Les Folies Cellulaires – An Exploration in Architectural Design Using Cellular Automata

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Abstract

Inspired by Tschumi's famous realization in the Parc de la Villette, the Authors explore the concept of cellular automata (CA), applied in architectural and urban design. The theoretical approach to the problem of cellular automata considers works of Krawczyk, Coates and other authors proposing various ways of using cellular automata in the design process, particularly in architectural design. The experimental activity is realized by the CA module of the software Fun3D which has been created to support generative processes in architectural design. The CA module of the software allows certain level of redesign of a basically cubic cell and other elements of a CA system, as well as combination of multiple cellular systems. A series of "follies" has been created in a design experiment with senior architecture students. The resulting designs retain some features of Tschumi's follies (scale, type of context, coloristic approach, spatial interpretation) introducing and examining cellularity as a main creative idea. This paper is part of a continued research activity titled Generic Explorations, within the Faculty of Architecture, University of Belgrade.

Keywords: cellular automata, cellularity, architecture, generic, experimental

Introduction

The concept of cellular automata (CA), introduced by Von Neumann [1] and later explored and popularized by Wolfram [2], has extensively been examined in various fields, including architectural design. Early experiments realized by Coates [3] indicated a significant potential of the CA in the process of spatial form generation, while Krawczyk [4] proposed architectural interpretations of a form based on the CA concept. One of the typical interpretations of a CA based form is certainly in domain of high-density buildings, as propose Herr and Kwan [5].

In their previous research in the field of CA, the Authors of this paper examine the design potential of the concept [6] and possible architectural interpretations of generated spatial form in a given context [7]. The research realised under the title Generic Explorations [8], included several design experiments with senior architecture students at the University of Belgrade. In these studies, a methodological approach based on the research by design with a critical number of participants, combined with certain additional analysis and systematizations of results, has been developed and tested. The studies were supported by CA module of the Fun3D software, created to respond to the specific needs of architectural design.

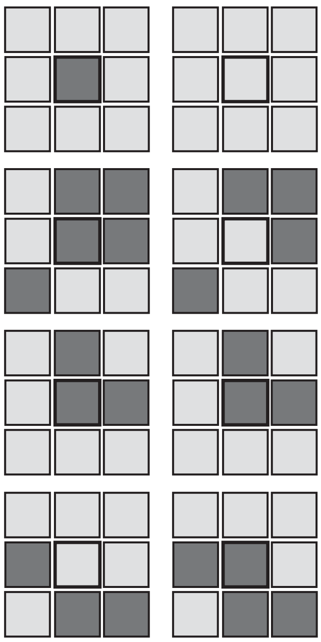
This study is focused on examining the CA generic concept inspired by a well known architectural realisation of a significant cellularity. Tschumi's famous "Les follies" realised in mid 80-es in the Parc de La Villette in Paris [9], consist of 26 spatial points materialised on a 3x3x3 system of cubic cells [10]. The characteristic cellularity of Tschumi's follies was a starting point for this exploration of the CA concept in architectural design.

Cellular Automata

A cellular automaton (CA) is a discrete dynamical system. Space, time, and the states of the system are discrete. Each point in a regular spatial lattice, called a cell, can have any one of a finite number of states. The states of the cells in the lattice are updated according to a local rule. That is, the state of a cell at a given time depends only on its own state one time step previously, and the states of its nearby neighbors at the previous time step. All cells on the lattice are updated synchronously. Thus the state of the entire lattice advances in discrete time steps.

Conway's Game of Life - The GAME OF LIFE is a CELLULAR AUTOMATON [11] devised by the British mathematician John Horton Conway in 1970. It is the best-known example of a cellular automaton. The universe of the Game of Life is an infinite two-dimensional grid of cells, each of which is either ALIVE (populated) or DEAD (unpopulated or empty). Cells interact with their eight NEIGHBORS, the cells that are directly horizontally, vertically, or diagonally adjacent.

At each step in time, the following effects occur:



LONELINESS: any live cell with fewer than two neighbors dies.

OVERCROWDING: any live cell with more than three neighbors dies.

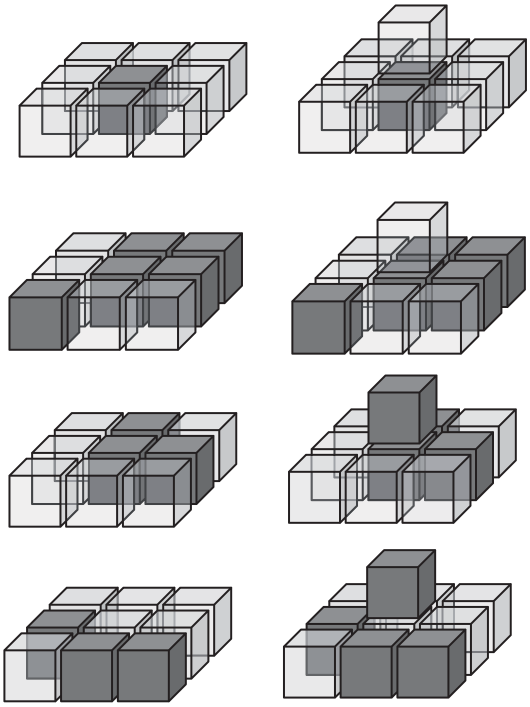
STASIS: any live cell with two or three neighbors lives, unchanged, to the next generation.

REPRODUCTION: any dead cell with exactly three neighbors comes to life.

Figure 20 – The rules of the Game of Life, 2D

The "game" is actually a zero-player game, meaning that its EVOLUTION is determined by its INITIAL STATE, needing no input from human players. One interacts with the Game of Life by creating an initial configuration and observing how it evolves.
The INITIAL PATTERN constitutes the first generation of the system. The second generation is created by applying the above rules simultaneously to every cell in the first generation -- births and deaths happen simultaneously, and the discrete moment at which this happens is called a TICK. The rules continue to be applied repeatedly to create further generations.

3D Layers Evolution View of the Game of Life - Considering a generative process as a set of layers instead of a change of a system single state, the flat cellular automata context becomes a spatial one, with a significant third dimension. The simple rectangular cell becomes a cubic block, reproducing itself in every following generation according to spatially interpreted rules of the Game of Life:



LONELINESS: any live cell with fewer than two neighbors dies.

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Figure 21 The rules of the Game of Life, 3D Layers

The layers of a single CA system, as shown on the Figure 22, define a spatial form that could be interpreted in different ways, depending of its own geometric characteristics and on a wider context.

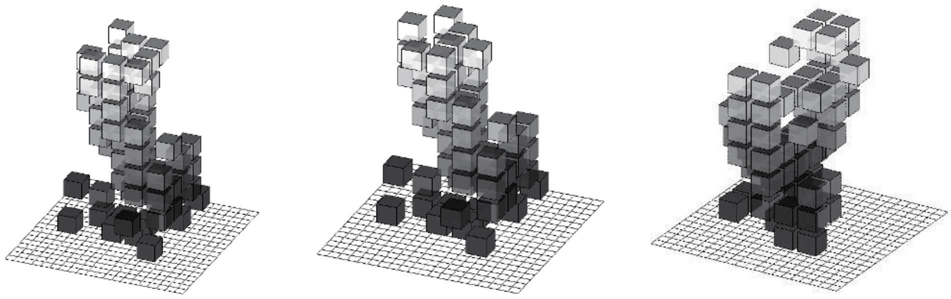


Figure 22 Typical CA spatial forms based on the rules of the Game of Life

The software

Fun3D (the name derived from “Function 3D”) is a software developed by B. Mitrovic, within the “Generic Explorations” project. Its development begun with a module supporting creation of parametric curves and surfaces, continuing with another module aimed at creation of 3D L-systems.

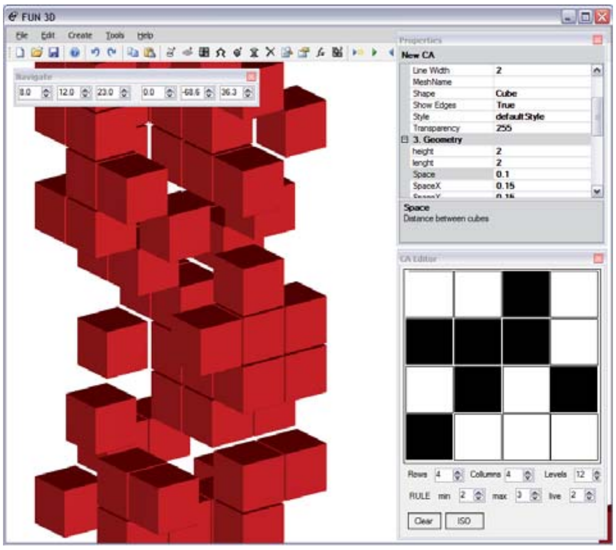


Figure 23 Fun3D (created by B. Mitrovic, within the “Generic Explorations” project)

The CA module of the software (Figure 23) allows creation of CA based spatial form, as well as control of the following CA elements:

- Initial configuration (controlled by a graphic interface)
- Rule definition (totalistic)
- Total number of layers
- Position of a system (x, y and z coordinates)
- Rotation of the system (along x, y and z axes)
- Proportion of the cell (height, width and length)
- Color range of the cell layers
- Transparency
- Gap between cells of the system
- Lighting
- Shadows

Variation of mentioned parameters, especially the ones affecting geometry, results in a range of spatial forms. A sequence on the Figure 24 represents variations of the CA system based on the same generative rule. As resulted forms have surprisingly different spatial characteristics, the Authors suggest a need for deep exploration in the field of geometry of 3D cellular automata.

The presented module can generate and visualize several CA systems within the same scene, each with different geometric parameters, and based on different rules. It also permits copying of an entire system and pasting it within the scene. Combination of various CA systems within the same scene, results in a spatial form of a significant complexity that needs to be additionally examined and interpreted.
One of the most important features of the CA module is export of .dxf file formats that makes the software fully compatible with a range of CAD programs.

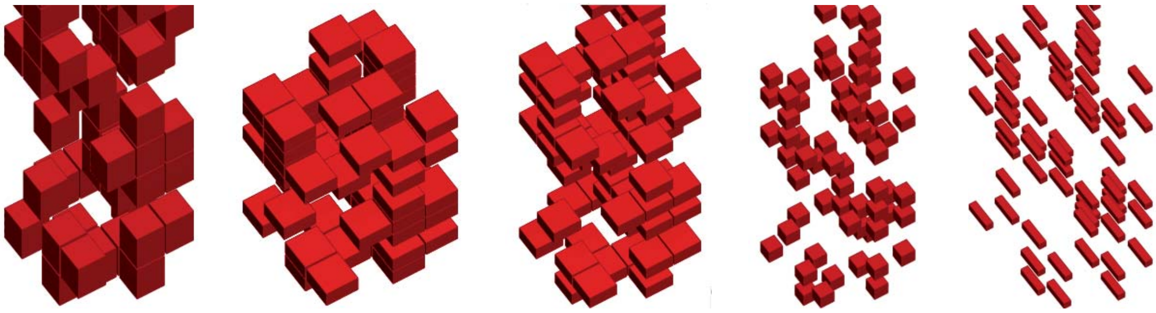


Figure 24 Variations of a single CA system based on the same rule (2,3,2)

Further developments of the CA module of the Fun3D software include some additional features both geometric and explorative. The improved geometric features associated to this research are related to definition of a basic cell, as well as to control of the gap between cells in x, y and z directions. The additional explorative features that need to be enhanced, presume a possibility to chose particular segments of a CA space (universe), both vertically (along generations) and horizontally (in the initial cell layout).

Fun3D software is protected by the Creative Commons license [13], which means that it could be freely used and redistributed, with mentioning its author (B. Mitrovic) and the context in which it has been developed (Generic Explorations project, Faculty of Architecture, University of Belgrade).

The experimental part of the study

In the experimental part of the study the two stages were completed:

- the computing stage (*in silico*) in which the reinterpretation possibilities have been examined by the CA module of the Fun3D software
- and the design stage in which a group of senior students has been asked to reinterpret Les Follies using the CA concept in general.

Computing experiments

In the initial stage of the experiment, the Tschumi's characteristic 3x3x3 grid has been examined using the basic functionalities of Fun3D software. A relatively simple initial configuration of 3x3 cells that has never been considered in our previous explorations, resulted in an unexpected variety of spatial forms, produced by applying different rules.

Figure 25 represents an explorative set of nine various initial configurations of CA systems, each of which has been a base for a spatial form generated by rules 2,3,2; 3,4,3; 1,3,1 and 2,4,2. An analysis of the results indicated that could be possible to combine multiple rules on the same initial configuration, if we manage to introduce different geometry to the initial cell of the system. This required an additional functionality to be included in the Fun3D CA module – possibility to choose geometry other than solid cubic.

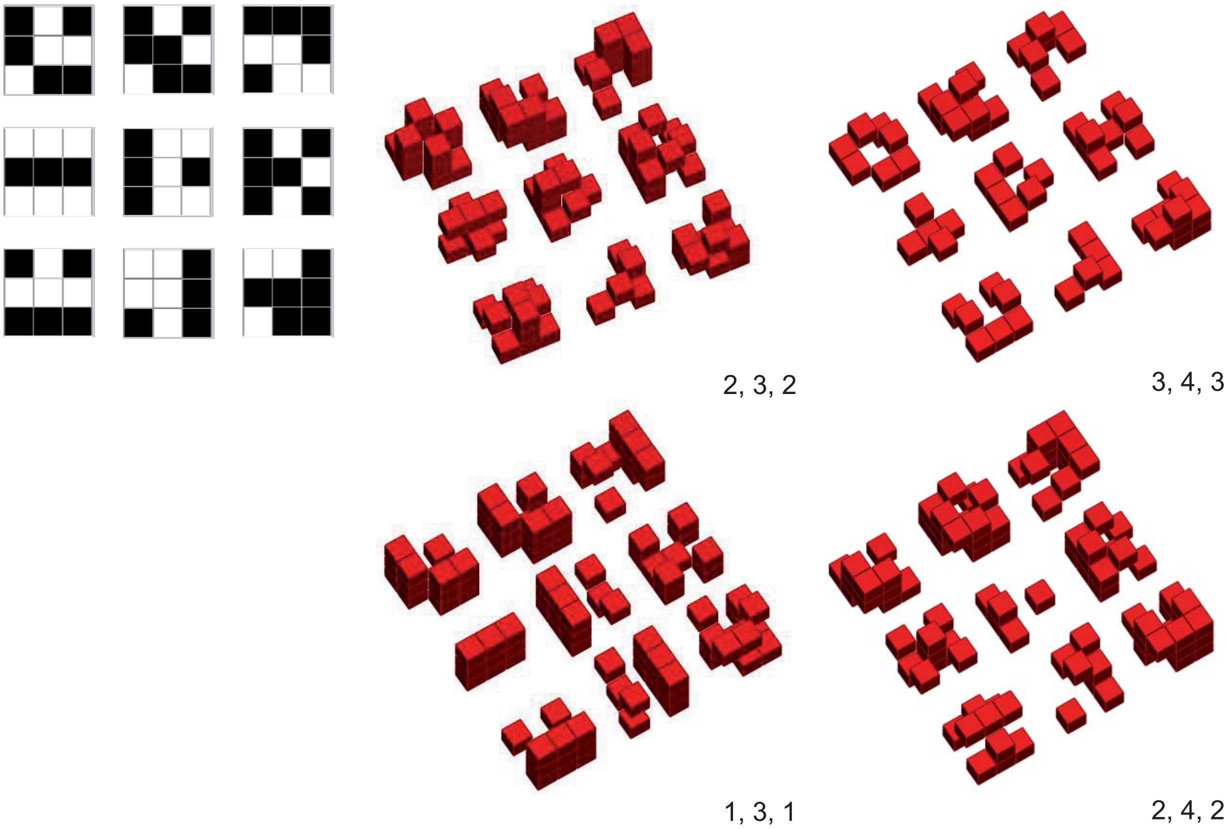


Figure 25 Application of various rules on a series of initial configurations

Figure 26 shows a combination of two CA systems: the first based on 1,3,1 rule (solid cells) and the second, consisting of wire frame cells, based on various other rules. In this stage we have shown that a combination of several CA systems results in spatial forms that might be considered as a generic reinterpretation of Tschumi's follies.

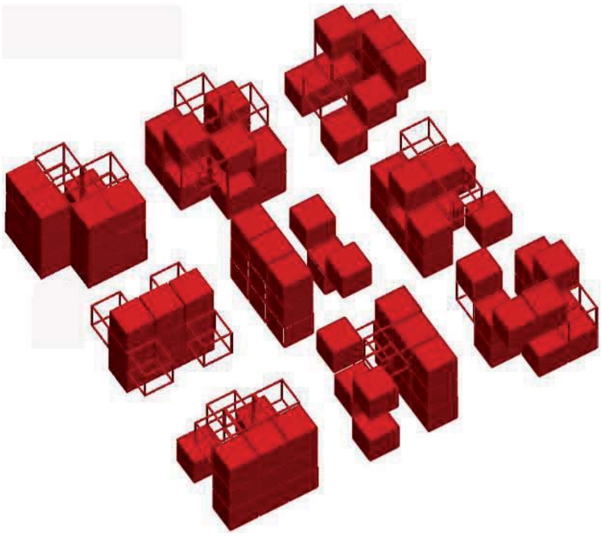


Figure 26 Combination of two cellular systems - a generic reinterpretation of Tschumi's follies

Experimental design

In this part of the study, a group of senior architecture students was asked to reinterpret the famous Tschumi's work, after an exploration of its geometry, and particularly its cellularity, that has been done in previous step.

The results from this part of the study, realised with students as a research by design, could be systematized in three groups:

- Variations of a single 3x3x3 CA system
- Multiplication of a CA system
- Changing the inner structure of a CA system

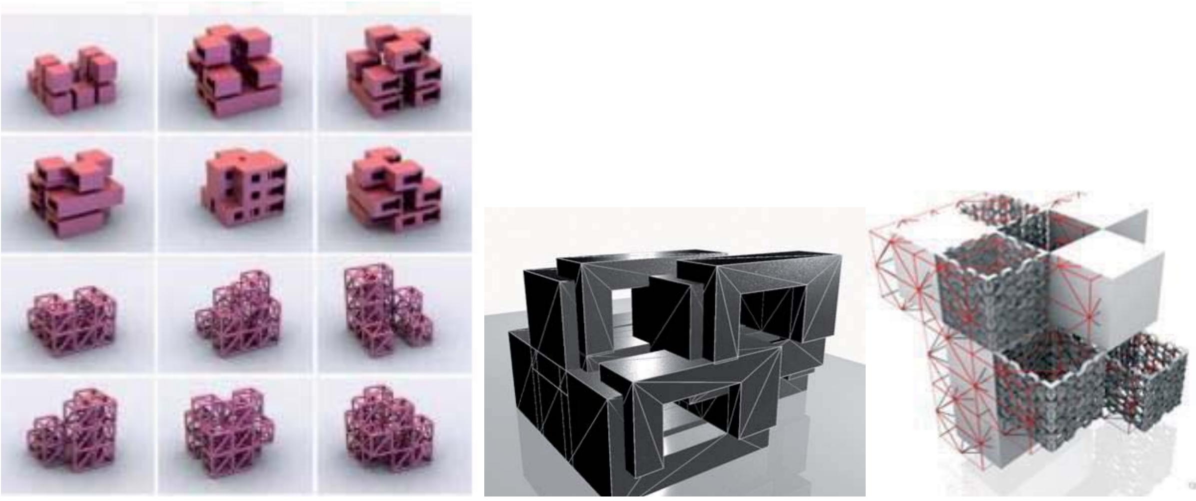


Figure 27 Variations of a 3x3x3 system

The first group of designs (Figure 27) represent relatively simple 3x3x3 systems consisting of one or several CA. Main characteristics of reinterpretation is change of initial cell, either its entire geometry or its proportion and texture.

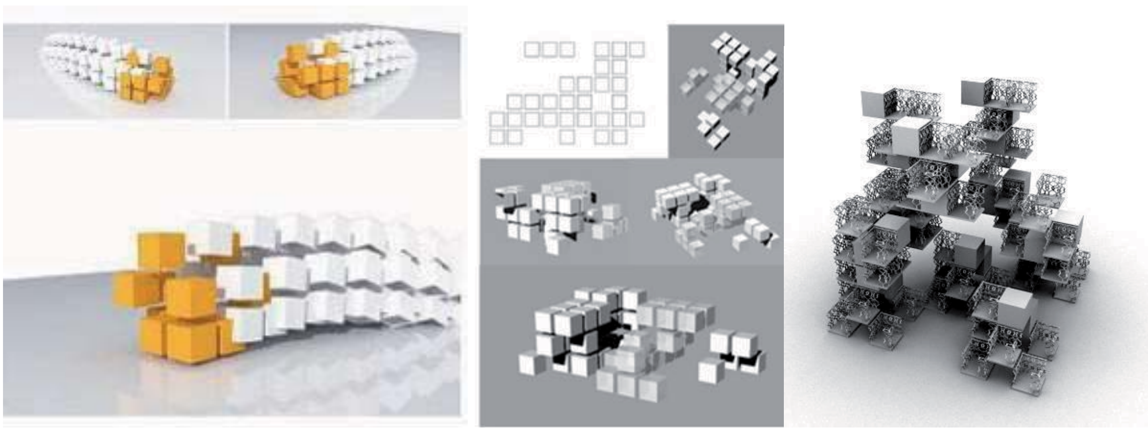


Figure 28 Multiplications of a CA system

Figure 28 shows the second group of results which main characteristics is a multiplication of the initial 3x3x3 CA system. While some designers retained Tschumi's orthogonal layout of objects, the others introduced alternative concepts like affine transformations, fragmentation, fractalization, etc.

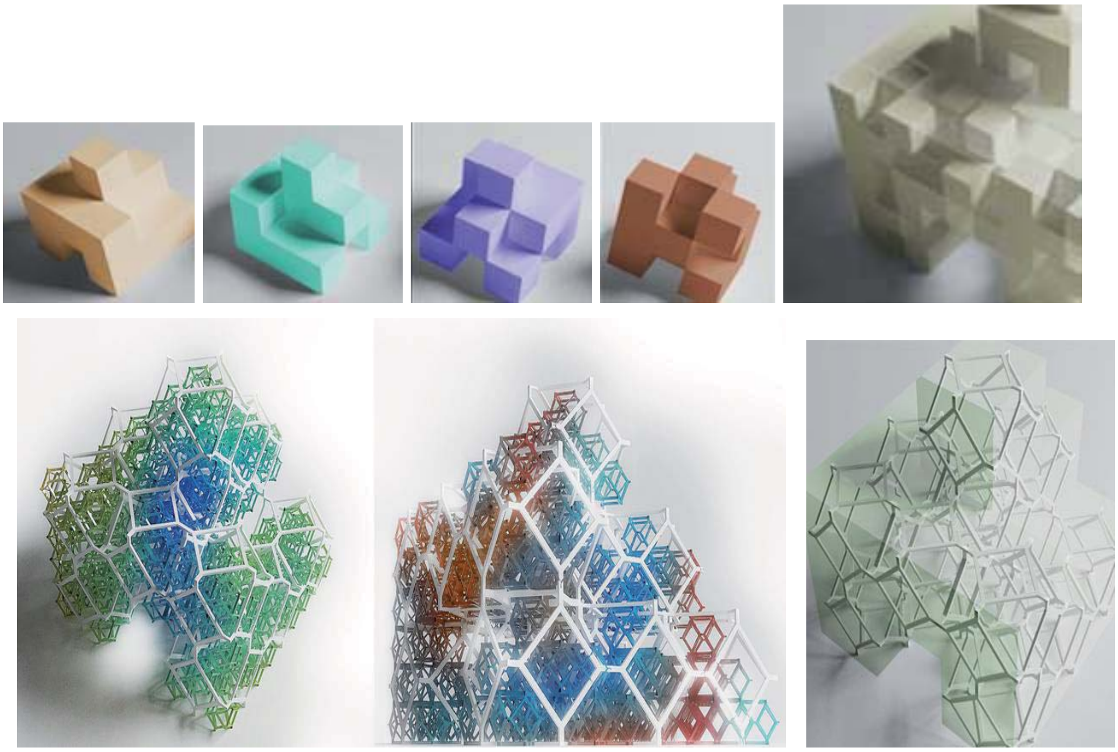


Figure 29 Changing of the inner structure of a CA system

In the last group of results (Figure 29) the 3x3x3 CA system changes its inner structure. This change is based on the fractalization mentioned in the previous group, but it is used just as a step towards introduction of more complex geometry within each cell of the system.

The resulted reinterpretations indicate that there's a significant potential in the simplest 3x3x3 cellular system. They require an additional architectural interpretation, as in many aspects the resulting designs lose an initial sculptural signification.

Fragmentation, compatibility, fractalization and hidden geometric potential of cellular automata

As a result of the exploration inspired by Tschumi's work, after the experimental stage, a range of issues on CA applied in architectural design, have been identified. The following four issues are highlighted:

- Fragmentation
- Compatibility
- Fractalization
- Hidden geometric potential

Fragmentation of CA systems

Tschumi's differentiation of basic structural elements required fragmentation of a CA system, i.e. decomposition of one CA system into combination of several systems. Consequently the ratio of x, y and z dimensions of initial cubic cell, has to be changed, and the cell becomes one of the elements forming the structure.

This fragmentation becomes possible by introducing various sizes of gaps between elements in x, y and z directions. This functionality has been included in the CA module of Fun3D software in the final stage of this study, and represents the latest improvement of the software. Some of the results are shown on Figure 30.

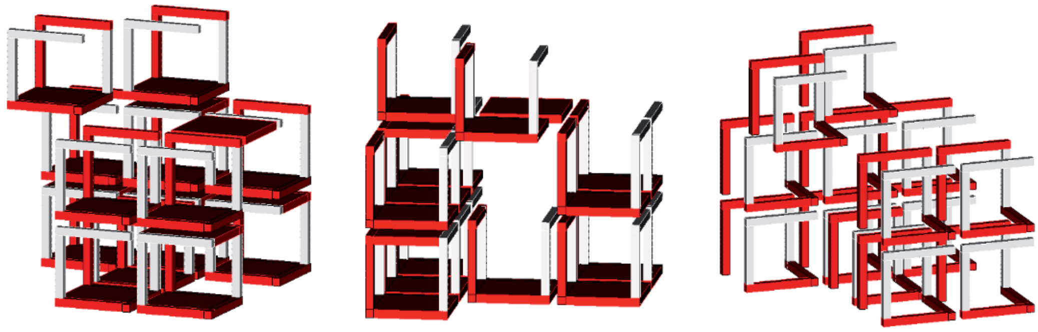


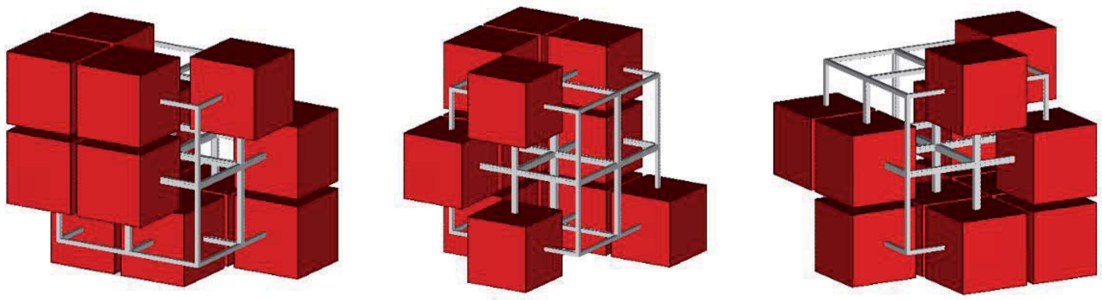
Figure 30 Fragmentation of a 3x3x3 CA system

Compatible CA systems

The issue of compatibility of CA systems came from combination of multiple CA systems. Combining a single 3x3x3 CA system with other systems could occur:

- On the same level, i.e. with one or more 3x3x3 CA systems (as shown on Figure 26 and Figure 30)
- With a 2x2x2 CA sub-system (□□□□□□31)
- With a 4x4x4 or higher CA super-system (Figure 32)

The sub and super CA systems are the systems one level lower/higher than the observed 3x3x3 system. The corners of both systems are placed in centres of the cubic elements of the 3x3x3 system.



□□□□□□31□□□□□□□□□□□□□□□□□□□

A sub-system of 2x2x2 cells can be treated as a special case of CA because of limited number of cells and therefore limited number of combinations of final 2x2x2 spatial forms. But, it seems to have a powerful structural potential (□□□□□□31), so it requires some further examinations.

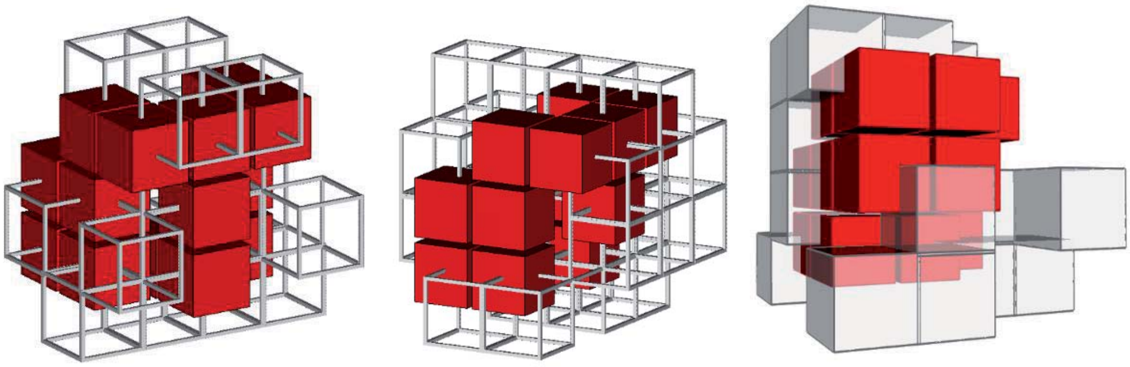


Figure 32 A CA super-system 4x4x4

The 4x4x4 super-system (Figure 32) is based on an altered initial CA configuration and could be generated according to a rule different than the one of main 3x3x3 system. Introduction of such super-system requires an architectural (instead of sculptural) interpretation of the resulted spatial form.

Fractalization

The fractalization of the 3x3x3 CA on Figure 33 has been realized by replacing the initial cell with the entire system, introducing thus the principle of self-similarity.

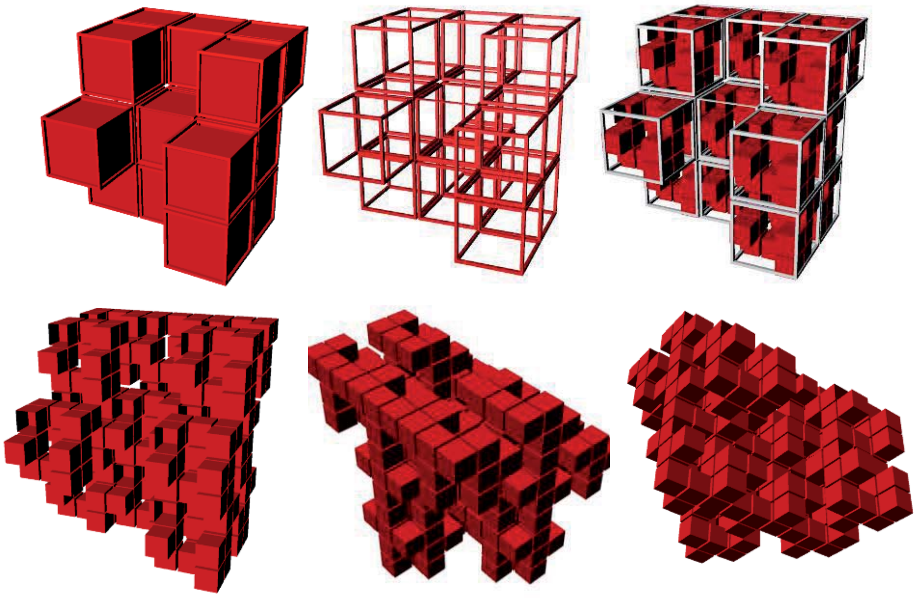


Figure 33 Fractalization of a 3x3x3 form

The spatial form resulted from the fractalization of an initial 3x3x3 CA, also requires an additional architectural interpretation, since its fractal nature suggests a mega-structure instead of a small-size sculptural object.

A hidden geometric potential

Finally, a single 3x3x3 CA system has been explored as a generator of a complex inner surface. In the example on the Figure 34, the system of cubic cell diagonals has been used as an input for a loft surface.

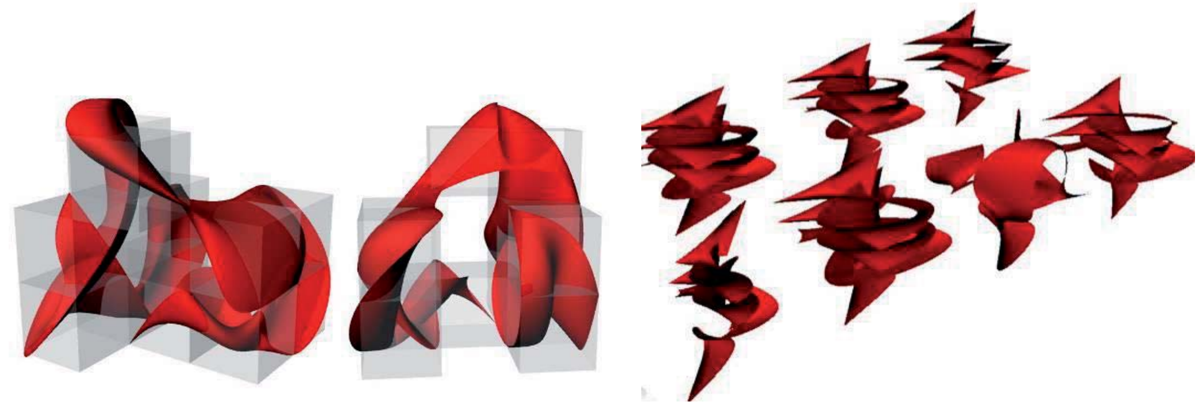


Figure 34 A CA as a generator of a complex surface

In this stage, it was necessary to use a NURBS modeling software (Rhino 3D), with a certain scripting support that permitted generation of a series of complex surfaces based on variations of 3x3x3 CA.

Conclusion

Focused on simple 3x3x3 grids, inspired by Tschumi's follies, this study demonstrates a considerable design variety resulting from application of well-known CA generative concepts. Variations of a single 3x3x3 CA system by introducing initial cell different than solid box, as well as multiplication of the system and change of its inner structure, call for new architectural reading of resulting spatial forms.

Reinterpretation of Tschumi's work, derived from an experimental activity, requires additional functionalities to be included in the CA module of the Fun3D software. Some of these functionalities have already been developed and applied (variations of initial cell, fragmentation), while some need to be further elaborated (advanced compatibility, fractalization, etc.).

Finally, this study indicates that there's also a geometric potential hidden within the simple CA systems, which could result in complex geometries. This requires either NURBS modelling to be integrated in the existing explorative tools, or the future explorations to be performed in NURBS modelling environments with flexible scripting solutions.

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