Discrete Space: Automason Ver. 1.0

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Abstract
This paper will demonstrate the power of digital technology by encouraging architects to become more involved in the creation of small scale, ad-hoc and task specific software tools. Rather than appropriating code originally designed to solve the visualization problems faced in other fields, designers should instead develop their own programming culture. Through the acquisition of new skills and better collaborative exchanges architects can advance the unpredictable desires of the poetic imagination while addressing the practical challenges faced by craftsmen, engineers and project managers.

This paper will therefore attempt to:

a. Expand the current definition of Computer-Aided Manufacturing (CNC Mills, Laser Cutters etc.) by proposing a new kind digital construction system,
b. Transform an old, ubiquitous building craft by writing proprietary code that can alter the performance of an advanced and ubiquitous communication technology,
c. Describe the basic features of a new architecture.

Note: Unlike classical machines (can openers, clocks and steam engines) a computer’s power is measured by its degrees of freedom. Because different codes can run on the same hardware without significant changes in its design a “universal machine” is able to evolve architecture beyond any fixed style or formal paradigm. Borrowed products that often force the imagination through a filter of hidden protocols and invisible logical processes currently limit architectural thinking. The ability to craft programs that address both the practical challenges of building design and the human capacity to imagine new forms has not yet been fully explored by the individual designer. As code writing becomes easier and machine languages less mysterious proprietary computing will most likely increase in popularity. Design tools will evolve like musical instruments built to play sounds heard first in the mind. This will be an unprecedented moment in the history of architecture.
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"With our artificial automata we are moving much more in the dark than nature appears to be with its organisms. We are, and apparently...have to be, much more scared by the occurrence of an isolated error and by the malfunction which is behind it."

John Von Neumann from “The General and Logical Theory of Automata” (1)

“A Space in Architecture shows how it is made”

Louis I. Kahn from “Architecture is the Thoughtful Making of Spaces” (2)

Contemporary architects are judged as much by individual buildings as they are by their ability to mobilize today’s most sophisticated design tools. A certain fascination with technology is natural to any discipline that thrives on innovation. While new digital technologies have had an especially profound impact on the architectural imagination, construction in America and around the world is still very much a diverse mix of processes, often supplemented by hand using both traditional and non-traditional materials. Instead of focusing exclusively on the fabrication of building components in the factory, this essay explores how information technologies can be deployed in the field to effect sweeping changes in the way craftsmen work.

While technologies like CNC milling are far from ubiquitous, the forms and materials associated with masonry structures have changed very little since the advent of computer aided design. Of course portable masonry robots designed for both factory and on site applications are now in the early stages of development but there are serious reasons to doubt that their employment will render human workers obsolete. In fact, as we look back on the history of information technology, especially in the last thirty years, the opposite seems to be the case. Instead of eliminating work, automation has forced many to adopt new skills and become technically specialized as both products and production processes become increasingly more sophisticated. Even if android masons do replace the need for human labor in the future, we still need to find new ways of enhancing the quality, efficiency and performance of existing construction techniques today. The narrow definition of Computer Aided Design and Manufacturing (CAD/CAM) must therefore be expanded to include a much larger set of tools and procedures. In addition to robotic pipe laying drones, laser cutters and rapid prototyping machines we need to include new human machine-interfaces that operate on site as embedded technologies that can change the way buildings are made in the present (augmented craft). This should be done with an eye on the body’s connection to, rather than its replacement by, technology. What’s more we need to honor this relationship by developing new and powerfully expressive building forms.

Because so much architecture today is conceived through descriptive techniques like AutoCAD,
digital processes are used mostly for the purpose of design and representation. Computation is rarely a direct process responsible for and self-evident in the work itself. To rectify this problem, we are developing a building technology that is based on the analogous operation of cellular automaton programs and masonry construction.

A cellular automaton program (CA) consists of a field of discreet cells divided into small groups or neighborhoods. Defined in terms of finite states, on or off, transparent or opaque, white or black, etc., a CA computation evolves over time. The condition of each neighborhood in a cellular automaton is used to determine the state of the next generation of cells. Repetitive and aperiodic, symmetrical and asymmetrical, homogeneous and heterogeneous patterns emerge as a result of the direct relationship between parts acting together to form a larger system from the ground up. By following local procedures based on laws of adjacency and iteration, masons following a fixed CA code build by stacking one brick at a time. This process is dependent on the relationship of each masonry unit to its immediate neighbors and is capable of producing a wide range of forms from very simple rules.

In an automasonry wall, form emerges from the direct expression of its materials and the way they are assembled. This follows one of the guiding principles of modernism but with a difference: structures driven by simple programs can be constructed without recourse to a limited inventory of pared down and platonic forms. The patterns created in the process are entirely natural to both the craftsman and the mathematics. With simple programs building details obtain their complexity for free, no external agent, author or extraneous system is needed to design them. This kind of complexity is not dependent on the incessant differentiation of parts (complexity for a price) but on the application of fixed rules in a discrete system that requires only two components.

With simple programs, designers can push masonry to its limits while respecting constraints both functional and tectonic that define its potential for complexity. The behavior and intrinsic randomness of certain CA patterns also challenges the basic assumption that deterministic systems necessarily follow predetermined ends. A brick does not necessarily want to be an arch. When considering emergent phenomenon as global patterns produced from the bottom-up by local interactions that spread through a system, then the “existence will” of an unfolding event, process or entity becomes meaningful in a way that an archetype does not. Most patterns generated from the iteration of cellular automaton programs generate evolving, teleonomic structures that cannot be described by a definite shortcut, formula or ideal type. The only way to know how a given rule will behave is to set it in motion. In this regard Henri Atlan writes:

“A teleonomic process does not...function by virtue of final causes even though it seems as if it were oriented toward the realization of forms, that will appear only at the end of a process. What in fact determines it (i.e. a teleonomic process) are not forms as final causes but the realization of a program, as in a programmed machine whose function seems oriented toward a future state, while it is in fact causally determined by the sequence of states through which the preestablished program makes it pass.”(3)

With a CA masonry system, details are self-organized whereas the overall pattern produced by the code forms a tight-fitting whole that is intentionally selected by the architect. In other words, the building’s design emerges naturally from the process of stacking bricks while the overall pattern is constituted in response to specific design requirements. Again, the code self-organizes the parts while the manipulation of the initial conditions (the starting point of a given pattern) gives the designer power over the whole.
An architect’s desires, his or her personal reading of the client brief, institutional protocols, functional constraints and the logic of construction merge with the rigorous operation of simple programs to produce an organic architecture that satisfies the imperative of commodity, firmness and delight. In this way autopoietic systems like cellular automata become active agents in the evolution of design. Details exclusively composed according to the will of the architect are jettisoned in favor of a self-organizing system that embodies, in both its function and appearance, the intricate relationship between artistic intentions and the systems of life with which they interact. As Katherine Hayles has pointed out, “…the prospect of humans working in partnership with intelligent machines is not so much a usurpation of human rights and responsibilities as it is a further development in the construction of distributed cognitive environments, a construction that has been ongoing for thousands of years…No longer is human will seen as the source from which emanates the mastery necessary to dominate and control the environment…To conceptualize the human in these terms is not to imperil human survival but precisely to enhance it, for the more we understand the flexible, adaptive structures that coordinate our world…the better we can fashion images of ourselves that accurately reflect the complex interplays that ultimately make the entire world one system.” (4)

Building without Drawings

“By 2008, analysts estimate, annual worldwide phone cam sales will reach 650 million (up from 150 million in 2004)” one California start-up has created...a special face recognition software that runs on the low cost microprocessors used in cell phones...the company has tweaked its...analysis algorithms to identify everything from a Coke can to the Mona Lisa...”

Wired Magazine (5)

More than just tools for communication, today’s cell phones have become powerful computers that serve a constantly evolving menu of functions including: gaming, navigation, photography, data storage and retrieval. By comparison bricks are primitive objects used to construct stationary walls that change very little over time. While the preceding text hints at a mathematical link between craft and technology no instrumental approach to masonry construction can be developed without first considering the body. To do this we must address the problem of human error.

In a wall built with simple programs, anything that interferes with the accurate performance of a code ends up undermining the intended function of the whole. Because an automasory structure expresses function and material use, it must be computed with great accuracy. An effective system of “error correction” is therefore needed to insure the correct placement of parts in a network of details that are extremely sensitive to small changes.

Figure 5. Trio 600 PDA/Cell Phone

To make a wall with simple programs masons must first look at the initial conditions on the ground floor. The initial conditions are divided into neighborhoods (N). The number of cells in a neighborhood is always constant for a given set of rules. In an N=5 computation, the code determines the state of a brick (black or white, clear or opaque) immediately above cell #3 in a 1-5 unit group. Since masons build by shifting a 5-cell frame one step at time, left to right or right
to left, they are forced to check previous moves at least 5 times for each block laid. While this approach decreases the likelihood of errors it consumes a lot of energy if workers are required to check rules, stack bricks and evaluate patterns documented on paper. Less time and effort will be required if the process is automated.

Using a specially programmed PDA (6) cell phone, nonstandard brick patterns can be constructed without reference to an external image of the whole. Again the process is entirely local. Complex masonry work can be achieved without the need for an equally complicated index of parts i.e. unwieldy templates, shop drawings, construction documents, etc. But how does a bricklayer compare work that takes place in physical space with information stored in a computer’s memory? How do masons know if an error has even occurred? The answers to these questions build off the recursive nature of CA programs and the ever-increasing sophistication of ubiquitous mobile communication technologies.

Here’s how the system works. Pattern recognition software normally designed to identify complex objects is used to monitor simple 3D wall configurations. The PDA’s onboard camera monitors what’s happening in real space while voice commands from both the computer and the mason determine block-stacking patterns. By relating pictures taken in close proximity to a craftsman’s body with the neighborhood logic of cellular automata the system is able to prevent errors in construction while supplying the workmen with accurate instructions for building. An error free structure makes CA patterns and their associated functions (fenestration, wall space, stairs, etc.) integral and precise. All of this is done “hands-free” and without paper drawings. Using the system, builders can also integrate standard PDA functions into the workflow making it easy to:

1. Communicate progress reports to job captains off-site using mobile email accounts.
2. Organize teams to work simultaneously on different parts of the same wall by forming a wireless network.
3. Store and display construction documents.
4. Read barcodes and track materials.
5. Aid in the resolution, redesign and clarification of building details by establishing better communications between architects and craftsmen.

6. Construct accurate mosaics based on hand drawings or photographic images following the neighborhood logic of cellular automata.

7. Schedule work, access itineraries and organize team members.

Of course applications like these will continue to evolve as mobile communication devices exploit, new sensing technologies, increased computational power and better, more efficient networking capabilities. Passive and Active Sensor Networks alone will effect sweeping changes in the way buildings are designed, managed and constructed. With “an internet of things” (7) where every object in the supply chain can be tracked using radio tags the prospects of developing more efficient and technically empowered building practices is more or less insured. The task of the architect today is to incorporate these developments into a holistic vision of architecture.

Ornament, Entropy and the Picturesque

For the proposed San Jose State University Museum of Art in Silicon Valley, we used a “class two” CA code (8) to produce both complex and simple patterns from binary strings of stone and glass block. The location of rooms with windows and exhibition spaces requiring large, blank display walls were laid out in accordance with the competition brief. Once these parameters were set in place, a search began for a rule that could grow the most appropriate form. For the museum’s exterior, internal subdivisions and fire stairs we used a 5-cell outer totalistic cellular automaton (9) that damped out the complexity of the lower floors to create a partly windowless tower with intricate openings at the base. (The top of the building is terminated by a skylight that draws the sun into a narrow atrium facing east.) From the complexity of the lower levels the project culminates in a quiescent and illuminated void.

Vertical supports for both the building’s walls and floors were aligned with the initial conditions of the CA code. A non-regular grid of columns produced different spans with beams of varying depth setting up an exchange between light, gravity and computation. Rather than being neutral infill the project’s surfaces actively shape an internal concrete armature that rhythmically fluctuates as the CA patterns ascend into space. The parametric relationship between enclosing walls and structure is a tectonic fact experienced
as a system of real interconnections forged during the process of design and construction. *The building is a computation.* In the San Jose State University Museum of Art, the nature and position of each masonry unit affects its immediate neighbors and the order of the whole. Because the system is extremely sensitive to small changes, every brick counts in a truly organic architecture created by the rigorous iteration of simple programs.

While these patterns are not themselves a product of organizing principles governed by structural laws they are also not applied decoration. In the process of unbuilding complexity, class two cellular automata drive the organization of structure and space. Far from a reduced simplicity achieved through the removal of intricate details, blank homogenous surfaces emerge out of heterogeneous patterns that negate themselves. *Literally ornament self-organizes its own disappearance.* This approach escapes the narrow dialectic that opposes formal excess on the one hand against a strict return to pure forms on the other. While the results look almost entopic as if matter was being subjected to erosion, this is not an architecture of death and decay. Ruins exemplify the destruction of ideal origins or types; at San Jose both complexity and simplicity are the bi-products of a single code. Unlike Site’s Best department store where shoppers are menaced by a picturesque simulation of falling bricks, nothing here is intentionally broken, fragmented or worn away.

The design and organization of San Jose express its code’s ability to efficiently produce asymmetrical patterns that are organically linked to blank, homogeneous space. These relationships are produced using local rules that are not based on the recursion of simple motifs, faithfully
rendered at different scales (self-similarity). No image of the whole can be found in the details. Neither scale invariance nor the repetition of a standard module can be used to guide the mason’s work. While the code for a completed wall can be ascertained through direct observation, the rules on their own give little indication of the kinds of forms that will be produced during construction. Order and randomness, consistency and inconsistency are therefore binaries that accentuate the morphological potential of simple programs. More importantly, they follow a material logic that organizes structure and space by avoiding the capriciousness of applied decoration.

These computational strategies open up architecture to new ways of thinking and are useful as an alternative to the already exhausted tropes of contemporary practice. The ability to integrate different functions and internal space requirements without resorting to antagonistic compositional strategies has traditionally been the motive behind “folding” in architecture. The work of Rene Thom is often used in this context to connect opposing forces on a single, deformed surface.

While Thom’s catastrophe diagrams are used mostly as a formal devise to exceed the operative limits of collage: abrupt changes in the composition of a system are not necessarily restricted to mathematical descriptions based on an infinitely divisible space. Discrete operations can be equally effective in generating networked relationships between distinct elements. (10) The fold as a leitmotif for contemporary practice (Eiseman, Gehry et al.) requires “a continuous variation of matter” that “articulates possible new relationships between vertical and horizontal, figure and ground…”(11) The architectural effects of the fold can be replaced by the iterative extrusion of simple programs like cellular automata where binary codes drive the production of complex and simple, random and ordered, homogeneous and heterogeneous space. The following categories, linked to their current formal expression give way to a new set of procedures:

![Figure 9. Automason's operational flow chart](image)
Conclusion: How to Make a Building with Stone, Glass Blocks and Cell Phone

As a design and production tool the computer is typically used to create folded, curvilinear forms made from mass-customized parts. These are conventions that have evolved over time as a result of specific machines and software technologies. These technologies operate according to a fixed logic, one that can be transformed by new codes developed directly by architects from the ground up. Automason Ver.1.0 allows craftsmen to increase the sophistication and efficiency of their work while affording them new opportunities to compete in a culture increasingly dominated by technological change. Through the process of software development architects can employ off-the-shelf technology to design and construct buildings that express these newly acquired capabilities. Task-specific tools can therefore affect a much closer link between different construction processes and the design imagination.

For the San Jose State University Museum of Art a simple cellular automaton program was used to generate the building’s form. The program drives the placement of columns on the ground floor. Changing span depths connect the Earth’s gravitational pull with the operation of an abstract code. The code is rendered in glass block, mortar and stone. Not a window is out of place because in the building each part affects its immediate neighbor. To achieve this, Masons will have to lean how to build without errors. Humans can do this only when they establish close collaborations with intelligent machines.

Notes


6. Personal Data Assistant (PDA)

7. A network formed by linking objects together with Radio Frequency Identification tags (RFID), The tags can be monitored in the field and connected to a database accessed via the worldwide web.


9. An Outer Totalistic set is a shorthand format for specifying Cellular Automaton rules.

10. Discreet Space more explicitly implies the joint; a clear division between parts whereas smoothness desires a seamless blending that is almost impossible to achieve in real buildings made from assembled parts.

Automason Ver. 1.0 (Technical Description)

The actual structure of the software used by the mason requires some explanation. A standard PDA cell phone is hung from the mason’s neck like a medallion with its camera facing away from the chest. This position insures that each picture snapped by the camera shows the wall under construction from the same relative angle and perspective. The focal length of the camera’s lens is set at arms length ensuring that anything outside the body’s range of motion is out of focus. (Pictures are automatically taken at 2-second intervals.) The computer’s memory samples and holds only two images at a time. All prior data is erased. When a mason begins work the phone is activated manually or by voice command using a head set and microphone to tell the computer where the first two blocks have been laid. Images of the initial conditions for a wall are analyzed by pattern recognition algorithms that register the location of existing blocks (Black or white clear or opaque). The initial conditions are determined by the position of columns on the ground floor.

The software based on CA neighborhood types recognizes four primary stacking variations and their associated joint patterns. With a 5-cell group for example, the first is a flat placement of two rows with a pair of blocks on top at position 1 and 2 with 5 units below. The top blocks are placed when work begins by following instructions given by the cell phone. The next configuration contains 5 units at the corner of the wall with the same 2 blocks on the second row above units 1 and 2. The last two configurations contain 9 blocks with one missing from the first space of the second row and a full group of 10. The last type occurs when a single course of blocks is complete and the mason has finished a complete loop. (Remember the left side of a one-dimensional cellular automaton is continuous with its right side.)

By analyzing pictures according to these block configurations the cell phone then determines the state of each cell in a given neighborhood. From simple shaded images the computer can distinguish between similar and dissimilar materials. When a block configuration is recognized and its cells states determined the computer calculates the next move following a specific CA rule. With a synthetic voice command the cell phone tells the mason which block to place. When a block is set the mason talks back to the computer which in turn records the work, checks for accuracy, and moves to the next group of cells. Combining the initial indexing procedure and a step-by-step record of actions the computer knows exactly where it is in space. (This procedure works even if all the units in a given neighborhood are the same or if a group of blocks are removed to make way for operable windows or doors.) As work proceeds the computer compares what it sees against a complete image of the finished wall stored in its memory. When a day’s labor is complete the mason deactivates the camera and a job report is automatically emailed to a pre-assigned address.