Cellular Automata as a learning process in Architecture and Urban design

Mads Brath Jensen[1]*, Isak Worre Foged*[2]
[1,2]*Department of Architecture, Design & Media Technology, Aalborg University*
[1,2]*www.create.aau.dk*
[1,2]*{mbje|iwfo}@create.aau.dk*

This paper explores the application of cellular automata as method for investigating the dynamic parameters and interrelationships that constitute the urban space. With increasing aspects needed for integration during the architectural and urban design process with the relations between these aspects growing in parallel, complexity of the design process and design solution increases. Additionally, aspects and relations are of a transformative character in that they change over time and therefore construct a time-based condition for which problems are presented and solutions are sought. An architectural methodological response to this situation is presented through the development of a conceptual computational design system that allows these dynamics to unfold and to be observed for architectural design decision taking. Reflecting on the development and implementation of a cellular automata based design approach on a master level urban design studio this paper will discuss the strategies for dealing with complexity at an urban scale as well as the pedagogical considerations behind applying computational tools and methods to a urban design education.

Keywords: *Computational design, Cellular automata, Education, Design exploration*

INTRODUCTION

Understanding the evolving complexities of the temporary city is a crucial challenge facing architectural and urban designers. Being able to deal with and respond to the many dynamic parameters and interrelationships that constitute the urban space could enhance the final design concepts of the designer. Strengthening such skills could be achieved by implementing computational design tools in the education of architects and urban designer thereby improving not only the quality of the students' design projects but also creating a more transparent learning process and a heightened understanding of the urban design field.

Managing urban growth and handling the dynamic mechanisms of an urban site has put the traditional master plan under great pressure revealing its inadequate formal layout and inflexibility (Popov 2001). This has lead to increased research in the field of computational design where generative design systems has been explored due to their ability to deal with mass amounts of information and parametric relationships. Most work in this field has focused on complex systems either demanding users to have a high level of scripting or programming knowledge or ending up with a limited level of user-customization - both extremes often with design solutions as the primary goal and applicable only to students with a certain knowledge and expertise in the field of computational design.

The research forming the basis for this paper has adopted a design approach based on John Conway's two-dimensional cellular automaton (CA) called the 'Game of Life'. Integrating this discrete model in the user-friendly parametric environment of the Grasshopper plug-in for Rhinoceros 3D has permitted the construction of a generative design systems that can deal with explicitly described design rules and allow design students to investigate time-based urban design concepts.

CELLULAR AUTOMATA

Cellular Automata (CA) invented by the mathematicians John van Neumann and Stanislaw Ulam and continuously explored and developed by another mathematician Stephen Wolfram contains the underlying framework for these studies in that a computational system can be devised which heavily utilizes computational parallism, considered a very powerful computational technique to generate different time based solutions from different input rules and axiom conditions. John Conway in his 'Game of Life' explored the development of CA as a continuously updated system, which illustrate the dynamics of interacting and interdependent actors in a system.

CA has for its general system setup, but powerful processing abilities, been applied to very different scientific inquiries from simulation of fire development, biological modelling, disease outbreaks (Huang, Sun, Hsieh, & Lin, 2004) to urban sprawl (Batty, 1997). The latter has illustrated different approaches to simulating complex urban development through the DUEM projects, generating various large city developments.

Architectural propositions using CA as a methodology has been presented among others by the office Kokkugia and Object-E, with both addressing large scale organisations, with what appears to be classical two-state CA, defined by 1 and 0, also described as On and OFF or lastly as LIVE and DIE in the context of Conway's 'Game of Life'.

The CA framework

The CA framework constructed through this research is based on a Moore-neighbourhood of r = 1 dimension, meaning it registers the eight cells touching the center cell either on its four sides or in its four corners, see figure 1 & 2. Additionally it surveys the entire cell space to detect if a described global threshold is met. The reason for this contextual awareness organization is twofold, 1) to only address immediate local actors for reasons of design rules with lower complexity compared to neighbourhoods of higher r-dimensions, and 2) to address if some states are overly dominant allowing a negative feedback function stabilizing the design system at a given desired condition set by the designer.

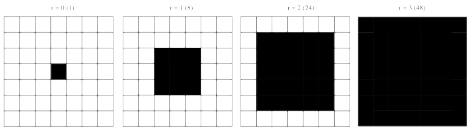
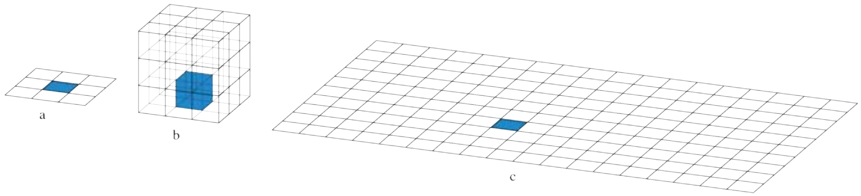


Figure 1
Moore neighborhoods for ranges r=0, 1, 2, and 3 with number of neighbors in parenthesis.

The 2-dimensional layer in which the development occurs is extended vertically, by a method where CA rule-sets are described as a 'vertically extended Moore neighbourhood', creating a rule set described as a 3-dimensional organization, but computed in 2-dimensions. This allows spatial constructs and diverse descriptions of states such as higher building mass, higher vegetation, e.g. trees, rather than lower plants. The development of a spatial organization is integrated in the rules described by the designer.

Figure 2
a) Moore neighbourhood, b) vertically extended Moore neighbourhood and c) cell space



The model is developed with a system boundary condition that terminates states if they are in direct contact. This is chosen over a 'toroidal shape' method in which a cell is wrapped to the first cell in the other end of the grid making the model spatial continuous. This makes the definition of the cell space important and closer aligned with real life conditions of contained spaces.

The complexity of the model can be described as a relation between the number (s) of cells including the centre cell, and the number (k) of states available, in the following equation, $k^{k^{s}}$, lifting each value to the power of its previous. With a 10 state system, with 9 cells, the following CA solution space can be described as $10^{10^{9}}$.

Constructing an intuitive computational system that enables design students without prior programming experience to explore a recursive rule-based system implies for educational considerations and the establishment of a new educational framework. Due to its intuitive and open-ended configuration Grasshopper® (GH), a graphical algorithm editor for Rhinoceros, was utilized as the platform in which to construct a CA-based design tool which were to be handed to the students at the commencement of the design studio. Before building the definition in GH it was imperative that the design tool could facilitate an immediate adaptation into the explorative work of students with little or no experience in GH or computer programming. As a result the final definition was constructed in such a way so that the student needed only to interact with a few groups of key components: the initialization of the cell space (including cell space resolution, selection of initial cells with corresponding states, and establishment of boundary curves), constructing the rule sets (using if/else conditional statements to ex. change the state of a cell depending on the states of its neighbouring cells), and lastly to extract desired data concerning the performance of the system (count of different cell states, increase/decrease based on previous steps, etc.). Due to the generic configuration of a rule set based on only a few simple components in GH it was possible to re-use this rule set configuration to establish a large variety of simple rules all acting on the results of the previous rule sets.

Grasshopper doesn't by default allow for recursive feedback loops but with the introduction of the Opensource Hoopsnake component, created by Yannis Chatzikonstantinou, it is possible to escape its otherwise linear data flow. As an advantage for the exploration and understanding of the evolution of CA the Hoopsnake component allows the user to control the completion of each successive loop in a stepwise fashion while simultaneously storing the data for each recursion for use in further analytical work and cross-population comparisons.

METHOD

In order to utilize the constructed CA framework a method was established that would allow design students with none or little experience in computational design to use the CA-system as an open exploratory playground allowing experimental studies in urban and architectural design.

The main goal of the design method was enabling students to use the computational system as a learning process with emphasis on detecting arising design problems rather than searching for design solutions. To achieve this, the method supported a transparent process where the outcome of each iteration was visible to the design student while simultaneously allowing the implementation of complex and integrated mechanism for design exploration.

Adopting the CA framework also required a conversion from a programming terminology dealing with binary data in a two-dimensional matrix to an architectural terminology generating a volumetric matrix for spatial organisation of urban programmes - a critical step in making the method accessible to architectural students and letting them explore and unfold the architectural language and diversity into a binary data structure. The conversion allowed for an examination of design rules that adopted the terminology of the loneliness/overcrowding rule-set of traditional CA (Shiffman 2012) enabling students to gradually construct and implement contextual parameters by setting up simple rule-sets and to study the developed relations and complexities of the design project. To further inform the design system the rule-sets in this method have been expanded from those of the traditional CA systems, where an analysis of very local criteria (the state of the cell's eight neighbours) form the basis of future actions, to also deal with global thresholds rendering it possible to inform the system when a certain design vision has been met.

Applying the constructed design system to an urban design workshop that explores design concepts evolving over a fixed 20-year time span made the time-based evolution of traditional CA directly applicable and enabled the design students to explore time-based design proposals allowing for strategic planning across the fixed time period. Rule sets were described by the designer, applying in each cell a given programmatic state, such as vegetation, void, infrastructure, building, but also meta-programmatic states, such as investor and creative class, understanding not only a state as a physical object, but also as a conditions that influence other states by their potential actions. Additionally, during the continuous step by step process, all activities for each time step is recorded and described in graph relations detecting the development of the spatial organization in order to understand consequences of a devised design rule set and the axiom conditions from which the development initiates from.

RESULTS

The generative design system and supporting design method described in this paper allowed for a transparent process where the student describes all the design rules through a visual programming environment supporting a gentle learning curve. Although technically simple and following an iterative progression where new rules were established from evaluation of the systems previous performance, the creation of the rule-sets showed to be a difficult task. Educated to describe and develop design solutions this method instead requested that the students began describing design problems and challenges, subsequently refining their rule-set to explore new design outputs within this altered multidimensional solution space. However, the system showed to support design thinking over a given time period and thereby made the students capable of involving the dynamics of the urban site. Instead of drawing a static "ideal" solution the students focused their design implementation towards how design aspect are related and how they unfold over time - this shifted their way of thinking design from the absolute design solution towards the potential and agent-based design solution, creating more focus on actors and relations (Figure 3).

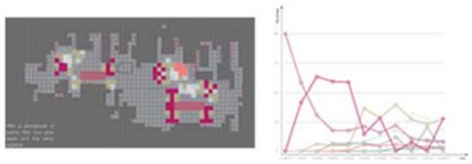


Figure 3
Example of student work showcasing the cell matrix and table visualization derived from the design system. Work by students Anne Marie Menå Heltborg and Stine Juul Christensen.

It is clear from the projects developed by the students using this CA framework and corresponding design method that a rich and challenging set of interactions occur. The level of predictability is largely dependent on the control intentions inserted into the design rules by the designer. This means that a preconceived and desired spatial design can be approximated in the design rules for which the application of the method has little use. However, if the design rules are described with sufficient diversity and without conditions in which one state will terminate the others immediately, a rich and time-based evolution develops, to which a designer can read, not only the spatial programmatic propositions, but also how the different states act against each other allowing the method and framework to become an architectural system which exhibits and informs the designer about interdependencies between the design states over time. While this will not be a 'truth' model for how the urban environment will evolve over a described time period in real life, it grasp the complexity, possibilities and limitations of a design development during the initial design phases as a support to design decision taking.

DISCUSSION

Reflecting on the work performed in both the development of the CA-based design framework and the corresponding design method, as well as the explorative work of the design students utilizing this generative design tool, there are a number of topics that stand out. One is that of control. When working with a CA-based system the machine computes the design solutions and the designer can only inform or control the outcome through the rule-set defined before the initiation of the iterative development process. Reflecting on the work of the involved design students this showed to be a difficult task and often ended in rule-set configurations leading to very dictated design solutions. One conclusion to this challenge could be that besides requiring an understanding of the design system, including the theory behind CA, working with the system also requires an enhanced focus on design intent and not design solutions.

Another topic is evaluation. How to evaluate solutions when there are no concrete optima and when all the steps in the design process are as important as the solution in the final step? One aspect that became very important when evaluating and understanding the complex datasets was visual feedback, which in the case of this design system, comprised of both a three-dimensional color-coded cell matrix and a variety of data graphs. In a teaching aspect this visual feedback allowed for an extended understanding of relations and solutions as a pedagogic/didactic learning method allowing the user to explore rule sets with different and multiple objectives.

Any system described inserts a series of boundary conditions, not only spatially, but also logically. Through the working with the model and development of the method, it is evident that understanding of the preconditions for the CA's spatial organisations needs to be well defined and understood in order to make the method truly instrumental beyond its abilities to generate formal and spatial propositions. Thus, it can be argued that a CA system in this framework has its strength in informing a designer about the complexity, time-based relations, boundary conditions and variable relations more than an ability to be a direct design tool for completed design solutions. However, when above has been understood, solutions and problems can be generated quickly with multiple elements and factors inserted simultaneously allowing for a deep integrative architectural process overcoming some of the drawbacks of common linear design processes, in which problems are handled successively rather than in parallel. The higher the number of states presented in the model, the higher the integration and informed architectural models. But it also appears important that the cell space remains large enough for interactions to be computed. The smaller cell space reduces the level of complexity, and thus the ability to evolve truly surprising and informative solutions beyond what the designer could propose without the model.

REFERENCES

Batty, M 1997, 'Cellular Automata and Urban Form: A Primer', *Journal of American Planning Association*, 63(2), pp. 266-274

Huang, CY, Sun, CT, Hsieh, JL and Lin, H 2004, 'Simulating SARS: Small-World Epidemiological Modeling and Public Health Policy Assessments', *Journal of Artificial Societies and Social Simulation*, 7(4), pp. 100-131

Popov, N 2011 'Generative sub-division morphogenesis with Cellular Automata and Agent-Based Modelling', *Respecting Fragile Places – 29th eCAADe Conference Proceedings*, pp. 166-174

Shiffman, D 2012, *The Nature of Code*, Creative Commons Attribution-NonCommercial 3.0 Unported License