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SPECULATIVE URBAN TYPES

A Cellular Automata Evolutionary Approach

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Abstract. The accelerated rate of urbanization in China is the motivator behind this paper. As a response to the observed monotonous housing developments in Suzhou Industrial Park (SIP) and elsewhere our method exploits Cellular Automata (CA) combined with fitness evaluation algorithms to explore speculatively the potential of building regulations for increased density and diversity through an automated design algorithm. The well-known Game of Life CA is extended from its original 2-dimensional functionality into the realm of three dimensions and enriched with the possibility of resizing the involved cells according to their function. Moreover our method integrates the "social condenser" as a means of diversifying functional distribution within the Cellular Automata as well as solar radiation as requested by the existing building regulation. The method achieves a densification of the development from 31% to 39% ratio of footprint to occupied volume whilst obeying the solar radiation rule and offering a more diverse functional occupation. This proof of concept demonstrates a solid approach to the automated design of housing developments at an urban scale with a ,yet limited, evaluation procedure including solar radiation which can be extended to other performance criteria in future work.

Keywords. Integrated Speculation; Generative Urbanism; Cellular Automata.

1. Introduction

Accelerating urban development has been - and still is- one of the key strategic plans of China in increasing its economic development. This strategy has worked well as an economic development tool but has also created a real estate market full of monotonous, vertical, repeated- tower arrangements for housing. These towers are essentially two dimensional in the sense that typical floor plans are simply extruded almost arbitrarily regardless of any context except the sunlight direction and conforming to existing building regulation. The exploitation of the third dimension that would increase density is very low. Our main case study under examination is the city of Suzhou in the Yanze river delta and its new Industrial Park (SIP), newly constructed in the last 25 years.

In Suzhou Industrial Park, the acceleration of construction of housing for urban population has eroded the agricultural land use in the area of Suzhou to about 1.5% of the total while the need for urban growth has not subsided. Apparently, there is a discrepancy between the still increasing demand for housing supply and the very limited availability of land for new developments. A solution to this discrepancy could be the densification of existing housing developments. A higher density achieved through densification above ground - in the third dimension - would sustain the existing greenery within the developments whilst providing more living space. A densification whilst obeying existing building regulations would result in a more efficient land use while sustaining an equally high standard of living. We examined one example of a monotonous tower housing development, analysing the determining building parameters including building regulations and their impact on the actual planning decisions made by the local planning office which led to the repeated tower pattern. The project then employed architectural computational techniques to investigate through qualitative and quantitative methods how to increase housing density. We transformed a standard cellular automata mechanism into an integrated generative and evaluative parametric system with evolutionary principles. In this paper we examine the possibility for optimisation of the building density, expressed as a ratio between volume and footprint, along with the optimisation of the sun exposure of the surfaces of the building, expressed as solar incidence number, as per regulations.

A novel introduction in our system, is the parametric representation of the social condenser, a constructivist concept of overlapping and intersection of programs within a building, employed by in the 20th century by architects such as Rem Koolhaas & OMA, Ivan Leonidov, Mosei Ginzburg. We were able to produce results with increased density and similar parametric profile of the current residencies, thus in theory similar quality of life. Apart from the integrative nature another innovative part of the system is the inclusion of programmatic variety in three dimensions, thus breaking the functional monotony we encounter in Chinese megacities and walled communities. The project is expected to provide an understanding of how housing density contributes to the sustainable development of the built environment of new towns like Suzhou Industrial Park, by stopping the transformation of land from agricultural and rural to urban (figure 1).

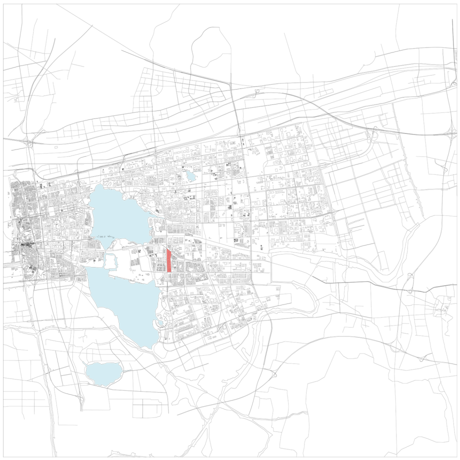

Figure 1. Suzhou Industrial Park with location of one case study noted.

2. Background

The project began with an examination of the volumes that repeated housing towers create in the Chinese urban landscape. By looking at the case study of Butterfly Bay though we discovered that the repetition of 10 cellular types of apartments defined the limited diversity of the towers. These cellular types, drove us to use cellular automata as the main engine in our generative system. Unclear termination rules in the cellular automata paradigm, i.e automata can run indefinitely, drove us to use evolutionary methods as optimization techniques.

2.1. CELLULAR AUTOMATA

Cellular automata are not new in the areas of designing dense towers or dense housing environments. Herr (2007) has in the past explored the mechanism of cellular automata as a tool for architectural designing and adapting an existing strategy of tower design with increased density. In a following work Herr (2015) has also explored the adaptation and exploitation of Cellular Automata in architectural design computation processes, ranging from the deterministic for generating a plan to the playful, conversational-with-the-designer use of cellular automata. Others (Khalili et al. 2015) equally recently have used Cellular automata as an engine for growth in dense housing conditions in the Netherlands, similarly with the present paper, focusing on accessibility, density and light exposure, however at a significantly smaller scale than the present China study.

The rule based creation of morphologies by the Cellular Automata is not able to discriminate produced solution per performance criteria such as solar radiation. Only the introduction of an evaluation algorithm connected with a search procedure would make it possible to discriminate better solution versus worse ones. The present method feeds the quality values of the evaluation algorithm into a Simulated Annealing or an evolutionary procedure to optimize the solution production.

2.2. SIMULATED ANNEALING

The "Simulated Annealing" is a robust search algorithm which unfortunately doesn't guarantee to lead to the global maximum of the solution landscape, but it is efficient and successful in discontinuous and fractal solution spaces since the algorithm can overcome local maxima peaks and minima valleys in the landscape.

In the presented case, the fitness of the respective solutions is established through the evaluation of solar radiation and density as the ratio of volume to footprint using different simulation and geometric evaluation tools to establish a single value of quality q which can be fed into the "Simulated Annealing" algorithm to enable an efficient search for good solutions.

The morphologic representation of the solution is the result of the applied Cellular Automaton which itself includes elements of randomness inbuilt into the growth algorithm but based on predefined starting conditions. The starting conditions which are to some extent the predetermining factors for the morphology of the solution are mapped towards the quality values of the fitness function. Depending on the results of the fitness function the initial conditions of the growth algorithm are adapted and the next (i+1) iteration of the morphological representation is grown and will undergo a fitness examination.

2.3. EVOLUTIONARY METHODS

. The creation of individuals by the cellular automaton is based on few parameters such as the grid size, the height and number of floors and specifications of the "Game of Life" itself. These parameters contained in the genome of the created individual are mapped against a quality value which represents the individual's performance per the set solar radiation and density requirement. The afore described search algorithm selects the best 50% of the created individuals and creates a new population through a randomized cross over recombination of selected individuals together with the selected individuals itself. The discrimination algorithm simulating a metallurgic annealing process, will only slowly focus the search radii as the 'temperature' decreases sustaining different areas of search within the solution landscape. Thus, the convergence of the evolutionary process can be controlled through the speed of 'temperature' decrease.

The combination of the search algorithm and the evolutionary process are implemented in Rhino Grasshopper TM and respective plugins thereof. The current implementation allows for population sizes of around 100 individuals to keep the system with an acceptable and reasonable response time using standard personal computation power.

3. Method

The project examined one housing case study in Suzhou Industrial Park (figure 2) and employed computational design methods to speculate about possible outcomes on increased density in SIP. The methods employed in the research were qualitative and quantitative in nature.

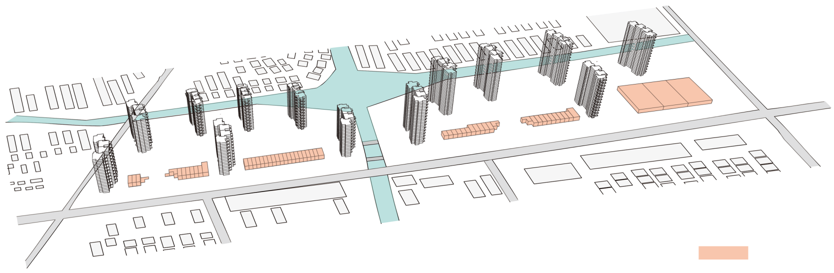

Figure 2. HuDieWan digital model, the case study examined.

3.1. FRAMING THE PROJECT'S BENCHMARK

3.1.1. Quantitative methods

The quantitative methods were focused in the speculative design experiment using computational design methods. Initial benchmarks were established by the Suzhou Industrial Park case study Butterfly Bay to other known case studies in Asia, known for their effectiveness and high density-

3.1.2. Setting Parameters and criteria for the cellular automata.

To be able to establish the parameters and constraints for the basic cellular automata to be used as a generative system we referred to the 'Technical specification for planning and design of residential area in Suzhou Industrial Park'

The regulation establishes basic metrics, maxima and minima in specific parts and functions of the building and at the same time establishes potential evaluation metrics of the performance of the building. We translated these parameters into a table that describes them along with the manner in which they are represented in our system and the evaluation/constraints criteria (table 1). The regulation establishes other criteria as well, such as fire truck and ambulance access, parking sizes and numbers, but we did not incorporate these in our current version of the algorithm.

3.2. IMPLEMENTATION: RHINO- GRASSHOPPER

The computational modeling environment was Rhinoceros with Grasshopper handling the parametric and evolutionary roles. We used the Rabbit cellular automata plugin, with our own extension in the three dimensions. The evolutionary algorithms used was the Galapagos evolutionary solver contained in Grasshopper. For the lighting simulation we used the Ladybug grasshopper plugin, connected again with the Rabbit and Galapagos solvers. To measure lighting we did not just restrict ourselves in the initial measurement at the sill of the opening, but established a grid of points on the surface of each cell that would measure incidence of light. This proved cumbersome and computationally expensive making the resulting lighting model difficult to handle and unresponsive.

Table 1. Parameters and evaluation criteria.

Parameters	Sub-Parameters	Geometry in Rhino-Grasshopper	Definition	Evaluation
Building Regulation				
Site	Shape of Site	XY Polyline	Polyline	minimum size
Lighting	hours of exposure per day	any 2d area / usually rectangular	line of sight from Sill to light source(sun)	over three hours per day
Building Height	N/A	Z vector or Z parameter		>1.3 X width of South Facade.
Floor Height	N/A			2.8 -3.5 m
Distance from site boundary	N/A	XY line	Polyline	>15m
Cellular Automata				
Neighborhood Rule	Game of Life	Cellular Automata	Born in a, Survive in u-v	number of housing blocks
	Public Space	Void Space	From Difference of	ratio of housing to public space
Social Condenser				
	Shape of Condenser	Box	XYZ Size; Centre Point; Type	
	Condenser attraction	Sphere	Service radius; Service Strength	distance of each block from condenser

The actual algorithm was on an alternative to Conway's game of life on the cellular automata game known as Conway's game of life and an extension of it in the third dimension. In the original a two-dimensional grid of cells is populated randomly and then rules of density determine whether a cell will be generated, or die and be erased according to how many neighbours it has (figure 3). In this new extension of the game each cell communicates with the other 26 cells around it to determine whether a cell lives or dies. We parameterise the rules in this form: if a cell has K neighbours then a new cell is generated. If the cell has N-M neighbours, then the cell dies because of loneliness or from being overcrowded. For evaluating the Neighbourhood we use the 3d concept of the Moore Neighbourhood (figure 4).

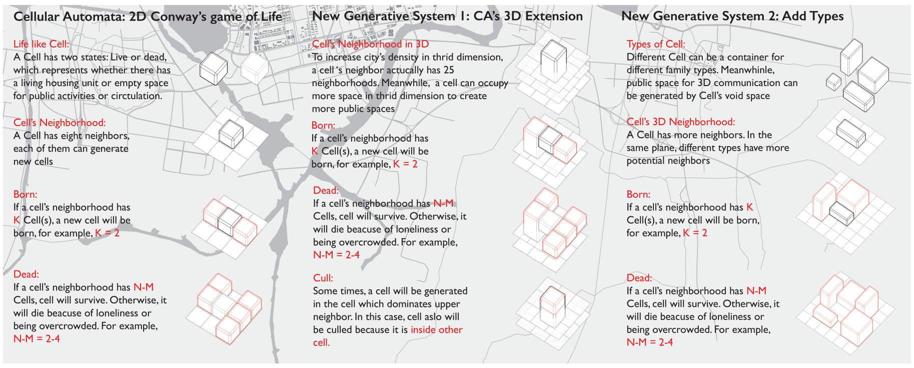

Figure 3. Extension of CA game of life in three dimensions.

In a subsequent improvement of the cellular automata in three dimensions, we also introduce a variety of functions in each cell to diversify the functions in the 3d building. The diversity of the functions inside a housing block work against the monotony of the single-function tower. Public functions are employed as social condensers: a three-dimensional version of neighbourhood centres as they are used in the original planning of the Suzhou Industrial Park. We envisage that the different functions can be represented in the future by different types of cells in the cellular automata mechanism.

However our current proof of concept only uses the maximisation of density and the maximisation of sun exposure as the fitness functions. We are building a proof of concept, evaluating for fitness one parameter at a time. The computational techniques employed in the study were measured in terms of their effectiveness in increasing density while all other parameters and factors remain constant.

Referring back to the building regulations we also established important parameters prioritised by the regulations. In the case of Suzhou industrial park exposure to sunlight of each space for a minimum of three hours per day was crucial on whether the building would receive building permission or not. As such the evaluation mechanism we established would evaluate all models for exposure to the sun, plus increase density in floor area and volume. We were able to increase volume occupancy from 31% to 39%, a small but important increase (figure 5).

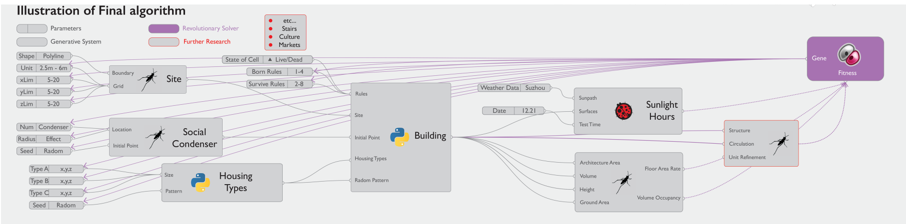

Figure 4. Final algorithm of quantitative method, generation and evaluation.

4. Results - Discussion

The results of the First version of the algorithm is presented in figure 5: A maximum height tower, in comparison with towers that resulted from optimal genomes in maximizing density to footprint ratio while still being within the constraints set at the parametric table 1. These results obviously prioritise the footprint rather than a balance in a multi-parametric optimisation.

The results of the third version of the algorithm lead to towers with maximum density to footprint ratio and maximum lighting conditions met, above the 3 hours daily. In this we used the ladybug plugin in grasshopper to simulate and evaluate the lighting conditions. The ladybug plugin evaluates lighting for each different cell, by first creating a grid of points of the surface of each cell, and then calculating the light that reaches those points. Thus the level of lighting as an average for each cell is calculated. The overall lighting for the tower is not computed at all as the regulations prescribe lighting conditions for each room and apartment rather than each cell. However more diversity in form of the tower was achieved with the inclusion of the social condenser in the grid of the cellular automata depicted in figure 6. A difficulty in this case was the absolute evaluation of the mechanisms involved, since in our implementation a python script was needed for generating the points in the grid for the social condenser. In future work we will incorporate the generation of the condensers in the cellular automata mechanism, a feat that will require multiple types of cells incorporated into the mechanism.

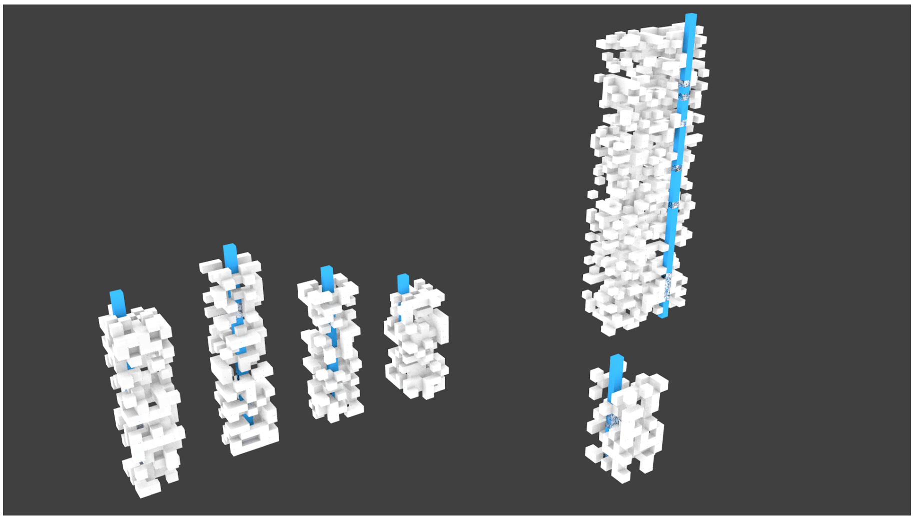

Figure 5. Maximum height tower, along with optimum genomes.

5. Conclusions and Further Work

We have demonstrated that it is possible to design a generative and evolutionary parametric system, integrating programmatic function, floor area, and sunlight exposure along with their evaluating functions. We have shown that it is possible using this automated system to develop large three-dimensional housing blocks, with functional diversity, increasing the density of the housing whilst retaining the size of the footprint. We will continue to developing the system with the inclusion of basic structural and circulation evaluation functions. Further potential of the system lies also in developing a tool that evaluates the building's financial performance, from cost of construction to the price of sale or renting to make a profit in a specific time. Thus we envision that a continuation of this system will lead into an integrated tool, combining the parametric generative system and a multi-parametric evaluation, helping architects and planners deliver competitive designs within fast developing environments. Further papers will follow in developing each of these parameters of the system, along with establishing the social condenser in the algorithms of the cellular automata.

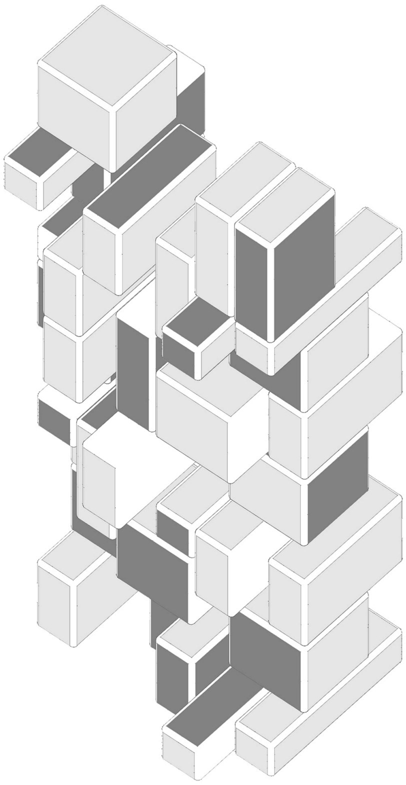

Figure 6. Results of the algorithm with the lighting evaluation according to the building regulation including the impact of the social condenser.

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