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Architectural Interpretation of Cellular Automata

Robert J. Krawczyk
College of Architecture, Illinois Institute of Technology, Chicago, IL, USA.
e-mail: krawczyk@iit.edu

Abstract

Mathematical constructions and concepts can be utilized in a number of methods to investigate the process of generating architectural forms. One is to technically layout architectural elements along such constructions, another is to explicitly develop forms corresponding exactly to the underlying concept, and another is to use such concepts as inspiration, a starting point for design. A hybrid method is to follow an interpretive approach, one that uses a mathematical concept as a framework to begin to investigate architecture forms. Architectural considerations are applied both at the beginning of the process and continually throughout the process as a better understanding of the underlying concept is developed. This paper attempts to use cellular automata is such a way. The process of investigating such concepts, it is believed, will help other such approaches, as well as, more traditional approaches of design development.

1. Introduction

Cellular automata is the computational method which can simulate the process of growth by describing a complex system by simple individuals following simple rules. This concept of simulating growth was introduced by John von Neumann [1] and further developed by Ulam [2] in the area of simulating multi-state machines. The concept gained greater popularity when Martin Gardner [3] described John Conway's “Life”, a game that generated two-dimensional patterns. Stephen Wolfram [4] began researching the concept to represent physical phenomena and has recently reintroduced the discussion in “A New Kind of Science” [5].

The connection to architecture is the ability of cellular automata to generate patterns, from organized patterns we might be able to suggest architectural forms. Cellular automata, viewed as a mathematical approach, differs from a traditional deterministic methods in that current results are the basis for the next set of results. This recursive replacement method continues until some state is achieved. Fractals and strange attractors are also created in a similar manner. Many digital methods in architecture are parametrically driven, Krawczyk [6,7], an initial set of parameters is used to generate one result. If an alternative is desired, the parameters need to be modified and the generation is repeated anew. The difference between these two methods is that in parametric methods the results can be easily anticipated, while in recursive methods the outcome usually can not. This offers an interesting and rich platform from which to develop possible architectural patterns.

The universe for cellular automata has evolved over a number of dimensions, Wolfram, one-dimensional, Conway, two-dimensional, and Ulam, three-dimensional. The three-dimensional universe is the one that we are most interested in.

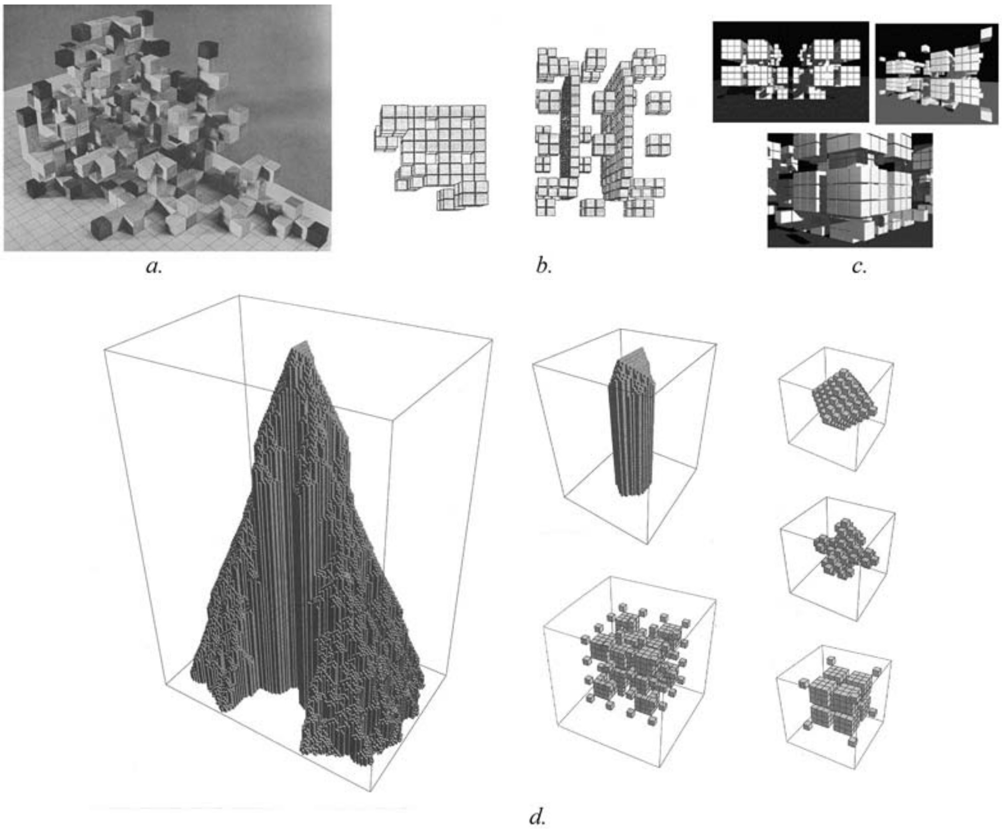

Figure 1. Three-dimensional cellular automata

An early example of three-dimensional pattern development is the wooden block model created by Schrandt and Ulam [2], Figure 1a. Investigating repeating patterns as Conway had found in two-dimensions is Bays [8], Figure 1b. and finally an highly inspirational architectural application by Coates [9], Figure 1c., much in the same spirit as Bays. The most recent is two methods develops by Wolfram [5], Figure 1d., in which a stacking method is explored, as well as, one similar to Bays. The striking similarity in these is the explicit representation of the cellular automata, even though each had taken a different approach and had a different application as an investigative goal.

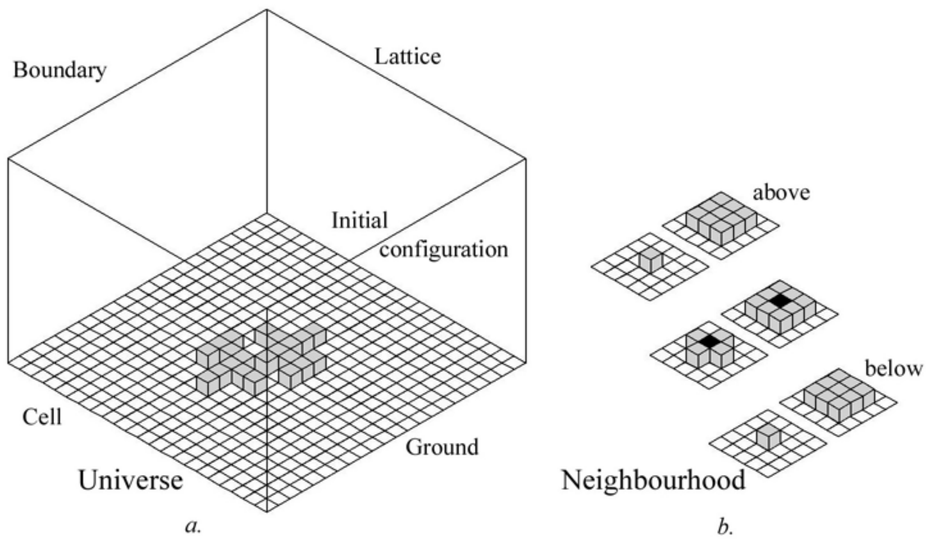

Figure 2. Basic cellular automata terminology

2. The basics

The three-dimensional universe, Figure 2a., of cellular automata consists of a unlimited lattice of cells. Each cell has a specific state, occupied or empty, represented by a marker recording its location. The transitional process begins with an initial state of occupied cells and progresses by a set of rules to each succeeding generation. The rules determine who survives, dies, or is born in the next generation. The rules use a cell's neighbourhood to determine its future. The neighbourhood can be specified in a number of ways, Figure 2b. displays two common methods of determining which adjacent cells to consider. The rule developed by Conway is: check each occupied cells' neighbourhood, survival occurs if there are two or three neighbours, death occurs if there are any other number of neighbours, and birth occurs in an empty cell if it is adjacent to only three neighbours. As each generation evolves, one of four cases can occur over some period of time. Either the cells find a stable form and appear not to change; or they become what is called a "blinker" and alternate between two stable states; or all or a cluster of the cells become a "glider", a group of cells that begins to transverse the universe forever, or all the cells die, extinction. A variety of rules have been proposed, with Conway's being the traditional starting point.

3. Architectural interpretation

The pure mathematical translation of a cellular automata into architectural form includes a number issues that do not consider built reality. For example, Figure 3 displays an initial configuration, 3a., and its raw results at the 8^{th} generation, 3b. The interpretation or translation to a possible built form can be dealt with after the form has evolved or it can be considered from the very beginning. Deciding to follow a combination of both approaches, as shown in Figure 2, a boundary is placed on the lattice to represent a site, along with a ground plane, and an orientation of growth that is vertical and to the sides, but not below. The cells are stacked over each other to create a vertical connection without a vertical displacement between layers of cells.

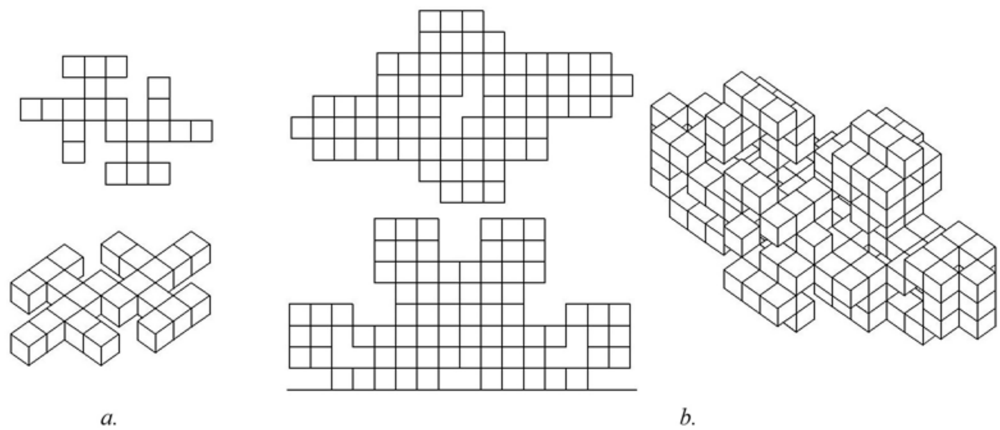

Figure 3. Sample generation

An initial review of the results highlighted a number of other issues; some cells were not connected horizontally to others and some cells had no vertical support. Also the cells do not have an architectural scale or suggest any interior space. Figure 4 displays a typical layer of cells and a series of interpretations that were made to address these issues, all of which are of interest architecturally. The centroid of each cell becomes the basis for this further development. The first issue is one of horizontal connections. Figure 4a. displays the initial cell configuration at a typical layer, each cell is adjacent to another. Cells are first joined together to form the largest contiguous floor areas possible. In this configuration, the cells that are diagonally adjacent do not connect horizontally. In 4b. the cell remains a square unit but is scaled so to overlap its neighbours. When joined, a small connector at the diagonals appears. In 4c. and 4d. , the scale of the square unit is increased to further develop a connector. The entire character of the exterior edge of the initial cells changes by these interpretations, as well as, addressing the interior horizontal connections between unit spaces. Additionally, a series of interesting interior openings begin to emerge.

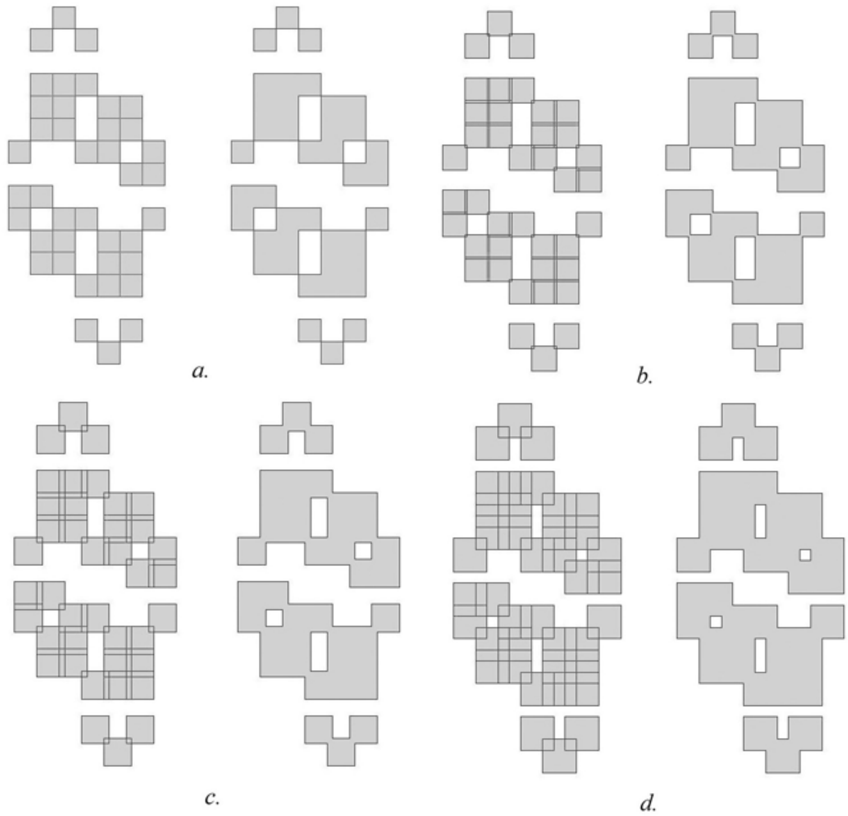

Figure 4. Horizontal connection of cells

In addition to a square unit, a variety of other shapes could be investigated that would articulate the building edge in other ways than the square and that could accommodate orientation and additional surface area in elevations for fenestration. Figure 5. displays a series of possible unit shapes: circular, super ellipse, rotated square, and a hexagon.

The joining of the units spaces, in addition to creating large contiguous areas, also creates a series of edge points, an envelope, that can be further given an interpretation or transformed. This envelope can be interpreted as a series of curve segments or a spline, as in the Figure 6. Depending on the type of unit shape, a variety of curved edges begin to develop.

As noted before, the initial cell configuration also lacked in having vertical supports. This issue could be addressed in the growth rules by limiting growth that had cell supporting it from below or to add supports to the final configuration. Figure 7. displays two possible support strategies, one with columns at the each cell corner and the second, columns located at the center of each cell.

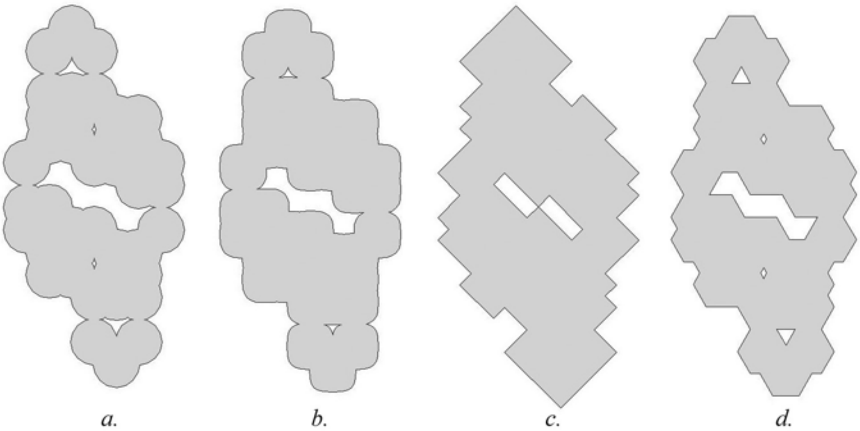

Figure 5. Variation of unit shape

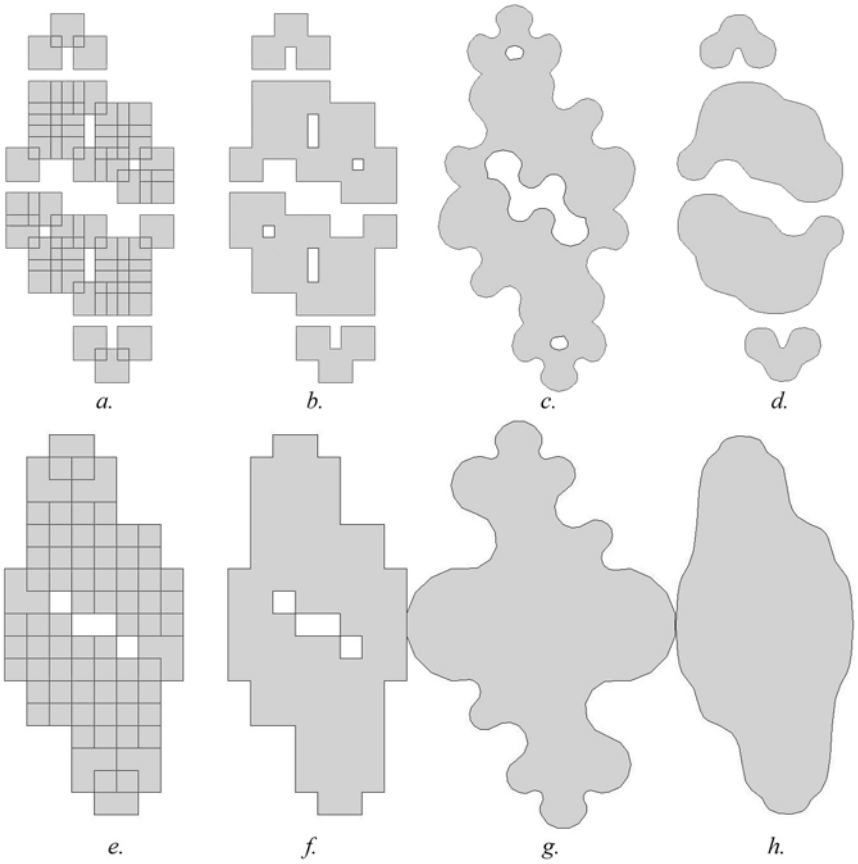

Figure 6. Envelope interpretation

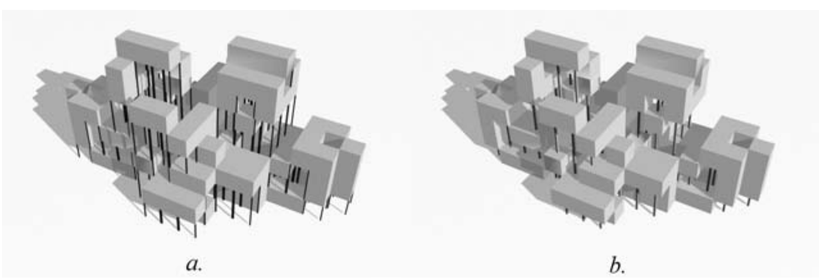

Figure 7. Cell supports

When seen in totally as in Figure 8. the following issues are also addressed. Displayed in 8a. is the raw cell configuration with supports represented as a mass model and with the cells represented as spatial modules of three floors each. Individual floor plates are included and each set of merged cells has a glass enclosure. In 8b. and 8c. are the curve and spline versions. One of the interesting aspects on this particular interpretation is the interior spaces created by the merging of the cells. A number of other merge schemes were investigated to further develop this concept. To articulate the edges of each layer of cells, a variety of spatial units, as shown previously, were also investigated.

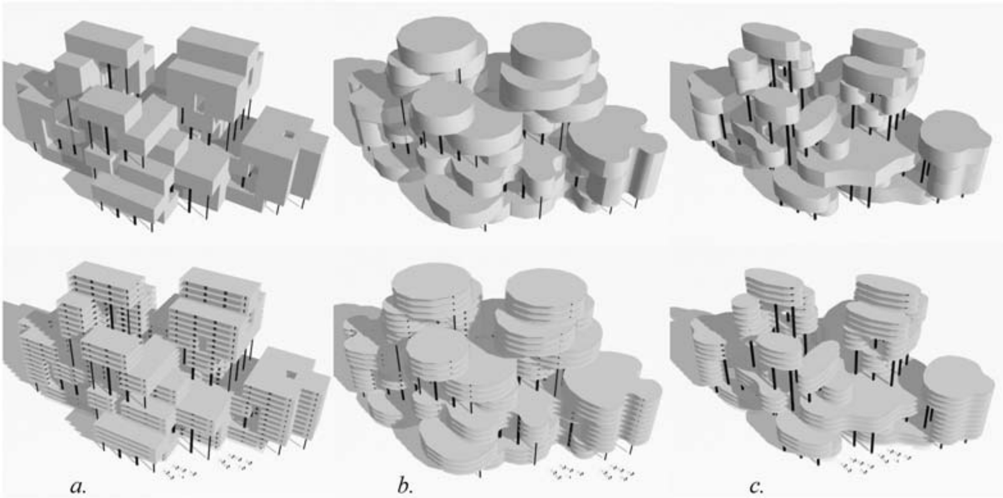

Figure 8. Basic architectural form series

Other approaches to the interpretation of the unit cells were also investigated. Figure 9. highlights an approach where the size of the unit cell is given a minimum and maximum, the actual size is selected randomly. The random method was also implemented in Figure 10., a minimum and maximum offset was defined for each vertex of a cell, then selected randomly. The shape in both of these cases remain approximately the same to the original.

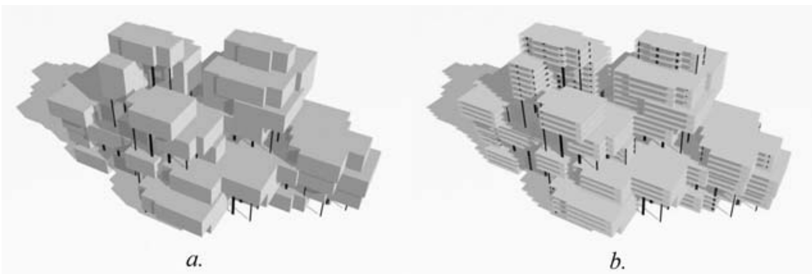

Figure 9. Cells of random size

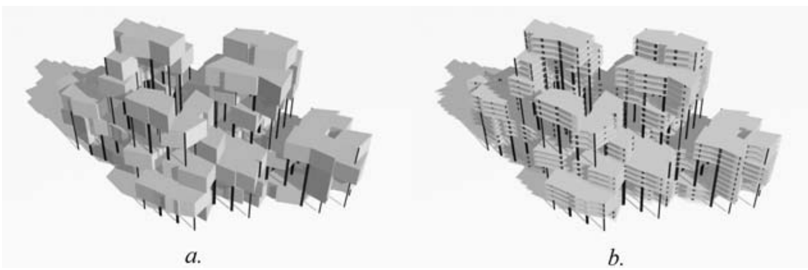

Figure 10. Cells with random offset of vertices

An entirely different approach was also investigated in that the vertical aspect of the stacked cells was considered as primary after the basic horizontal connections were made. Figure 11. displays one such example using the square cell unit.

The final concept considered was to interpret the cell formations as they are created. In this case, called retained growth, in each generation when a cell survives, it increases in size. This approach considers the actual growth process in the cellular automata and interprets it directly. Figure 12. display such a example.

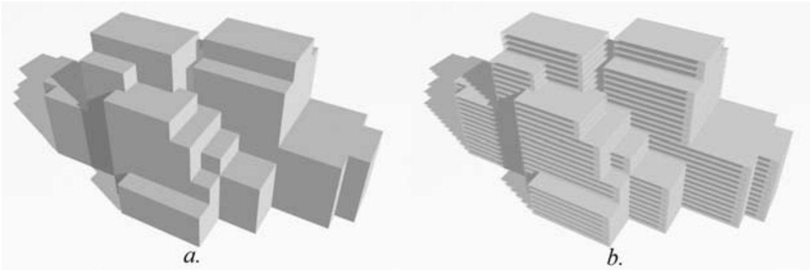

Figure 11. Cells as vertical volumes

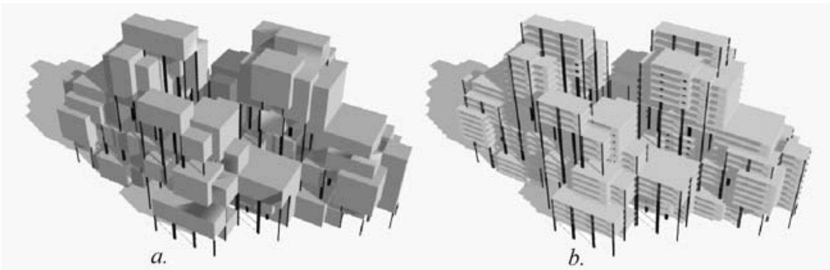

Figure 12. Cells with retained growth

Still other methods which have been developed by others, offer possibilities for future investigations. One in particular was suggested by Coates [9], Figure 13., in which the entire three-dimensional cell configuration is skinned with an envelope. The challenge would be to use this method but still embed the floor and unit space concept that was developed in this paper. The variety of methods on interpretation are only limited by the actual mathematics of the generating concept, the ability of the tools we use to model it, and our imagination.

Figure 13. Skinned Envelope

4. Observations

The goal for this investigation has been to recognize elements of a mathematical concept that can be transformed or interpreted into architectural elements. Still many issues remain: what should be the initial configuration of cells, maybe Jean L. Durand's [10] compendium of neo-classical design rules, which generation to stop at, neighbourhood definition, type of growth rule, definition of cell, shape of spatial unit, overall scale, support conditions, lattice configuration, restriction to number or area of placed cells, introduction of existing or fixed elements, other concepts for connecting cells, and other methods to interpret cell locations. All of these issues, and others, can be addressed at the beginning of such a generative process and be developed or revised as the investigation unfolds. No one software tool can anticipate all the possible directions that can appear, each individual software module developed in this research is an specific response to something that has occurred. This enables the process to develop the unexpected, as well as, the architecturally possible.

The most important aspect of this research is the process; taking raw data from a generative method, finding a pattern and then defining methods in the interpretation of that pattern. The study and development of all the considerations that are encountered is the basis for better understanding the design process itself. The end results are not the goal, the goal is what can be learned in the process of generating them.

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