EXPLORING THE MASSING OF GROWTH IN CELLULAR AUTOMATA

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Abstract
In the investigation of cellular automata as an architectural massing generator, as a cell survives generations after generation, a question occurred if the survival property could be integrated into the final form so its history is not lost. One method that could be considered is color, single generation cells having a different color than ones surviving multiple generations. Another method is to increase the size of the cell as it survives over time. When both methods are considered they are able to add an interesting variety to the massing of an architecture that is basically made from the regular placement of single cells.

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 (von Neumann, 1963) and further developed by Schrandt and Ulam (Schrandt & Ulam, 1970) in the area of simulating multi-state machines. The concept gained greater popularity when Martin Gardner described John Conway's "Game of Life", (Gardner, 1970) a game that generated two-dimensional patterns. Stephen Wolfram began researching the concept to represent physical phenomena (Wolfram, 1984) and has more recently reintroduced the discussion in "A New Kind of Science" (Wolfram, 2002).

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 subsequent set of results. This recursive replacement method continues until some state is achieved. Fractals and strange attractors are also created in a similar manner. A number of digital methods in architecture are parametrically driven, (Krawczyk, 1997, 2000), 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 cannot. 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. An early example of three-dimensional pattern development is the wooden block models created by Schrandt and Ulam. Investigating repeating patterns as Conway had found in two-dimensions is Bays (Bays, 1987) and finally an highly inspirational architectural application by Coates (Coates, 1996), much in the same spirit as Bays, based on the work of Frazer into polyautomata (Frazer, 1995). The more recent are two methods developed by Wolfram (Wolfram, 2002), in which a stacking method is explored, as well as, one similar to Bays. The striking similarity in all of these is the explicit representation of the cellular automata, the expression of the individual cells, even though each had taken a different approach and had a different application as an investigative goal.

As this research was developed (Krawczyk, 2001, 2002, 2003) a number of others have also conducted a variety of investigations. Some highlights: cellular automata for building elevations (Herr & Fischer, 2004), demonstration of module size and configuration development (Chen, 2003), shape variations (Soddu, 2003), and the generation of geometry for structures (Anzalone & Clarke, 2003).

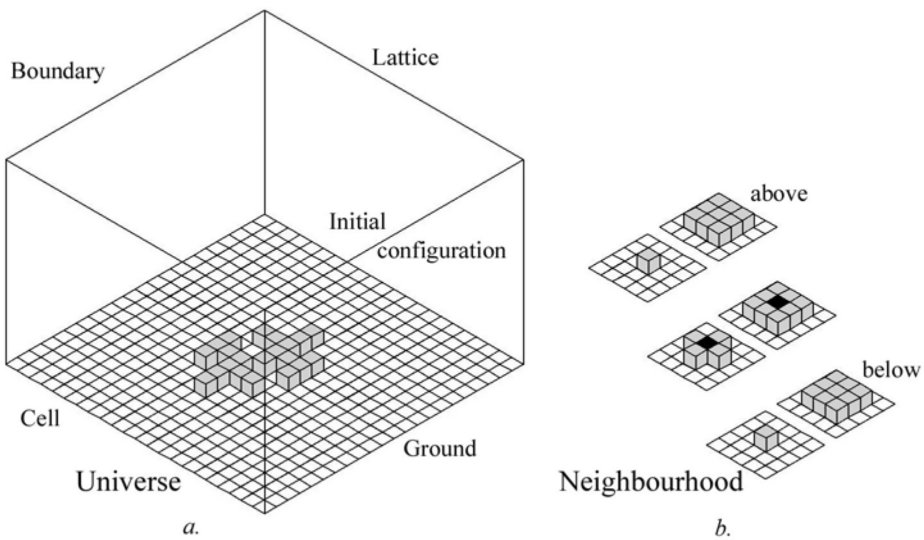

Figure 1. Basic cellular automata terminology

2. The basics

The three-dimensional universe, Figure 1a, of cellular automata consists of an 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 1b displays two common methods of determining which adjacent cells to consider. Being in three dimensions, cells adjacent are considered as well as cells above and below. 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 finally, 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 cellular automata into architectural form includes a number issues that do not consider built reality. For example, Figure 2 displays an initial configuration, 2a, and its raw results at the 8th generation, 2b. 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 1), 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.

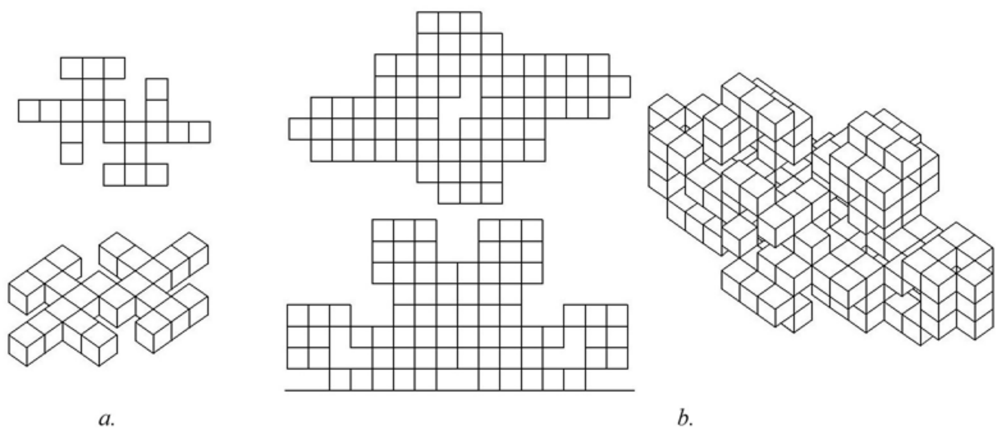

Figure 2. Sample generation

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 explicit architectural scale or suggest any interior space. Figure 3 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. 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. Next, the cell remains a square unit but is scaled so to overlap its neighbours. When joined, a small connector at the diagonals appears. The scale of the square unit can be increased to further develop this connector, as seen in Figure 3. 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.

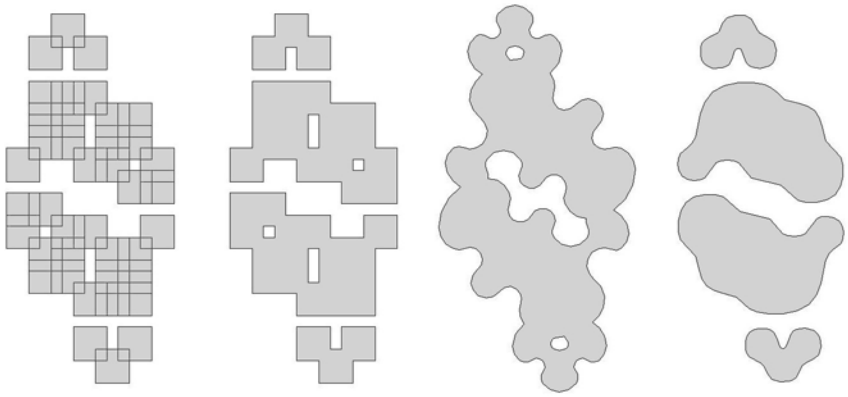

Figure 3. Development of the horizontal connection of cells

In addition to a square unit, a variety of other shapes were 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. Possible unit shapes included: circular, superellipse, rotated square, and a hexagon.

The joining of the unit 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 3. Depending on the type of unit shape, a variety of curved edges begin to emerge.

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. Two possible support strategies were considered, one with columns at the each cell corner and the second, columns located at the center of each cell.

When seen in totally as in Figure 4, the following issues are also addressed.   Displayed in the column is first the raw cell configuration with supports represented as a mass model and with the cells represented as spatial modules of three floors each.   The others in Figure 4 represent the massing translated to a curve and spline version. The massing version is then transformed to include individual floor plates and each set of merged cells is surrounded by a glass enclosure, Figure 5. 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 discussed previously, were also investigated.

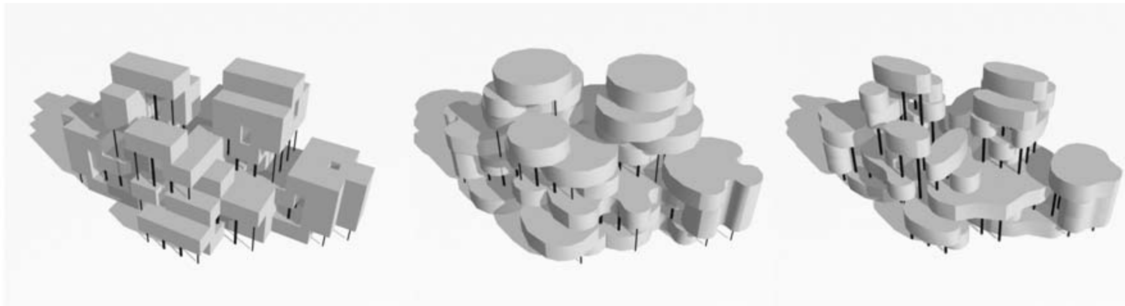

Figure 4. Basic mass architectural form series

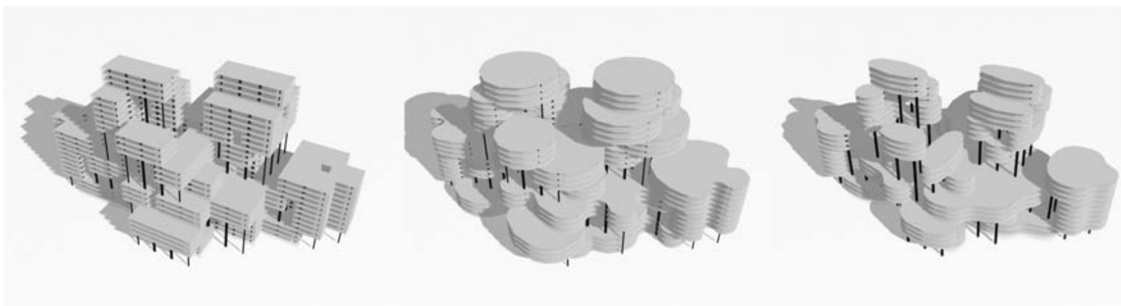

Figure 5. Mass architectural form with floor plates and enclosure

Other approaches to the interpretation of the unit cells were also investigated. In one approach, the size of the unit cell is given a minimum and maximum dimension; the actual size was then selected randomly. The random method was also implemented using a minimum and maximum horizontal offset to define each vertex of a cell, then having the offset selected randomly. The shape in both of these cases remained approximately the same to the original.

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. All the cells were extended to the ground level giving each a base.

The final concept considered was to interpret the cell formations as they were created. This case, called retained growth, is based on observations from previous research that the massing of the cells at any one time never included consideration for the cells that had survived from generation to generation. The question that resulted was: could this property be displayed in some fashion in the final form. Showing this property would increase the visibility of the underlying cellular automata method used.

4. Recording Survival

The first method in recording survival was to simply display the surviving cells in another color. The top row in Figure 6 displays three original results without color differentiation. The second row displays surviving cells in a different color.

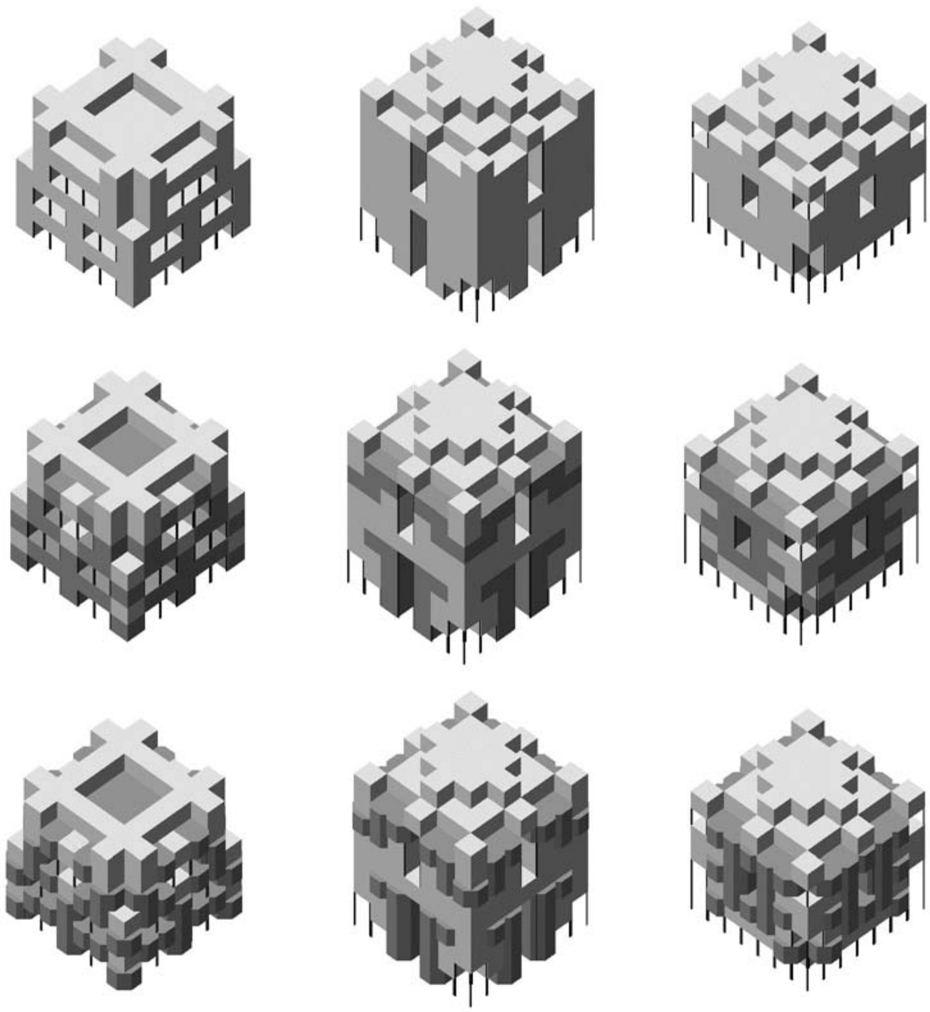

Figure 6. Survival as color and shape

The architectural patterns that were generated were interesting but the overall massing still remained the same. The architectural implementation could be a complimentary cladding or some variation in the curtain wall. The next option was to represent the surviving cells in a different shape from the others. Row three displays one such variation, an octagon as the cell shape. These did further accentuate the surviving cells, but were not strongly integrated into the remaining square cells. The horizontal connections became much stronger than the vertical.

These results were further developed into the concept of varying the cells not by shape but by size. Row one in Figures 7 displays the same results with the surviving cells modified by only height. As the cell survives from generation to generation it increases its height by a small amount. This also enables survival to be represented as growth. Row two displays the same results by giving the cells only horizontal growth instead of vertical. Finally, row three displays the results when both horizontal growth is included with growth in height. With growth in all directions, the architectural massing greatly deviates from the regular cellular one of simple square cells. This offers a variety of expression and also a visible history of the survival of the cells.

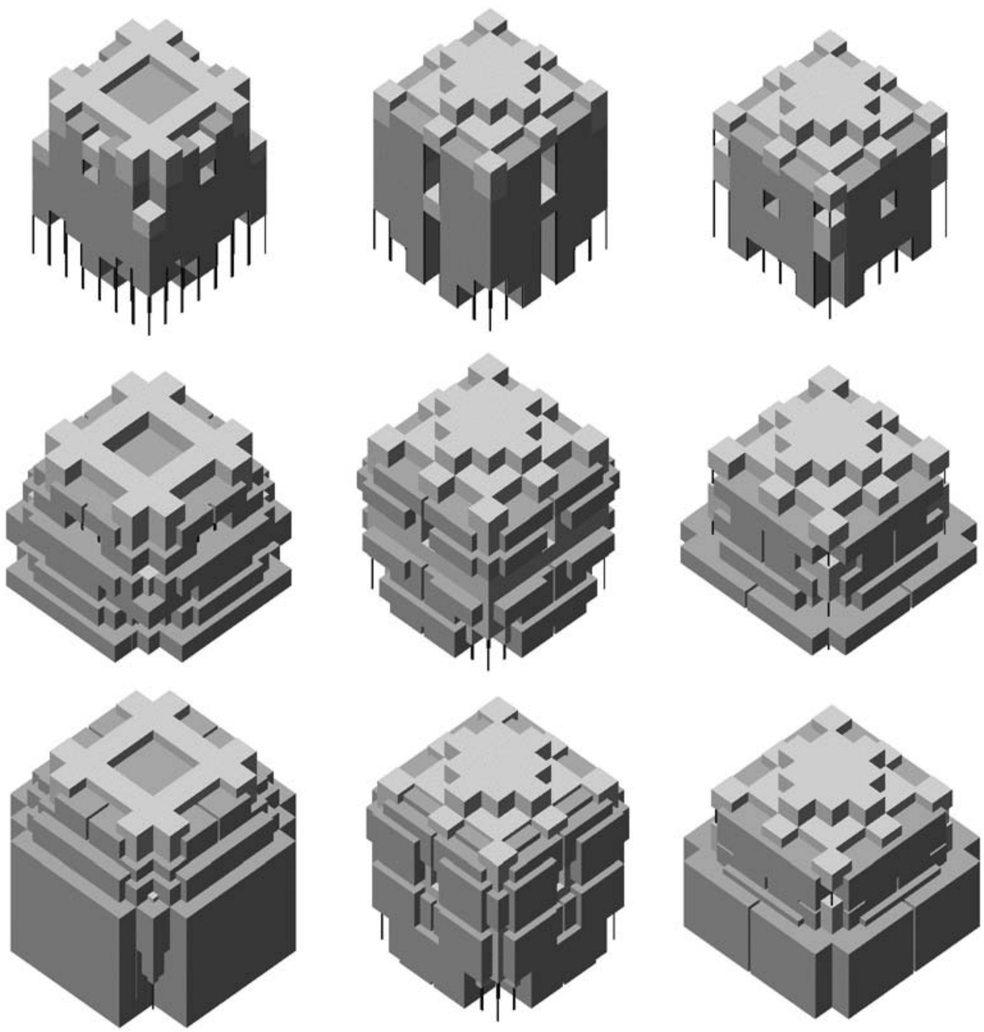

Figure 7. Survival as variation in size

A further investigation could include the rate of increase for each generation or the grouping of cells having survived the same number of generations, color-coded in some fashion. The original shape of the cells could also be varied. This research only considered the square and later the circle as possible cell plan layouts.

5. Generating Variation

To be able to investigate the possible variation that might be possible with the retaining of survival and displaying a growth method, a series of experiments were performed. From previous research a series of parameters of boundary, survival/birth rules, neighbourhood definitions, and number of generation was established. In the first series 1,144 trials were executed. This included all the results from two boundary conditions, one limited and the other unlimited; thirty-seven rules, based on a survival/birth neighbourhood count having a variety of combinations of a maximum of eight cells; four neighbourhood definitions: six locations, four on the same level, one above and one below; the classic twenty-six locations, all adjacent cells on the same level and all the ones above and below; seventeen locations, all the cells on the same level and all the ones below; fourteen locations, diagonals on the same levels and diagonals directly the level above and below. Each of these parameter sets was executed for five, six, nine, and fifteen generations. The initial configuration consisted of eight cells outlining a square arrangement, with the center cell empty. Selected results from this series are displayed in Figure 8. The lighter colored cells are first generation and the darker ones are ones that have survived multiple generations.

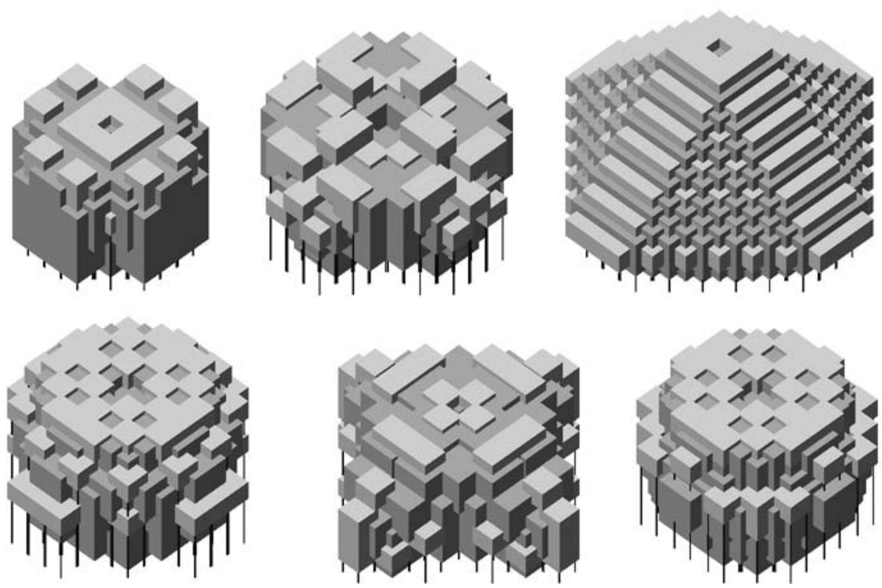

Figure 8. Regular survival series

In reviewing the generated results, some were eliminated; the arrangements that became extinct within the number of generations and the ones that became overly fragmented. Only the ones that retained a fairly connected mass were considered. Architecturally, the process developed connecting masses that further enhanced and highlighted the cellular automata method used to create them. The standard method treats all cells equally; this massing retains the survival history of the cells. When the total series was examined, the possibilities of interesting subgroup arrangements were observed. Further research could find the relationship of these arrangements with the generating parameters exploring the concept of natural occurring styles.

Another series was also investigated that further attempted to introduce a method to increase variety within the results. Figure 9 displays a sample of massings where at every generation a mutation is applied by randomly selecting a new survival/birth rule and neighbourhood count. Architecturally, the concept explores a method to break any evolving pattern so the forms are further unpredictable and offer an even wider range of massings without introducing a natural style. The boundary condition is set to unlimited throughout, with the random selection using all thirty-seven rules and all four types of neighbourhoods. In this series the life span is set to six generations and the space module is represented as a cube. The initial configuration consists of the same eight cells in a square arrangement as before. Over 2,000 random trials were generated.

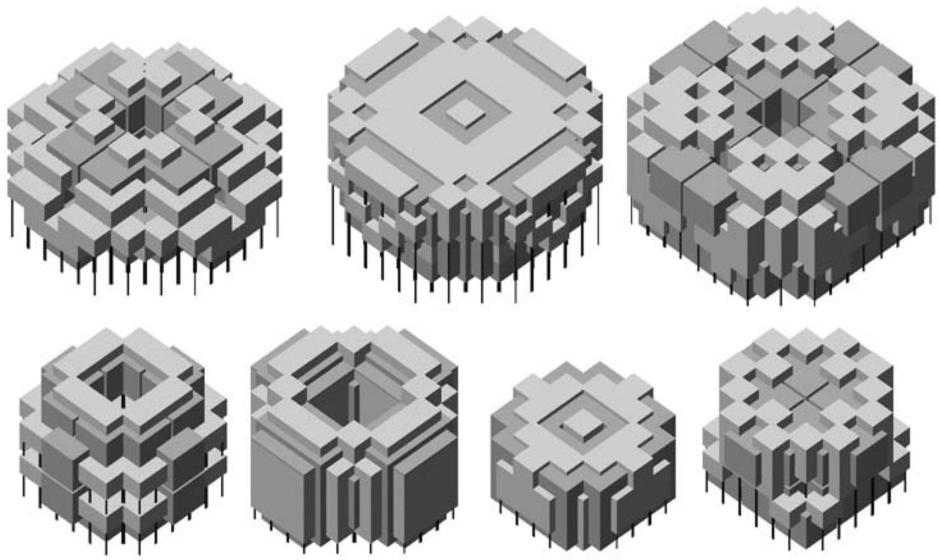

Figure 9. Mutated survival series

Figure 10 displays an initial sampling of massing developed in the same manner as described above except that the cells are represented as circular volumes and are limited to seven generations.

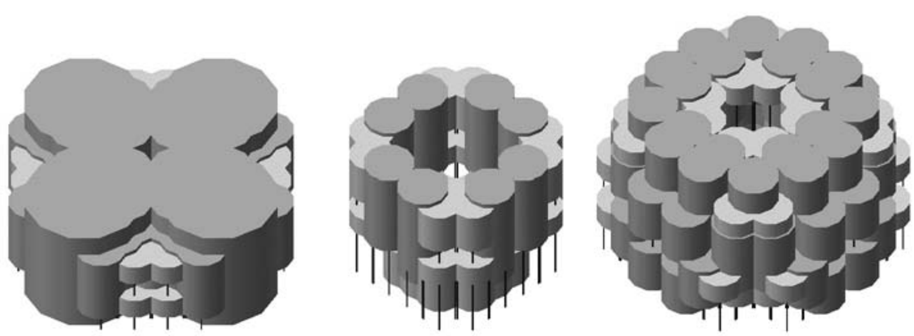

Figure 10. Mutated survival circular series

Still other methods that have been developed by others, offer possibilities for future investigations. One in particular was suggested by Coates (Coates, 1996) 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 research. 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.

6. Observations

The goal for this investigation has been to recognize elements of a mathematical concept that can be transformed or interpreted into architectural form. Still many issues remain: what should be the initial configuration of cells, maybe Jean L. Durand's compendium of neo-classical design rules (Durand, 1802), 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, the 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 a 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 resultant forms are not the goal, the goal is what can be learned in the process of generating them.

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Further Areas of Research

Variation to Individual Modules

- random size
- random offset of vertices

Variation on Module Interpretation

- vertical volumes
- retained growth

- faceted modules
- skinned modules

- other structural configurations

Cellular Automata and Architectural Design

- consistent framework
- generation of patterns
- allow for interpretation or translation
- rich set of rules and conditions

Some Remaining Questions:

- what can be the architectural meaning of the initial state?
- what are other possible neighborhoods?
- what results do other survival rules generate?
- what are other possible lattice configurations?
- can some lattice locations be fixed?
- what are other possible representation for cells?
- how can cells be connected in other ways?
- what other interpretations are there for the cell location?
- what methods can be used to stop generation?

Computational Methods and Architectural Design

- exploration, alternatives and variations, is the core
- relationships and limitations can be developed
- representations that are capable of interpretation
- methodology which is transparent and repeatable
- element of unpredictability

Process
Data Pattern Interpretation