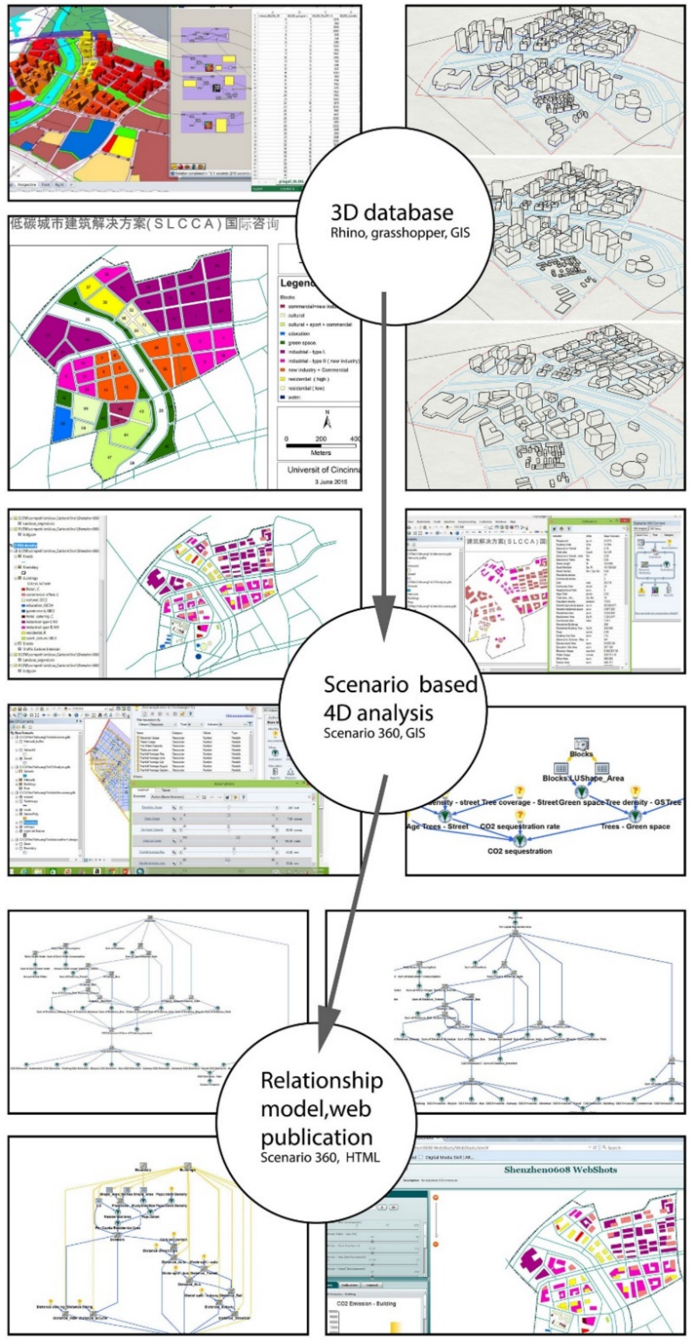

Figure 7. Process of Scenario based urban modeling. By Ming Tang, Xinhao Wang. http://ming3d.com/pingdi/

Step 3: Construct site database

A digital 3D model of PINGDI site is constructed using advanced parametric modeling tools in Rhino and Grasshopper, which includes block and building. Street network, Land use type by block, FAR, Building height, Building use type, and other parameters will be coded into a database allowing further computing. Three scenarios named as high-density development, mid-density development, low-density development were constructed.

Step 4. Scenario based 4D analysis

Using advanced 3D and scenario analysis software, the parametric modeling results are analyzed based on low-carbon city criteria related to various service including zoning, transportation, renewable energy with a solar panel, green infrastructure with green roof and trees. We have constructed various analysis model to discuss its impact on carbon emission. The conclusions are made based on the analysis of different scenarios based on the GIS scenario 360 program in the relation to the low carbon planning methods. The estimated population reached 15,000, 7,500 and 5,000 based on high, mid, and low density development. As a consequence, the total carbon footprint is decreased from high value to lower value.

These 4D analysis examined approaches where assumptions and indicators were set and integrated into the quantitative analysis pipeline to explore the potential to evaluate various scenarios and optimize a solution. The research is extended to the mathematical interaction within the planning parameters and their controlled geospatial outcome. The evaluation was accomplished through the exploration of several modeling techniques, either formula driven or fixed values from science. We believe that the results expanded the boundary of conventional GIS planning strategy through relationship modeling and simulation. Adjacent to the topic of scenario based morphogenetic, the topic of CO2 sequestration has also influenced designers to think of planning as a part within an eco-system where impact of each element is a multiplied across an urban field. Here, the formal order of individual components, such as FAR, Population density, zoning, etc., is decentralized from the predetermined rules and exclusively ordered through its relation with all other elements of the system. So instead of thinking about the planning code as the center, scenario based analysis has taught architects, planners and developers to specify the process of planning first before defining the multiplicity of elements and local sources that will determine the formal elements topology such as building mass, type, size or materials. This scenario based process is inherently new to the architecture and planning profession and can only be applied if there exists an understanding of complex relationship amongst the local conditions. As developers, we need to be methodical about the system of inputs we feed into the parametric utility.

However, to facilitate this new analysis process, the marriage between the human planning decision and computer analysis rules needs to have a seamless integration that allows planers, developers and decision makers to set the right rules to evaluate the urban development iterations. In our research, a web-based interface was developed to give the entire team access to these variables and exercise various manipulation methods. (http://ming3d.com/pingdi/)Through this web-based 4D interface, users can rely on the rules to change the design and observe the evaluation related to carbon emission, transportation, population, employment directly. Developers can testing different input and try to find the answer to the questions such as “How much carbon emission my site will generate if the industry C02 emissions reduced 20%? What if the estimated population is increased from 5000 to 15000? What if the tree along the street coverage is increased from 20% to 50%?”The final results of the analysis can also be reviewed regarding how successful the CO2 sequestration was in determining the tree density, renewable energy generation, the amount of green roof and many other factors.

We can conclude that the scenario based analysis process and 4D data representation have created a concept of relationship model, instability and de-centralization of the static solution. The paradigm in the digital landscape has been conceived as an ideal solution captured as single design scheme. It was not until parametric urban theorists such as Patrick Schumacher noted the possibilities of parametric relationships between urban systems that we were critical of the design, planning process and outcome. From the interactive model constructed by 4D based scenario analysis, we can see a much more interactive process influencing the evolution of urban infrastructure as a dynamic system composed of a vast number of inter-related parameters. Within the process of scenario based design and web distribution, digital landscape is now understood as a process of conceptualize various urban components, or modulation the set of variables through an open end process, to the specific planning criteria (such as carbon neural) it has to meet.

2.2. Data Simulation

A digital landscape can also be constructed from data simulation and bottom-up methods. An agent-based simulation (ABS) consists of numerous agents, which follow simply localized rules to interact with an environment, thereby formulating a complex system over time. The concept of the agent-based system has been widely used, including swarm intelligence, decentralized social networks simulation, and economic growth modeling. 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 defines the agent as the physical entity within the field of urban and landscape simulation. 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.

Our research began with an abstract landscape form by creating a movement network across an open field. The goal was to create optimized paths. This approach uses a few simple behaviors of individual agents to interact with the environment and other agents, which ultimately increases the complexity of the system as a whole. First, a group of agent-based spatial nodes were woven into an initial, rigid network. 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 Frei Otto's wool simulation method. Instead of a simple "dumb" static system, each agent along a path becomes an active, moving element. The agent 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 by the microenvironment 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 in modifying its 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 appeared to be deformed and merged into one another based on their contextual relationships. Different behaviors can be assigned to form alternate emerging patterns. (Figure 8).

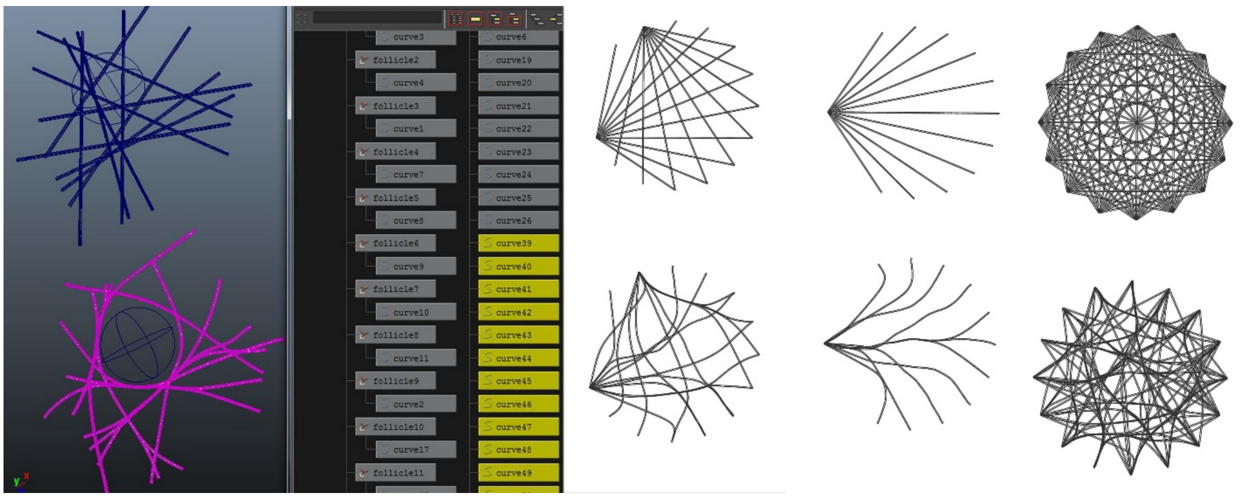

Figure 8: A system of agents with unique values and behaviors are calculated and manipulated. The initial grid is optimized similarly to Frei Otto's wet grid network, which is a physics-based analog method[2]. A movement system is optimized by the computer simulation based on the proximity and interaction of agents and their trails. Tools: Autodesk Maya, Rhino, Grasshopper. By Ming Tang.

Project: Silicon Valley of China

This 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 data-driven design methods in the conceptual design stage. Space syntax was used to create an "attraction map" and combined with other GIS data in the schematic design phase. Then, we used a parametric method to construct a fully detailed 3D landscape model in the end. A self-organizing pattern of movement network emerged based on the external rules including the proximity to the existing urban infrastructure, the 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. An extremely 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 field pattern to promote the most efficient pedestrian flow and vehicular streamline. (Figure 9)

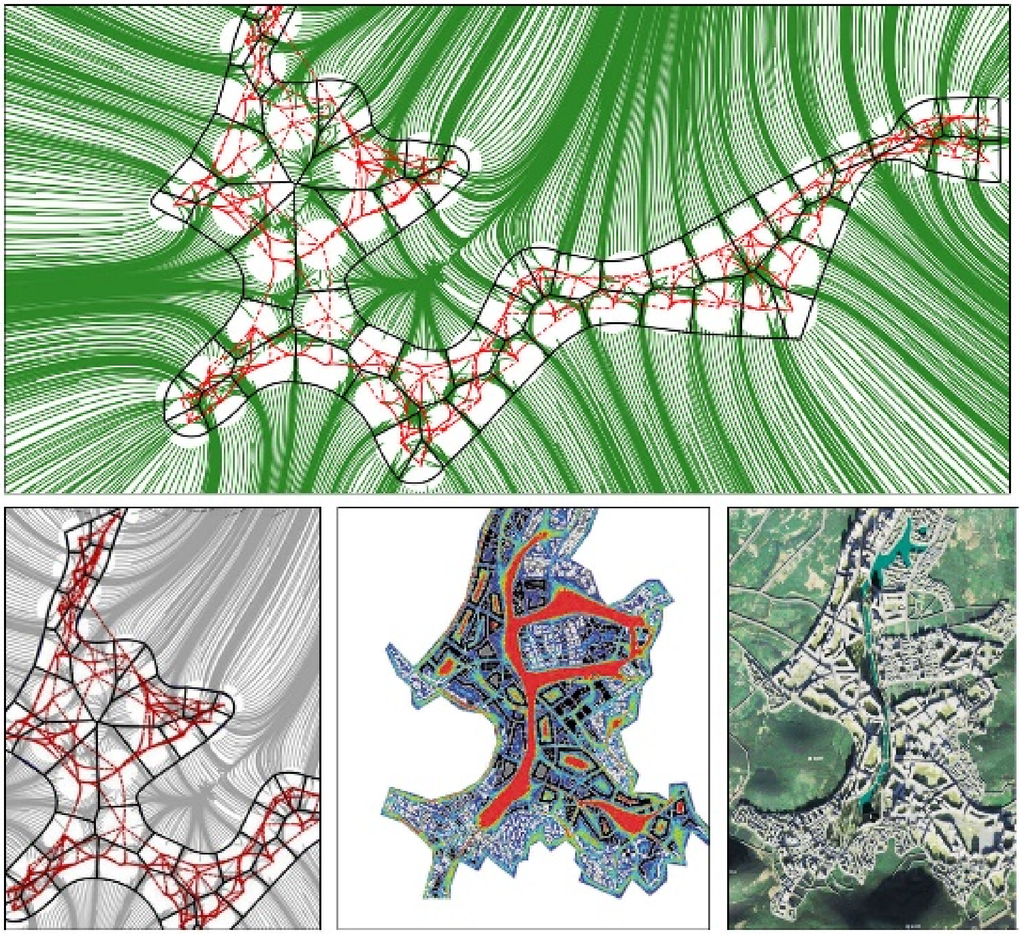

Figure 9: Silicon Valley of China. Tools: Space Syntax, ESRI City Engine, ArcMap, Autodesk Maya. By Ming Tang.

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 analyze 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: digital landscape based on "attraction map". Green corridor, central park, and riverside park system were added to 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 modeling process had been completed, the skyline along the river and east-west axis were evaluated and modified by designers.

4. Conclusion

The research presented in this chapter is intended to realize the potential of streaming the abstract geospatial data into a parametric landscape. In these methods, the integration of non-geometrical parameters within the form seeking, animation, scenario-based analysis, simulation and fabrication process resulted in a series of conceptual make-ups models. The digital landscape was developed by manipulating zoning, transportation network, city block and various building types. Ultimately, the data-driven design looks to build upon the strengths pre-defined in the various representation and simulation methods and capture the benefits of emerging computational technology. It can seamlessly integrate vital geospatial components in the equation and alter the way people explore the possible design solutions to generate the ideal landscape forms, either 2D, 3D or 4D. We believe the geospatial database can provide a rich resource to produce design solutions with respect to ecological performance criteria. The demographic, traffic, economic data from data set contains the trace of activity and event parameters of the urban life process. As Schumacher described in the parametric city, “parametricist continuation is always possible in myriad, unpredictable, and qualitatively diverse ways, but it is never random” (Schumacher, 2010). Different from traditional landscape design process, the data-driven model provides us a range of the abstracted diagram, rather than a particular design solution. In another word, the outcome of data-driven design is the consistently morphing forms driven by the changing relationship of information, which can be interpolated into physical landscape features. The value of parameterizing landscape related data, either conceptual or diagrammatic, became a valuable design method in planning, architectural, landscape, and urban design field through digital computation and fabrication. It created an interesting notion of the data representation and simulation, and further exploited the idea that design solution can evolve from the massive volume of data available and accessible to us.

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Endnotes

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[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] 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.