Randomness as a Generative Principle in Art and Architecture

by

Kenny Verbeeck

B.Sc., M.Sc. in Civil Architectural Engineering
Vrije Universiteit Brussel, 2004

Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Architecture Studies
at the
Massachusetts Institute of Technology

June 2006

Signature of Author: ______________________

Department of Architecture
May 25, 2006

Certified by: ______________________

George N. Stiny
Professor of Design and Computation, M.I.T.
Thesis Supervisor

Accepted by: ______________________

Julian Beinart
Professor of Architecture, M.I.T.
Chairman, Department Committee on Graduate Students

Terry W. Knight
Professor of Design and Computation, M.I.T.
Reader

Martha Buskirk
Associate Professor of Art History, Montserrat College of Art
Reader

Randomness as a Generative Principle in Art and Architecture

by

Kenny Verbeeck

Submitted to the Department of Architecture
On May 25, 2006 in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Architecture Studies

ABSTRACT:

As designers have become more eloquent in the exploitation of the powerful yet generic calculating capabilities of the computer, contemporary architectural practice seems to have set its mind on creating a logic machine that designs from predetermined constraints. Generating form from mathematical formulae thus gives the design process a scientific twist that allows the design to present itself as the outcome to a rigorous and objective process.

So far, several designer-computer relations have been explored. The common designer-computer models are often described as either pre-rational or post-rational. Yet another approach would be the irrational. The hypothesis is that the early design process is in need of the unexpected, rather than iron logic. This research investigated how the use of randomness as a generative principle could present the designer with a creative design environment.

The analysis and reading of randomness in art and architecture production takes as examples works of art where the artist/designer saw uncertainty or unpredictability as an intricate part of the process. The selected works incorporate, mostly, an instigating and an interpreting party embedded in the making of the work. The negotiations of boundaries between both parties determine the development of the work. Crucial to the selected works of art was the rendering of control or choice from one party to another – whether human, machine or nature – being used as a generative principle.

Jackson Pollock serves as the analog example of a scattered computation: an indefinite number of calculations, of which each has a degree of randomness, that relate in a rhizomic manner. Pollock responds to each of these outcomes, allowing the painting to form from intentions rather than expectations. This looking and acting aspect to Pollock's approach is illustrated in the Jackson Pollock shape grammar.

Ultimately the investigation of randomness in art is translated to architecture by comparing the Pollock approach in his drip paintings to Greg Lynn's digital design process in the Port Authority Gateway project.

In the Pollock approach to digital design agency is given to the tools at hand, yet at the same time, the sheer indefinite number of designer-system interactions allows the design to emerge out of that constructive dialogue in an intuitive manner.

Thesis Supervisor:

George N. Stiny

Professor of Design and Computation, M.I.T.

To all the random people that influenced this investigation

RANDOMNESS, FROM ART TO ARCHITECTURE

Design is about making conscious decisions that eventually lead to a coherent whole. At first sight it does not seem to make sense to introduce randomness, chance, or uncertainty into that process. Each of these concepts implies a loss of control, yet, the designer nowadays is marked by a rational approach to design. Designs need to make sense, who can argue that?

However, designs only need to make sense at the end of the ride. The origin of that sensible design and the design actions and decisions from that point on are of equal interest. What is published in glossy magazines is indeed the final result, either being the final drawings, or the building itself, and only in some case the early sketches.

Even though the published sketches often have a remarkable resemblance to the final design[1], it is in sketching, during the initial phase of design, that the design thinking is explored. When still discovering the possibilities and opportunities in the project, there is no fully formed or developed concept or idea yet, there are *maybe's* and *potentially's.* At that point drawings are ambiguous and incomplete. These early sketches are meant to push the creative process forward, rather than to clarify, to define, or to label. Their potential to be suggestive and to spur a re-evaluation of prior hypotheses is their value.

Yet as designers have come to see computers as engrained in architectural practice, a preoccupation with computer science problem-solving methodologies has taken over the problem-setting aspect of design. Rather than focusing on creating ambiguity, no effort is spared to replace ambiguity by definitions, primitives, and specifics. Ambiguity in the design process feeds and stimulates (re)interpretation; specificity in the early stages of the design process tends to bypass that process of reconsideration.

Some designers seem to agree that a paperless studio is not only possible, but even a worthy goal in itself. Before the invention of paper there already was architecture, so conceiving of a paperless studio is not that hard. However, in the information age, paperless happens to be synonymous with 'consisting of only bits and bytes.' The digital pioneers in architecture have taken up the computational environments at hand as design tools throughout the entire design process, thus taking over the computer science concepts these environments are made of. A line is a mathematical construct between two sets of coordinates, rather than the result from moving a pen across a piece of paper. The need of the computer environment for precise data – even an ill-defined line needs exact coordinates – is contradictory to the notion of exploratory design. In the early phase of design precision should not be required, only ideas, notions of, and wants are.

This thesis therefore aims at finding a computational strategy and attitude that inserts some of that physical environment messiness into the digital realm. The hypothesis is that design explorations benefit from abstract drawings, diagrams, and models that have gaps, glitches, or faults. Each of these latter concepts is considered to contribute to the creative act. By not defining the parts a priori, one leaves the door wide open for reinterpretation of the whole.

Introducing uncertainty and randomness in the early stages of design – limiting the designer's control over the digital medium – is thus intended to allow for computational design exploration. At the same time randomness presents the designer with an unintentional influence on the design that forces re-interpretation of the whole.

- advertisement for iPod shuffle, from Apple.com

Randomness is considered by many a computer science concept, while it is a natural and cultural phenomenon as well. Random numbers are generated to test economical theories. We cannot explain why that fluffy cloud has that specific shape. We hope the lottery picks are random. Some things are *so random*. As Apple puts it: *Life is random*. To complicate matters a bit, there is also the issue of that what looks random but is not. Visual randomness is the notion of patternlessness, originlessness, or meaninglessness without excluding the possibility that the object/process does contain patterns, have an origin, or stem from logic. These aspects may simply not be immediately apparent.

Randomness is often dealt with in terms of order and disorder, yet in light of this research this binary is of less importance than the notion that our intuitive definition of randomness aligns randomness with unpredictability, and its refusal to be controlled.

This research aims to illustrate that allowing chance and random actions – not controlled by the designer – to exist within the process of design opens a path to the discovery of newness. Randomness, as not being able to fully explain the resultant of events (and why would one want to anyway), is studied as both a point of departure for and a perturbation within the work of art and architecture in order to propose a method of utilizing randomness as a generative principle in architectural design. Randomness is thus considered not a loss of control, but as a gained elasticity in the design. By being disconnected from its context, the random event forces the designer to re-interpret and renegotiate each assumption in the outcome. The uncertainty to randomness thus precludes a pre-cognitive model of designing.

Artists have experimented extensively with the rendering of design decisions to chance and randomness. The selected works incorporate, mostly, an instigating and an interpreting party embedded in the making of the work. The negotiations of boundaries between both parties determine the development of the work. Crucial to the selected works of art was the rendering of control or choice from one party to another – whether human, machine or nature – being used as a generative principle.

Hans/Jean Arp used chance composition techniques in order to come to new concepts of composition, and worked from these *random* compositions to produce a work of art. He dropped pieces of paper onto a flat surface *according to laws of chance*. The result from that event allowed him not to deal with a conscious first mark on a blank canvas, but start off his collages as responses. Ellsworth Kelly cut up drawings, and re-arranged the pieces in a random fashion. Reconfiguring drawings according to chance added a visual liveliness absent in Kelly's minimalist drawings. Roxy Paine counts on the room conditions – which are beyond his control – to impact on his sculptures in order to suggest a machine creating the work of art. The precision of his computational input is then countered by randomness inherent to the production unit. This results in sculptures and paintings that play off the natural-artificial binary from the assumption that industrial production is contradictory to uniqueness. Jackson Pollock used the randomness inherent to the physical system as a creative event to react against. His technique of gestural painting – having a specific intention, without expectation of form – introduces a dialogue between the artist's intentions and system's outcome that creates the painting along the way. It will be further investigated how this Pollock approach to painting resembles the exploratory nature of design.

- Jackson Pollock uses the unpredictable nature of dripping enamel to develop his painting

Analyzing these artists' methods further – and briefly introducing others' – will allow for a more nuanced view on the use of randomness in art. The found *random* strategies will form the jumping board to discuss architectural case studies that either intensely employ computational strategies void of randomness or, quite the opposite, do employ randomness in the design process. This will result in a detailed study of differences and likenesses between artists' and architects' approaches to randomness as a generative principle.

The underlying idea for the thesis is that the architectural complexity created from all-rules-at-once approach to rule-based design is actually perplexity, in the sense that it may deliver perplexing results, but allows only shallow deep understanding by the designer. Thus this research is a manifesto for the scattering of computational power into smaller bits – each may be locally random or arbitrary and impact the designer's intentions – in order for the computational design process to become exploratory by nature, again.

THREE GENERATIVE PRINCIPLES

Computer technologies are at all levels and scales in our civilization. Everything is digital – copy machines, hair dryers, microwave ovens – but we don't refer to them as 'digital.' Why should we bother to refer to digital art? [2] *–John Maeda*

Although the computer has already claimed a prominent place in the architectural design process, by and large it has been a medium not that different from a ruler or a pen. It allows architects to draw straighter lines, more lines and definitely more complex lines than any human draftsperson had ever imagined before. The designer's intentions are made explicit and exact for the computer to calculate from; very few architects are actually employing the computer as anything else but a highly accurate ruler, or pen, or powerful calculator.

As designers have become more eloquent in the exploitation of the powerful yet generic calculating capabilities of the machine, the resourcefulness of designers in terms of finding constraints, setting up design systems, and creating generative environments starts to border on the ridiculous. An entire hyperfluid façade for a skyscraper, the façade evidently being the shape and structure of the building, is mathematically built up from the location of three points in space.[3] Locating these three points then indeed becomes the most important decision in the project. Yet should it be? Should a physical building really depend on three mathematical concepts that have neither physicality nor tangible existence? Just as Maeda finds little reason to refer to 'digital art', I would like to raise the question why 'digital architecture' has allowed itself to become estranged from 'just design', by depriving itself from a strong design-designer relation for the sake of system purity.[4] Provided that a computer can indeed take over some of the tedious aspects of design, the question remains whether that is enough of an argument to allow the computer to take away design opportunities with that. A computer is indeed at its best when presented with clear rules that need to be applied over and over again. Yet, in 'just design' applying these rules over and over again leads to a better understanding of all of the exceptions, potentials, and problems of these rules. How can a computational device still provide the computerization of the tedious bits, while maintaining the opportunity to change the rules along the way?

One of the justifications for setting up rule-based design generating systems is that every artist[5] applies rules unconsciously anyway. Similar proportions occur across projects. There is a tendency to turn to a specific set of materials. Some angles just feel right. More importantly, these rules or recurring behaviors surface most prominently as a unique yet unconscious signature of the author. However, key to this notion of unconscious rules is that the artist can disregard or ignore his/her signature marks. These rules express a designer's preferences and intuitions. In the digital realm, these rules need to surface and be expressed explicitly and precisely in order for a machine to take over (a part of) the design process. This then results in a rule-based design system that is by definition backward in nature. All previously unconscious rules are now explicitly determined before the design takes off. Even if we consider these rules to be capable of describing a design process, the current modality of generative system engineering seems to leave little room for designer-design interaction inside the computerized process. As soon as the rules have been determined, they function as set in stone. When a designer overlooking the computerized process sees an opportunity, many of the systems do not allow for that soft breaking of the system. There is little dialoging between computer and human, at best each works in turns.

At this point architectural practice has found several distinct models in the human-machine relationship. Firstly, the architect uses the machine as a more accurate and faster draftsperson, as does Frank O. Gehry, whose office uses the computer to draw shapes and forms which a human draftsman may not reproduce as easily. Secondly, the computational machine has to calculate solutions to a system set up by the architect, as does Norman Foster, who introduces mathematical formulae that represent his initial expectations and then has a fancy computer to calculate his structurally eloquent, yet monotonous form. Thirdly, the designer, such as architect Greg Lynn, establishes explicit and implicit constraints that form a reductive design system that will generate a form.

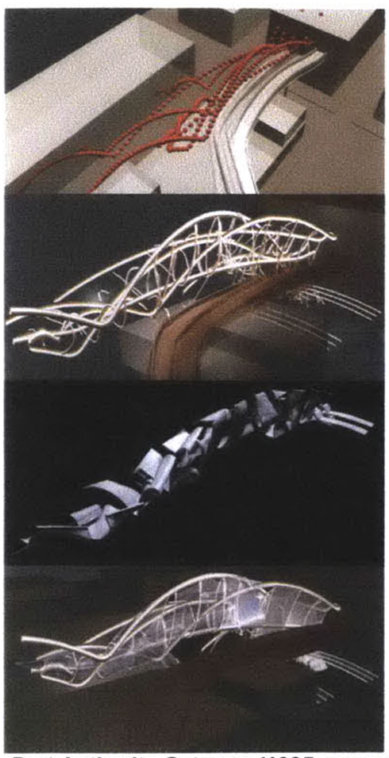
All three strategies require only solving power from the computer. Due to internalization of the design process within the computer there is no possibility for rethinking or renegotiating of the initial conditions by the designer either. As design decisions are instigated by a mathematically defined hypothesis[6] the only prospect of encountering an unexpected event within the design lies in the architect's inability to imagine the full extent of his mathematically formulated commands. When shapes or situation emerge from the applied set of rules, chances are that to the computational machine these shapes or situations do not exist and are thus not addressed. There is no agency within the machine that may swerve the design process away from the initial conceptions.

The first designer-system model of the three is that of the highly skilled draftsman. This model does not engage any of the computational device's actual generative power; it is mainly a representational tool. This Frank Gehry mode of employing the computer changes little to the design process itself. All design happens in physical space, on paper and in paper three dimensional models. It has introduced 3D scanners as an object-equivalent of tracing paper and a vague sense of precision by converting a physical model into bits and bytes. Even though Gehry Technology is lauded for its use and promotion of Catia modeling software, it is actually an analog design practice and is thus of little importance in this investigation.

The strategy presented by Foster and Partners is one of pure reason, a problem formulated as a structural equation. This mode has an initial design intention that is expressed as mathematical formulae rooted in structural engineering. This is not about the *expression* of an idea, but about the construction of a building from that structural idea. More than any of the other methods, Foster and Partners, use the computer as an almighty calculator determining the form from computer simulations of the structural idea.[7] At no point does Foster claim nor intend to design in a computational generative manner. The actual designs can be retrieved from his sketchpads. Even though his calculating is highly sophisticated, this approach to design uses the computational device to constrain the design possibilities in order to a level of structural soundness, accuracy, and precision unattainable by any paper-bound engineer.

Design does supposedly happen within a computational device. The systems set up by Greg Lynn have generated designs that have expanded the vocabulary of architectural form beyond belief. Greg Lynn (and his office Greg Lynn FORM) has always been at the forefront to use computational techniques in the architectural design. His 1995 Port Authority Gateway project is an early and straightforward example of design by animation. Although the project dates back 10 years, the basic concept of a rule-based environment that produces 'new architectural forms' has altered little since. The design arena is defined at the beginning, and changes little over the course of the design.

In the Port Authority Gateway project, Lynn introduces the concepts of particle currents and force fields that shape the design.[8] The project, located downtown New York, reduced the perceived chaos and hectic activity on 42nd, 43rd Street and 9th Avenue to vectorized forces that affected the path of virtual particles launched from the Bus Terminal. Without doubt, Greg Lynn Form went through numerous iterations of setting up all particles, hitting the start button and looking at the computer's screen to see whether the right settings were found such that the outcome matched the intended form. After creating the digital environment and determining the behavior of all elements in that environment, the *design* is actually a matter of finding the right values that develop into the expected shape, forms, and spaces. It is less about what happens inside the computer calculations, than it is about whether the calculations deliver the expected.



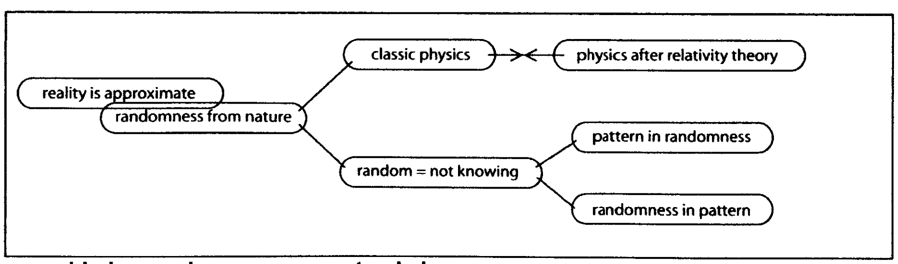
- Port Authority Gateway (1995, never built), Greg Lynn FORM

Obviously, this is a major over-simplification that does not do justice to the complexity of designing the system, nor does it emphasize the ground-breaking nature of the project of introducing animation techniques into the design process. The main point of critique is simply the stagnant character of this process. It is about finding the right initial values; the generated design depends entirely on *the first marks*. Rather than building on earlier decisions, an entire design-generating array of decisions is collapsed in an initial decision of point location.

These three common models are often described as either pre-rational (the Lynn and Foster approach to design) or post-rational (the Gehry approach). Yet another approach would be the irrational. What happens if rules are only there to make the design actions explicit, rather than to restrict them? What if a computer would be able to work as fluidly with logic and mathematics – both concepts are imperfect – as a painter with conventions and paint? What would computation look like if computers could handle soft principles and guidelines, instead of hard instructions?

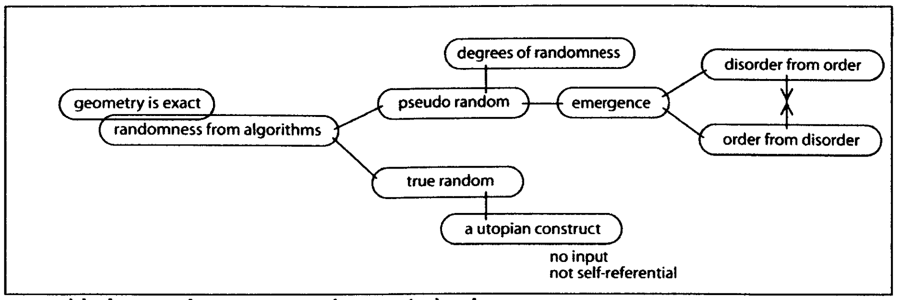
TWO CONCEPTS OF RANDOMNESS

In essence there are two different concepts to randomness. There is the randomness we find in natural phenomena – we cannot control all influences, provided we know all influences. On the other hand there is an abstract scientific concept of randomness – we try to construct randomness from equations and transformations. The former concept is tangible and stems from the complexity of things. It is a randomness we try to avoid by generalizing it into common laws. For instance, we recognize what dry ground looks like, but have no hand in exactly predicting where the cracks will go. In dealing with physical materials and situations, there is always uncertainty and randomness involved.



- considering randomness as a natural phenomenon

However, science is often about finding the rule within the exceptions. Same goes for randomness. In science randomness is perfect. In science, true randomness is a utopian construct, as far removed from the physical world as possible. True random cannot be influenced, has no internal structure, and is homogeneous. It doesn't even come out of the blue, it just is.



- considering randomness as a (computer) science phenomenon

The nature of the randomness employed in the projects considered for this thesis is, in a sense, of less importance however than the actual context of application of randomness. This research has focused on how, where and why randomness was employed. The diagrams indicate some connections – but by no means all connections – that can be made based upon the origin of the randomness. These diagrams are not meant to provide the structure for reading through the examples, but to illustrate some of the aspects to defining randomness.

A SPECTRUM

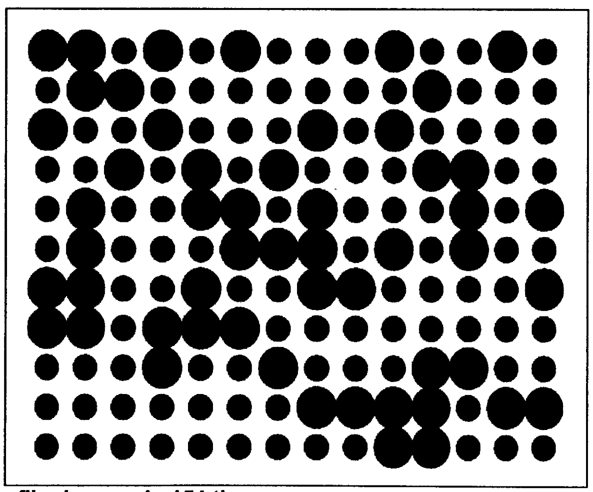
In the very first years of gambling on the internet the order of the cards was generated by an algorithm that used elapsed time as its input. It did not take long before some analytical poker players recognized the feed and were able to predict which card would be played next in their online poker game. Obviously, shuffling the cards had lost its significance; the players knew exactly which cards had been played and which cards were coming to the table. The money players did of course not mind the sudden change from chance to certainty.[9]

Even though online gambling might seem a trivial example, one can imagine other applications – such as encryption – that need a random number generator that is as independent as possible. The further the outcome is separated from the input the harder it becomes to predict the next event.

According to the science of statistics the sequence resulting from flipping a fair coin is very likely to be random or at least to seem random, for both heads and tails have an equal chance of occurring, and the coin has no memory, so one event is unrelated to the previous.

During the early emergence of computing and programming, programmers were looking for a way to find what they call *pure random*. The idea of a computer creating randomness may seem preposterous, since computing is based on pure logic and reason, where randomness is about the absence of both logic and reason.[10] Nevertheless, computer scientists wanted to create an algorithm that was completely independent from its context. It would not use any input to generate a random number or sequence of numbers; any number was equally probable to emerge. In the end these independent *pure random* generators generated correlated output: the outcome became predictable after analyzing the previously generated numbers.

What intrigues the world of science is how to recreate a simple system such as flipping a coin artificially. How can any machine independently construct noise – as a metaphor for randomness – without remembering what it did before, without borrowing complexity or unpredictability from the physical world?



- flipping a coin 154 times

There is no way of creating the so called *pure random* artificially. The randomness generating algorithm uses either self-referencing – thus creating a link between one event and the next – or an arbitrary feed – a physical influence from outside the algorithm. *Nearly pure random* numbers have been generated, for example, by using background noise from an office as feed.[11] As long as the user does not know what is happening in that office, or what part or aspect of the noise actually determines the feed, these series of numbers attain a high level of randomness. Other sources are lava-lamps and atmospheric noise from a radio, both are considered to be uncontrollable, and chaotic in their behavior.[12]

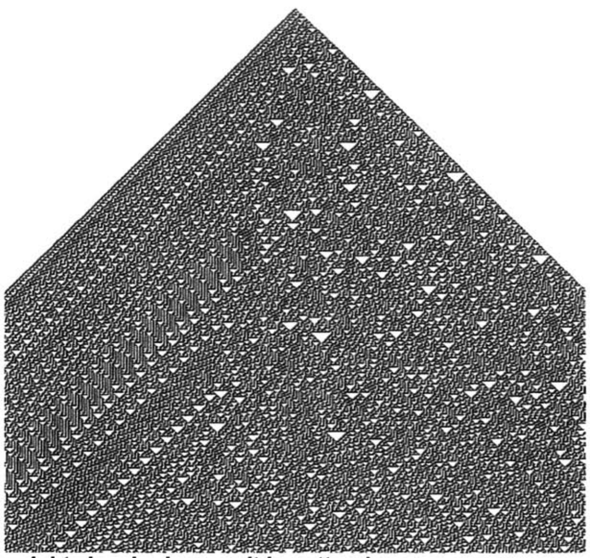
The highest aim for constructing randomness now is a minimized relationship between input and output. A minimized relationship is regarded as a realistic way of approaching *pure random*. However, even events isolated from reality still have a context that cannot be denied. As a mathematician defines dividing 1 by infinity to be zero; computer scientists now aim at approaching a *zero relation between context and output*, step by step.

Computer science presents a spectrum of randomness, ranging from *nearly pure random* to *pseudo random*. *Pure random* – also called *true random* – uses complex algorithms and is as independent as possible. *Pseudo random* on the other hand uses a definite seed and does not claim to be independent, or unpredictable. It achieves a certain level of random, it may contain patterns, it may be perfectly reproducible, and it will simply re-order a series of numbers or events in a somewhat haphazard manner. This latter type is commonly used in our everyday life. It determines the order in which we randomly play the tracks of a CD; it shuffles the cards in a computerized game of hearts, determines who is summoned in a company drug test, picks a winner in a lottery and so on.[13] In these applications there is not always a need for perfect randomness – which comes with time-consuming calculations – but rather for a certain separation from personal involvement, be it to objectify a choice or simply for the sake of not having to choose ourselves.

VISUAL COMPUTING

Stephen Wolfram has dedicated a large part of his book 'A new kind of science' to randomness in nature, stating that every form or pattern in nature – whether it is a zebra's stripes or the shape of a mollusk shell – can be explained and generated from simple rules.[14] He claims that no matter how complex these patterns seem, they each excel in conceptual simplicity.

A graphic way to compute randomness is the use of cellular automata. For years Stephen Wolfram did research on different rules that steer cellular automata. The basic concept is to set up a limited number of rules that determine how one basic cell/element/unit should behave depending on the state of its immediate neighbors.[15] Wolfram found that some of the rules actually gave way to completely unexpected patterns: randomness emerged from structure. The rules are as simple as can be; there is no choice within the system. Once the first cell, first line, or first field has been determined, the system automatically starts transforming. Some of the rules generated patterns that did not seem to contain any repetition, any form of patterning. There were some recurring forms, but their place of occurrence could not be predicted, unless one would run the cellular automaton.



- eight visual rules result in patternlessness

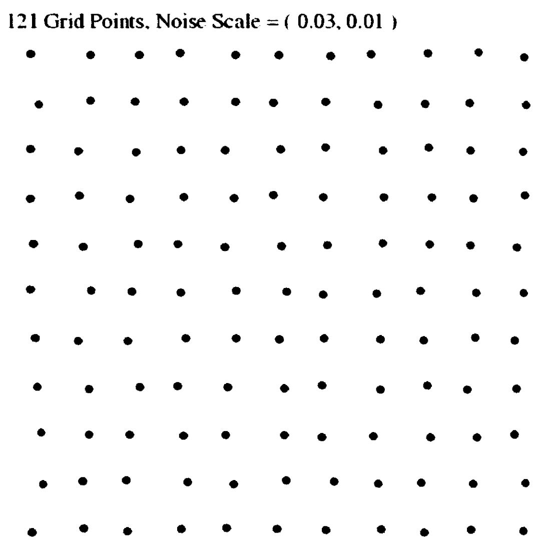
Wolfram's random pattern is in conflict with Gregory Chaitin's definition of random. Chaitin, a statistician, defines a random series as a pattern that cannot be reduced.[16] Whenever a sequence has to be written as it is, without finding a way of compressing it, Chaitin considers that a *true random* sequence. Wolfram patterns however are exactly generated based upon eight simple rules and can be exactly reproduced, over and over again. However, when looking at the generated graphics it is tempting to conclude that they are random. This raises the idea of introducing the concept of *visual randomness*. This allows us to declare the emergent *non-patterns* as visually random, even if there is a structure underneath.

DEGREE OF RANDOMNESS

A distinction can be made between the randomness of the physical world and the mathematical computer science definition. The former is defined by being beyond our control, the latter exactly by being controllable. As the artificial randomness can be controlled, it also allows for degrees of randomness to be applied.

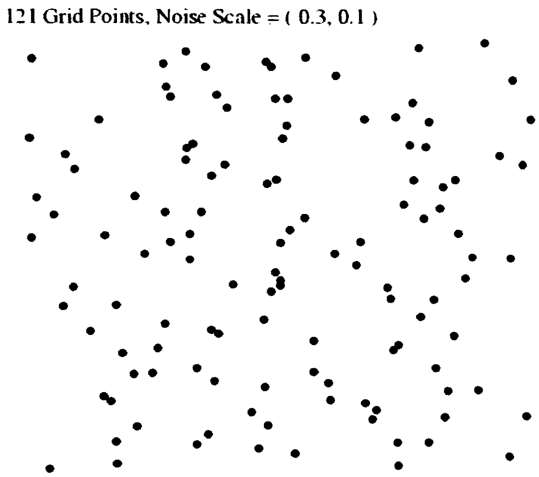
Randomness happens within a certain range, within a pattern. So far, randomness had been associated with a lack of patterns in computer science. By tweaking the degree of randomness, there now exists an entire spectrum ranging from perfect rectilinear grid over a messy grid to random points.

Dosing the degree of randomness of an array of points results indeed in the creation of a messy grid, which – in a sense – moves the computer generated grid closer to what a draftsperson would draw. Though a skilled draftsperson would draw a seemingly perfect grid, it would not come close to the *mathematical perfection* of numerical coordinates. When pushing the range of the point locations however, one ends up with a point cloud rather than a grid.



- rectilinear grid, slightly perturbed

Is this collection of random points more useful in design than the original grid? Who knows? However, for the computer the iteration with a high degree of randomness is still a square matrix. There are still 121 pairs of highly precise coordinates. Nothing has changed. Yet visually for the designer, this is an entirely different situation. In the messy grid a designer might recognize crooked squares, rectangles, wavy lines, or a skyline. In the *visually random* grid – if there ever was such a thing – a viewer might pick up on triangles, quadrilaterals, a bird, or a nose and an eye. Is one situation richer than the other? Probably not. Both grids have a tremendous number of shapes embedded within. Yet the perfect, the messy, and the random grid are different to a designer, but hardly to a computer.



- rectilinear grid, highly perturbed

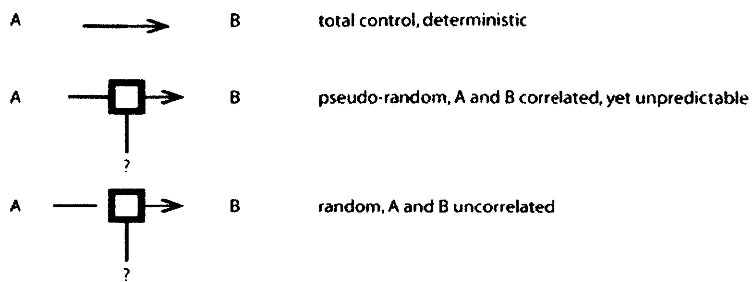
AN IRRATIONAL APPROACH

If one accepts that the early exploratory phase in the design process is in need of ideas – regardless of their source – and of stimuli that might lead to ideas, irrationality can be considered as a way of facilitating the creative act of exploring the design.

How can irrationality be inserted as a method into the computational design process? How can we assure that by turning to a computational/instructional model of design we are not reducing design to a rote and predictable experience?

In Marvin Minksy's view of the mind, there are multiple *agents* that function in parallel.[17] As Minsky sees it, every task can be broken down into a computation of sorts, as a finite set of instructions – but, science has not even come close to figuring out all of them.

An argument can be made for the use of randomness literally to break the chain of logical decisions that is rule-based design. Inserting randomness in the computation does not intend to create *new* solutions. It is supposed to present the designer with unforeseen combinations, and unanticipated situations. Quite clearly there are computations that do not include any randomness and still present the designer with emergence. Yet deliberately inserting randomness is close to foreseeing the unforeseen.



- three types of randomness, ranging from not random (total control by the designer) over pseudo random (randomness can be explained to some extent), to true random (creates a clear break between input by the designer and the output of the algorithm)

Returning to the previous distinctions between the *true* and *physical* randomness, this also presents us with two possible ways of thinking of randomness in the design process. Quite obviously, it is argued that computerization of design decisions is actually about total control. All possible conditions that can surface during the design are constrained and boxed. This would be a design process where one has full control. However, if considering that any design process may have some irrationality to it, the origin and end result of a design process are related, yet probably in a somewhat unpredictable way – an capricious association of Minsky's agents.

The goal of inserting randomness in the rule-based design is, in a way, to overthrow the solidity of these rules. Rules in design are everywhere, but mostly implicit. Making the rules explicit is one thing, at once considering the rules being rigid another. By inserting randomness into the design, the designer faces a disconnection from expectations – randomness is a degree of separation from the designer. As the design in the end needs *to make sense*, sense needs to be assigned to the possibly random outcome of design rules. This also means that

the design calls for reinterpretation right after the application of randomness: the designer regains control.
This assumption of reconsidering the design points at the danger of using randomness, and probably why many dismiss it as a potentially creative impetus. If randomness is inserted and simply accepted without evaluation of its effect, something random rather than a design is produced.

DESIGN BY CHANCE

In contemporary architectural practice randomness is loathed as an evil necessity. Many designers see the computer as a tool that allows infinite accuracy and precision, throwing out ambiguity for iron logic. More importantly, when the reasoning is there, the computational tool can speed up the design process through automation: every decision can be coded based upon an anticipated system of values and logic. In that mechanism of carefully laid out design thinking, randomness seems to have no place as it presents an uncertainty that goes against the paradigm of design through reasoning. However, when the computational aspect of generating a design becomes a large nebula that resists the recognition of some correlation between cause and effect, the final object has already been turned into a random object, void of any affection with design or designer.
Sol LeWitt deliberately leaves *execution decisions* to draftsmen, issuing ill-defined instructions to produce particular wall drawings. Roxy Paine conceived his contraptions in such a way that their inherent imprecision and slowness illustrates the possible reversal of the common notion – since Walter Benjamin – that industrial production leads to generic copies. The drip paintings by Jackson Pollock will provide an understanding of how to generate a painting by embracing the randomness of the physical system, of how to continuously interpret and respond as a mode of computing. The compositional experiments *according to laws of chance* by Hans/Jean Arp argue that a random point of departure has the capacity to liberate the design from unconscious customs and habits.
Yet when choices in the architectural design process are consciously left to others or chance, architects tend to turn pale when suddenly confronted with the surrendering of control. Even when that randomized choice does not determine or affect the outcome, the designer would feel more at ease being able to exert

his role as decision maker. When picked by chance or by hand had no influence on the process or the result, the designer would hand pick. Why would an architect want to use randomness in the design process?

In the ongoing research of Mark Goulthorpe's Borromean Voronoi Sculpture in New York, an applet was created to transform any shape – preferably a smooth and curvy shape – into a finite set of flat panels, collapsing structure, ornament, and detail into a single layer of computational wizardry. To construct the intricate three dimensional mesh of flat elements, the computer starts off from a random composition that will then be iteratively improved – based upon pre-determined parameters such as overall curvature, panel size, and panel proportion. No two solutions will ever be the same, and each will, regardless of the initial condition, look equally random. Even though the random scattering of the initial faces has little to no effect on the final product, Mark Goulthorpe expressed his urge to distribute the faces manually over the initial surface. For randomness, to his sense, has no role of importance to play in architectural design. This denied role of randomness or chance in architecture is symptomatic for the designer's misinterpretation of randomness as being meaningless and a reduction of the A in Architecture.

A highly romanticized notion of the importance of the first line – or even point – still exists in architecture. The first mark is somehow supposed to trickle up or boil down to the final result. In short, that first gesture will determine the entire project. This type of reasoning can be found prominently in the generative systems set up in the name of avant-garde architecture: an entire design generating system might depend on the location of three single points.

The computational muscle at hand permits architects to be more precise than ever before; however, the design software actually *requires* a high level of precision throughout the entire process. This need for precision has taken away the possibility to design; it precludes the sketched idea from being inaccurate or incomplete. When using computational methods, a sketch is no longer a scribble, a doodle or an automatic, unconscious drawing, but must be meticulously constructed, using particular points in XYZ space, connected by Bezier curves, covered by sweeping an ever-present lofting operation, related by specific rules and constraints. Can randomness fill in the blanks in a digital sketch? Can randomness in these locations be an asset to the creative process?

DOING WHATEVER

What happens at the drawing board – from now on referred to as analog design – could be generalized as a sequence of action and evaluation moves in John Habraken's world of design games.[18] We look at what is in front of us – which is the evaluation or interpretation of the drawing – and base our next action on the interaction of what we see and what we already know.

When computerizing these design moves – embedding design decisions in rules – the seeing part is altered, as it can from then on only *see* what has been accounted for in advance. Hence, computerization is simply a sequence of actions.

analog design :	**[... — → — → ...]**
computerization :	**[... → → → → ...]**
insert randomness :	**[... ■ ...]**
unknown situation :	**[■ — → — → ...]**

- design is looking and responding [evaluation = — ; action = → ; randomness = ■]

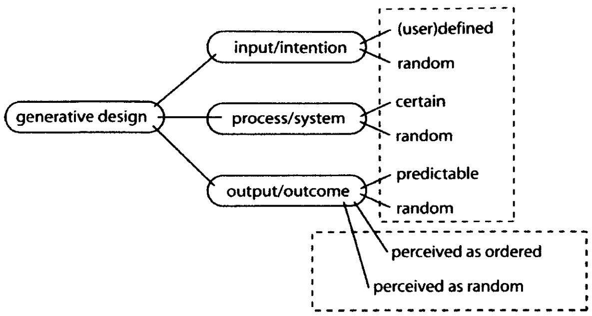
Inserting randomness in that process of computerization attempts to move outside the comfort zone of anticipated situations. It should present the coder-designer with unforeseen circumstances, precluding the possibility coding all in advance. The introduction of randomness into the rules of design behavior may seem counter-intuitive, but I would argue that randomness is very much part of our design behavior already.

When a small child is presented with new toy that it has never seen before, it has no clues of how to approach the object. As the child does not know what to expect, he or she will *do something, do whatever* to the toy, to elicit some initial knowledge. A random action can thus lead to more targeted actions, gradually becoming less random.

COMPUTATIONAL DESIGN

Generative art refers to any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art.[19] *–Philip Galanter*

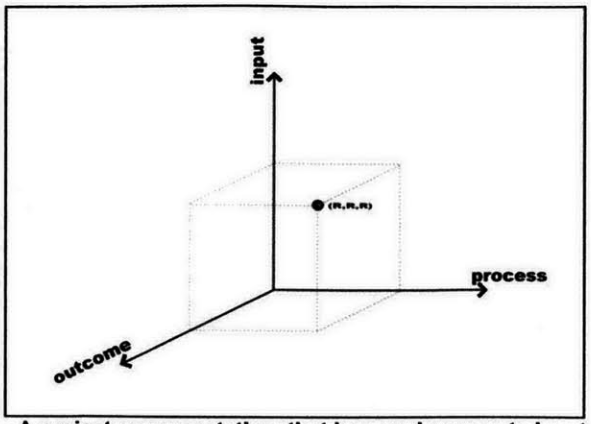
Computational design has, in a sense, little to do with computers itself. It is a collection of formalisms that make the design reasoning explicit. Often this takes the shape of rule formulations that determine or describe the transformations from idea into design. A process is applied to an initial situation – the input to the process – and results into a (new) situation.



- generative design systems made explicit in terms of input, process, and (perceived) outcome

To allow a comparison of works of art and architecture that employ randomness, a spatial notation of their generative system (input, process, and outcome) in terms of randomness is introduced. Each axis represents whether that aspect of the generative system – input, process, and outcome – employs randomness. On the vertical axis we plot whether the input has some randomness, the horizontal axis shows the process, and the axis at an angle represents the outcome. The origin of the space represents *no randomness* in any part of the design, (0,0,0). Obviously this can be read as (zero, zero, zero) and/or as (order, order, order). When randomness is employed throughout, this is represented as (r,r,r).

As we acknowledge that it is impossible to determine whether one process is more or less random than another, we have deliberately chosen to indicate the presence of randomness as a binary situation. Either it has randomness, or it has not. This transforms a continuous space – ranging from a fully order system to a fully random one – into eight points that can occur in terms of randomness. Evidently, this may plot projects that are quite different on the same coordinates. Nevertheless the notation brings coherence to the discussion of *random* projects.



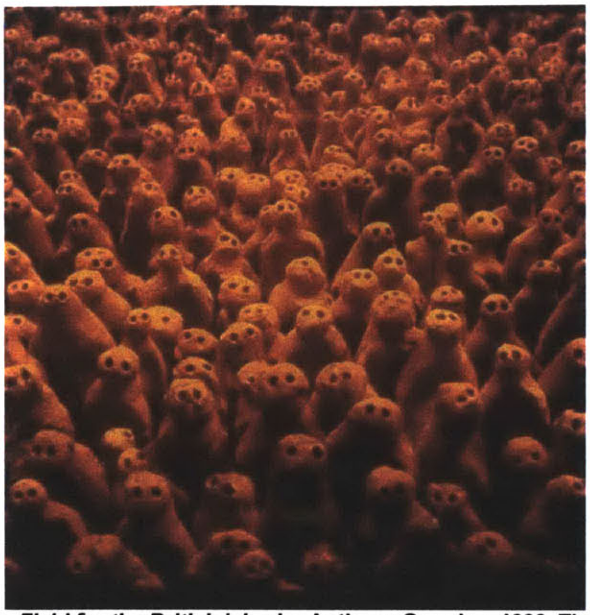
- A project or computation that has randomness to input, process, and outcome

UTTERANCES OF RANDOMNESS

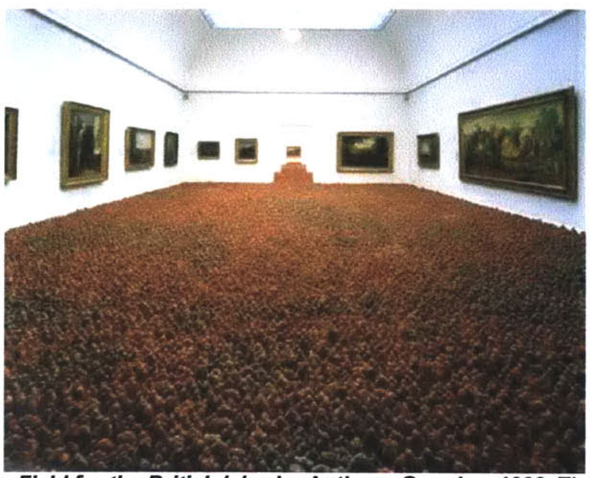
Randomness is employed for various reasons in works of art, regardless of the origin of that randomness. Yet in each of the examples, the randomness can in some way be read as a separation from the artist, designer, or writer.

Some of the works of art mentioned in this short survey of interpretations of randomness will be further analyzed later on. Locating when and how randomness is employed will be investigated in detail at that point.

The most straightforward way of interpreting randomness is as the boundary of what the artist considers relevant to the work of art. In Anthony Gormley's *Field for the British Isles* over 35,000 figurines were made by hand according to some basic rules describing the shape of the figurines. It did not matter to the artist what the figurines exactly looked like. Neither did it matter how they were placed in the room, as long as they would fill the space from wall to wall.



- ***Field for the British Isles*** **by Anthony Gormley, 1993. The figurines are made according to incomplete instructions.**



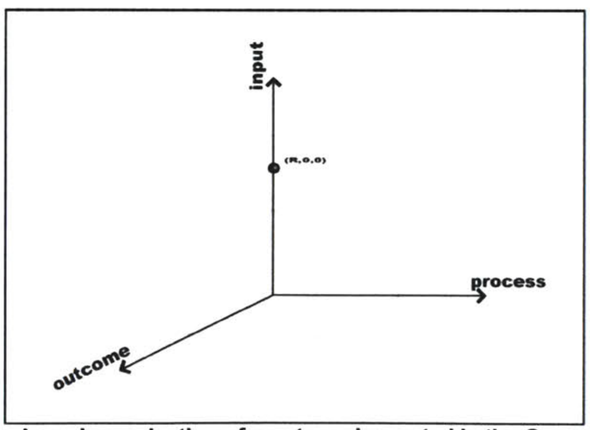
- ***Field for the British Isles*** **by Anthony Gormley, 1993. The figurines are 'to flood the space.'**

The projects more interesting to this research employ randomness as an intricate part of the production of the work of art, rather than considering randomness to fill the blanks irrelevant to the work of art.

Artists seem to think of randomness – or chance – as either a higher order – or quite the opposite – as having no order at all. The work of both Hans/Jean Arp and Ellsworth Kelly shows chance operations as being determined by a force outside our field of knowledge.

When considering randomness as being independent, both from the artist and the world, there is a schism between randomness being objective and randomness being subjective. In the wall drawing by Sol LeWitt randomness is unique to the draftsperson. In Jeffrey Ventrella's Gene Pool randomness is called upon exactly because it is supposedly objective and impartial in choosing the initial conditions for his simulation of the evolution of artificial life.

- *Gene Pool* by Jeffrey Ventrella, The evolution of A-life gains credibility by choosing a random initial population



- A random selection of creatures is created in the *Gene Pool*, their procreation and behavior follows specific rules, the hypothesis being that order will emerge out of the initial randomness

In Inverso a computer picks phrases from a library, and assigns a random layout according to haiku rules, thus suggesting the computer assuming the role of an author/poet and playing out randomness as capable of creating meaningful poetry.[20]

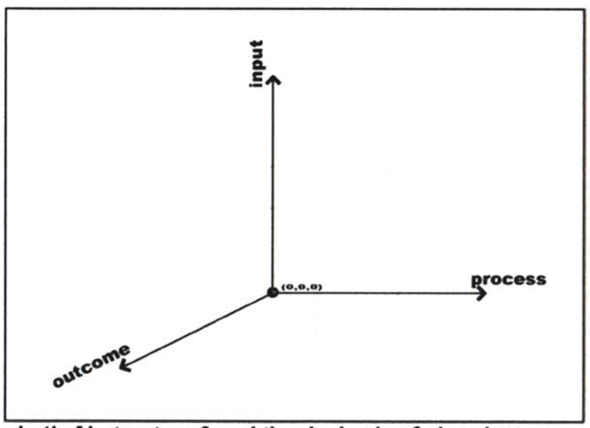
Some artists use randomness explicitly as a voice in the creative process, and engage in a constructive dialogue with the outcome to these random events. Hans/Jean Arp modifies random compositions of pieces of paper to achieve works of art he would not have been able to construct himself. Jackson Pollock uses the randomness in material behavior to respond to in his paintings. Roxy Paine makes the randomness in materials explicit by fabricating imprecise machines in his Painting Manufacturing Units.

A final approach to randomness is that of simulation. By deterministically converting the decimals of pi into colors a field of visual noise is created. The pattern looks random, but is not. In *Abstract no.6* Roxy Paine meticulously and purposefully recreates the randomness found in nature.

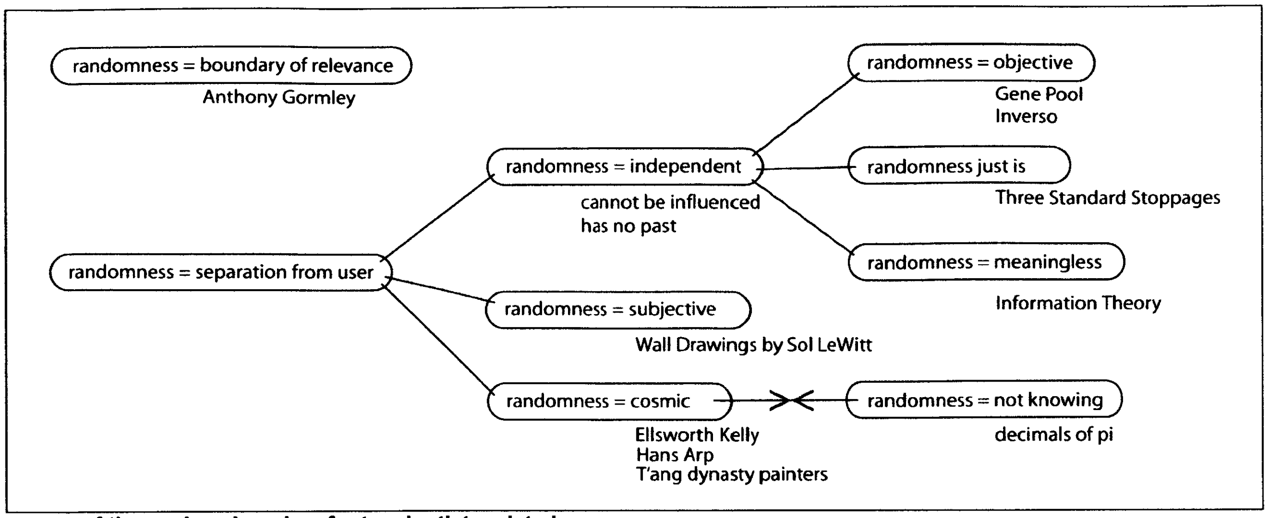
In *Dirt Painting (for John Cage)* Robert Rauschenberg paints with natural materials and mould such that the painting evolves independently and unpredictably from the artist.

- *Abstract no.6*, by Roxy Paine. Artificially modeled natural appearance

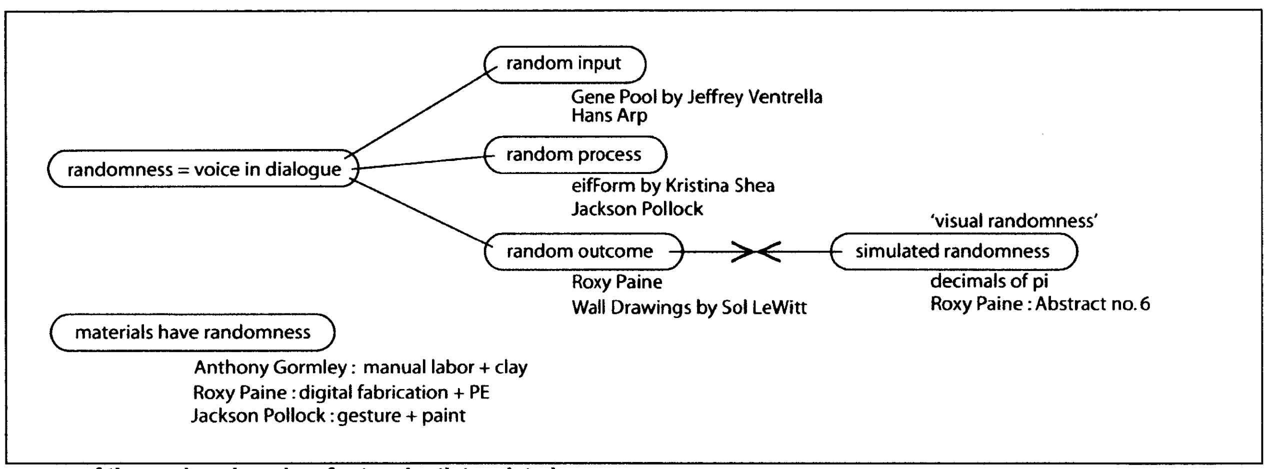
- *Dirt Painting (for John Cage)*, **Robert Rauschenberg, 1955. Consciously composed painting evolves into natural randomness**



- **both *Abstract no.6 and the decimals of pi project are created consciously, resulting in an intended and controlled result that can nevertheless be perceived as being random***



- some of the analyzed works of art and artists related according to their interpretation or use of randomness



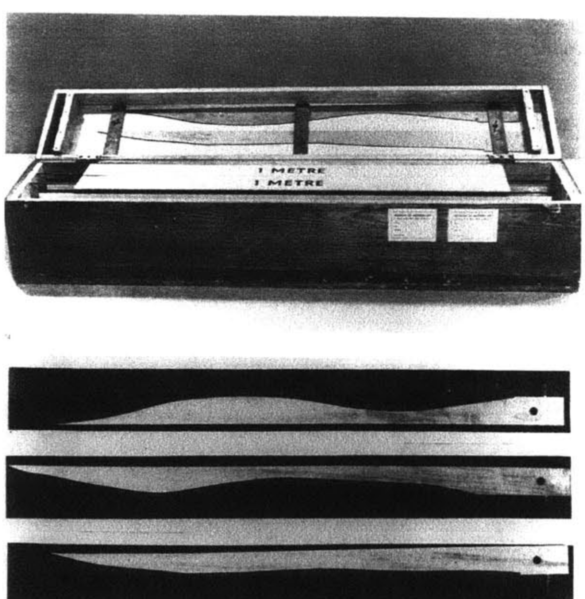
- some of the analyzed works of art and artists related according to their interpretation or use of randomness

CHOOSING IS KEY [—]

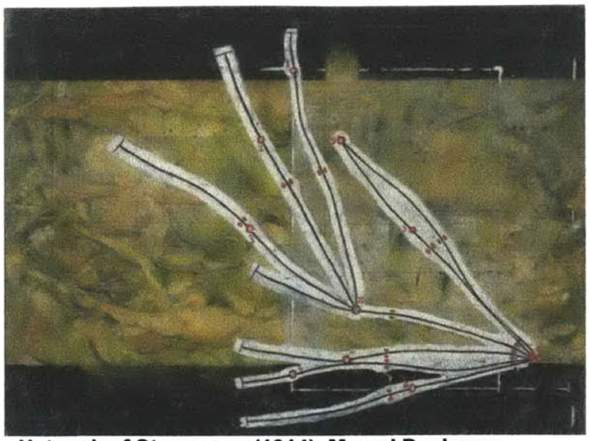
The seeming conflict of encountering randomness in a creative act is explained by Marcel Duchamp after his *Fountain* was refused entry in the *No Rules, No Prizes* sculpture exhibition of the Society of Independent Artists.[21] When the Society declined to exhibit the R. Mutt submission on the grounds of it being 'immoral, vulgar' and 'plagiarism, a plain piece of plumbing', Duchamp replies via the journal *The Blind Man* that all these arguments are without meaning. Sure, that urinal could be seen in any plumber's store window. But he, the artist, chose this particular object and consciously created a new meaning for that everyday object.[22] Considering choice crucial to artistic utterance seems to conflict with randomness in art. Randomness, indeed, is about the artist *not choosing*, about inserting an external voice into the creative act.

Duchamp resolves this collision between chance and choice by deliberately choosing where to deploy chance and by responding to the outcome of chance. It is the positioning of the artistic expression that is of utmost importance, as if an artist should choose what to take up and what to leave to chance. In *Three Standard Stoppages* Duchamp drops pieces of rope that are exactly one meter in length from exactly one meter high, and marks the shape the fallen pieces of rope. This randomly generated curve is then placed against the common notion that a ruler of length one meter should be straight. *Three Standard Stoppages* illustrates that a chance operation can become the conceptual basis for the work of art itself: the randomness of Duchamp's measuring device undermines the arbitrariness of any other measuring device.

Whereas in *Three Standard Stoppages* the randomness of free form-finding of the three pieces of rope is the work of art itself, Duchamp uses that randomness as a point of departure in *Network of Stoppages*, where he consciously and deliberately assembles and composes the final work from the randomly generated components.



- ***Three Standard Stoppages*, Marcel Duchamp**


- Network of Stoppages (1914), Marcel Duchamp

APPROXIMATE NATURE [■]

I use the word "approximation" because a measuring mind can never finally measure nature.[23] *–J. Cage*

John Cage transforms the known binary of *sound/silence* into a subjective binary of *intended sounds/other sounds*, the *other sounds* being *so-called silence*, because silence does not exist.[24] Even in an anechoic chamber – where all effort has been made such that sounds would either not enter, or vanish into thick sound absorbing walls – one faces the sound of nerves and blood being pumped through your veins. Even when all possible sound has been silenced, we encounter sound. If there is no such thing as silence, then Cage rightfully so proposes to discuss sound only in terms of what is intended and what is not.

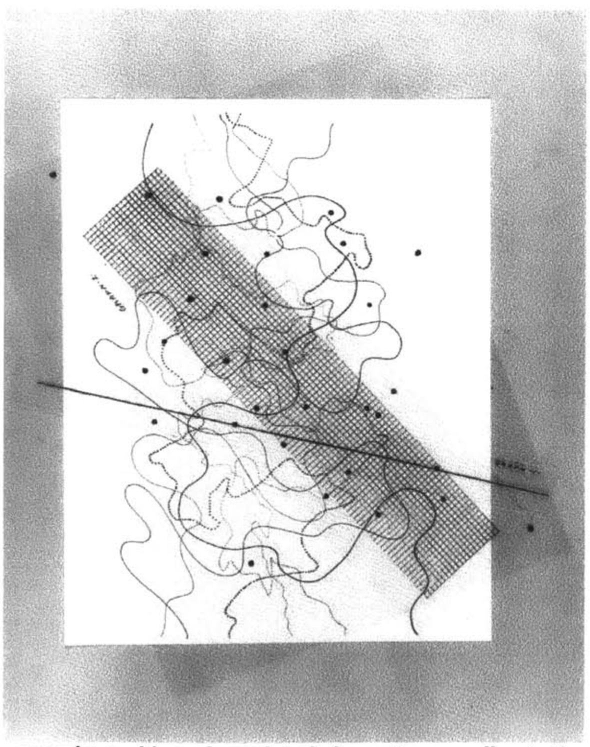
In his 4'33" composition his play on the *intended sound* and *so-called silence* is brought to the front. The play is defined by duration. The only tool John Cage uses to compose music is time, thus emphasizing the presence of unintended sound. The recorded version thus primarily replays random music, noise, so-called silence. In a realm defined by deliberate decisions Cage put the random sounds center stage, emphasizing that randomness – unintended sound – is inevitably part of any environment, even in the anechoic chamber.

By recording the unintended sounds, Cage articulates the possibilities of turning any sound into music, if one is willing to listen. By intentionally not composing any music Cage foregrounded the presence of random sources of sounds, but at the same time, the recorded sounds are only picked up as music during Cage's performance. It is the Duchampian notion that art is about choosing that is now played as not choosing in one way – Cage chose not to touch the piano – and at the same time as very deliberate choosing – since Cage chose the time, location, and an exact duration for the performance.

SUPERIMPOSING THE UNRELATED [■ —]

In John Cage's world of sounds randomness was not only an aspect of sound that could not be avoided, it also a goal in itself. In *Fontana Mix* Cage deliberately constructs a random composition of musical notes, in order to emphasize the importance of listening.

Cage's way of constructing randomness is by superimposing unrelated patterns and deducting from that a musical score. A rectilinear grid, six wiggly lines, a straight line, and a set of haphazardly placed points are combined and generate a musical piece.



- superimposition of unrelated elements according to the instructions for *Fontana Mix*, 1958

It is fascinating however to see how meticulously John Cage prescribes the system to generate this drawing – and thousands of similar scores. Although the drawing seems a pile of incoherent layers, Cage issues instructions to combine exactly these layers without specifying how they should go together. Yet all components are meticulously laid out.

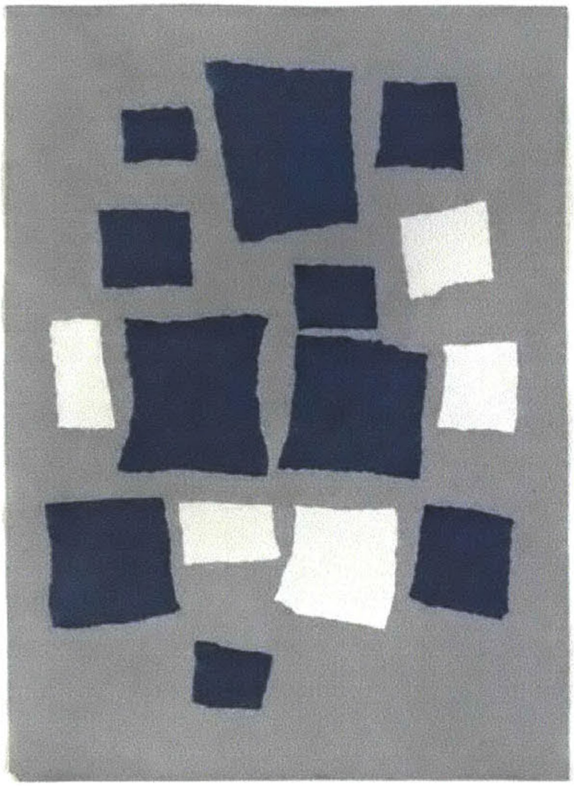
While being specific about what the components to the drawing are, Cage never discloses what the parts mean – though he does suggest possible approaches – so figuring out how the composition results into music is literally left to the reader or viewer. Rather than presenting us with a random composition, Cage created a system that was so far removed from anything known as a musical composition at that time that it could be interpreted as being random. But it also indicates that it is merely a matter of interpretation that turns a random composition into composed music.

UNCONSCIOUS TOOL [■ — → ... — →]

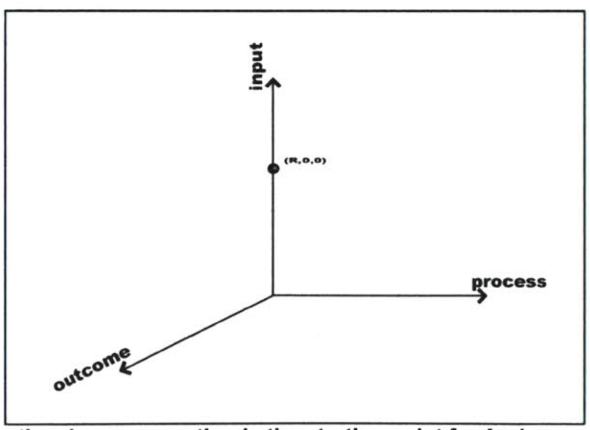
One of the artists in the early 20th century, renown for his use of the aleatory as a method to realize a level of objectivity unattainable by a conscious act, was Hans/Jean Arp. Paradoxically, his attempts to erase his personality from the work of art by using chance operations have since then become a signature of sorts.

Hans/Jean Arp uses chance and randomness both in his collages and poems to remove personality and subjectivity from the creative act. The chance operations in the collages – dropping pieces of paper on a flat surface – had to open a world of compositions that he considered inaccessible by his conscious self. Yet Arp makes a clear statement in the accompanying captions that chance was only *used*. The chance operation is a tool to Arp, just as the Fontana Mix is a system to John Cage.

Dropping the torn pieces of paper, as well as tearing them, was a way to create a random point of departure. Yet, rearranging the fallen pieces allowed the artist to take his collages into unanticipated territory. The chance operation let him discover new compositions, rather than constructing any. The random locations of the pieces of paper on the background provided ideas to conceive of new compositional structures, but in the end, Arp found the structures and ideas within the random composition.



- ***Collage with squares arranged according to the laws of chance*, Hans/Jean Arp (1916-17)**

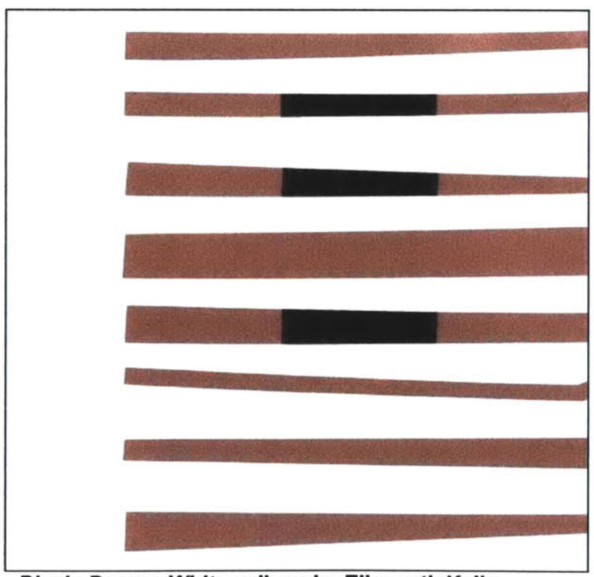


- the chance operation is the starting point for Arp's deliberate continuation of the composition

RE-COMPOSITION [— → ... — → ■]

Ellsworth Kelly uses chance to externalize compositional decisions, such that the work of art could be created even without his aide. Some of his *by chance* collages involve the slicing and rearranging of a discarded drawing or painting. One could pose the question how rearranging pieces from a mediocre drawing – that was initially not even considered worth keeping – according to the laws of chance adds to the creative act. Beyond the destructive act of segmenting the initial drawing, it may seem hard to consider the random recomposing of pieces of a drawing to be an artistic utterance. Yet, in Kelly's book without words, *Line Form Color*, the pages that absolutely seem vibrant of personality are the ones made according to the laws of chance. Whereas the monochromes and single line drawings come off as impersonal, the layer of randomness in the collages seems to have captured a compositional vitality.[25]

The Black, Brown, White collage is a good example of how the random re-composing approach can actually transform a very modest drawing (a black rectangle in a brown rectangle) into a more intriguing series of parts. When making the drawing, however, Kelly did not have these cuts in mind. It was simply another abstract drawing that ended up being transformed by chance, into something radically different from his habitual drawings.



- *Black, Brown, White* collage by Ellsworth Kelly

Although both Kelly and Arp use randomness to construct a composition, their use of randomness as a creative tool shows interesting similarities and dissimilarities. Where Arp would use plain paper torn to pieces to create a composition, Kelly would slice up a discarded drawing. To both, the chance operation thus forms the beginning of the actual composition. In Kelly's case it is about re-arranging the pieces in a haphazard sequence, on a messy grid. Arp on the other hand uses chance to arrange – rather than rearrange – the parts he has on a horizontal surface to which he then applies order, creating order within randomness.

These two seemingly similar projects are thus fundamentally different: Kelly presupposes a linear structure, whereas Arp applies a compositional structure after the facts.

CONSTRUCTING MEANING [■ —]

A haiku poem is strictly rule based and is, as such, an analog generative system in itself. A haiku must contain 17 syllables, should refer to a season, and have two contrasting parts within the three sentences. The content should be about a moment or an impression that moved the author. However within this structure one has the ultimate freedom.

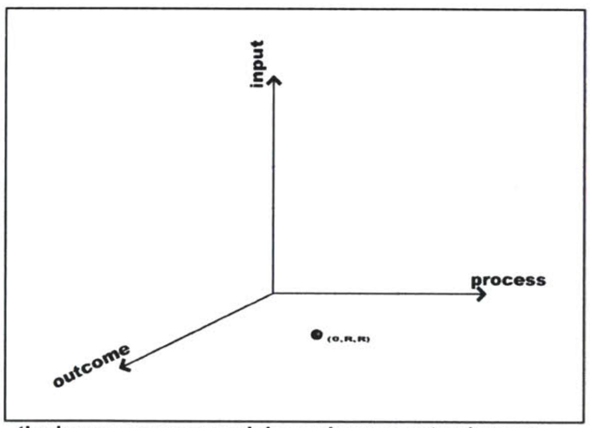
However, what happens when the author of a poem has no intention beyond making a poem? This is exactly the question Inverso takes up: a computer generates a haiku on demand.[26] Do people notice the lack of intended meaning and coherence? Can a poem be sensible when the author *wrote* without any intention whatsoever?[27]

Without going into the discussion whether a computer program can actually write a poem, the Inverso program is coded to comply with all possible haiku rules using lines of poetry that have been used in haiku before. Also, the concept of using phrases from other poems is typical to haiku, where entire online communities collectively adapt and alter each other's poems.

All the Inverso program does is randomly choose three phrases from its extensive library and apply a random layout to the poem. The phrases, which have meaning in their original context, are compiled into a new poem without any intention. The program does not analyze phrases, or context. Unlike the careful picking and placing of words, this program just assembles poems from parts that are known to fit the haiku concept.

In a sense, each haiku was written as a collaborative enterprise by three independent authors, each adding a line without knowing where the line would end up. Thus in the context of the new poem only the reader assigns meaning to a poem that sometimes is so abstract it could mean anything.

- haiku poem by Inverso

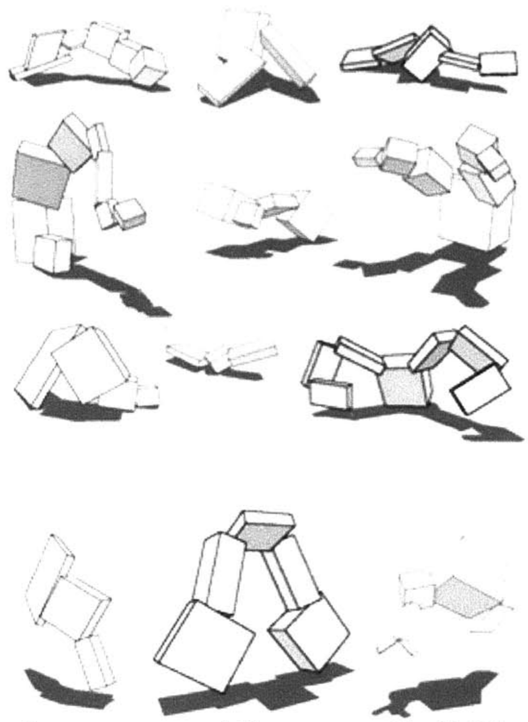


- the Inverso program picks and represents phrases randomly from a tailored haiku library, yet the reader assigns meaning to the poem, though the outcome is random

EVOLUTION [■ → → ...]

Karl Sims sets up a digital experiment of evolving creatures, not with the intention to witness a society evolve – Jeffrey Ventrella's Gene Pool – but to see new species emerge.[28]

Sims builds life from a combination of geometrical elements. His program joins rectangles, spheres, and circles into a creature. The cunning part of his work resides in the fitness function that decides, based upon objective parameters, what creatures are able to live up to arbitrary requirements. These fit creatures are then allowed to keep evolving; others are thrown out of the pool.



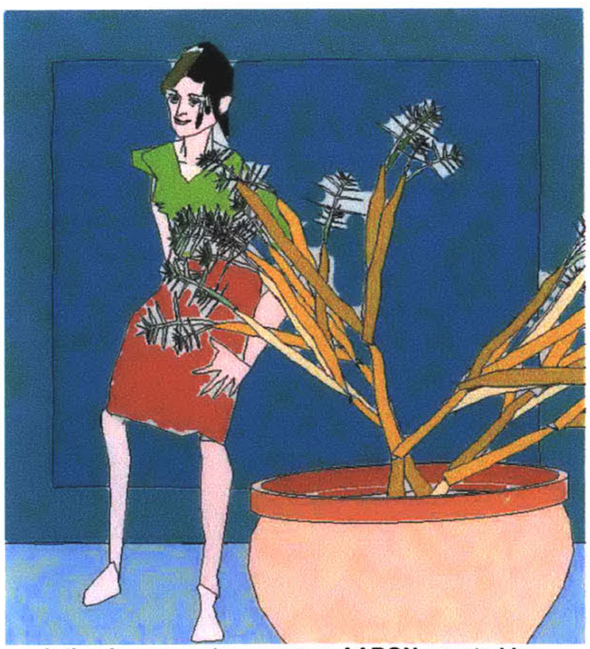
- randomness as an evolutionary concept by Karl Sims

In the Gene Pool by Jeffrey Ventrella, the viewer can define how the creatures reproduce, what behavior they would show. That viewer-system interaction is not part of Karl Sims' program. When the programmer finishes his job, the computer starts generating and evaluating creature after creature, ad infinitum.

Sims' program does not need random; it could basically live without any randomness at all. Yet to represent a way of looking at Darwin's Evolutional Theory, Karl Sims has incorporated randomness as his lovely assistant, picking random combinations of rectangles and squares that make up a creature. The random selection of body parts also defines how they can move. Their ability to move is the only criterion as to whether they survive or not. When Karl Sims first ran his program, the random combinator could have failed on him by only composing sure-to-die or existing creatures. But when the program runs often enough, it will generate creatures Sims might not have designed himself. And that is exactly the point: the embedded randomness allowed the programmer to witness the rise and fall of creatures he otherwise might not have thought of at all.

(SIMULATING) CREATIVITY [— → ... ■ →]

When Harold Cohen started his project to create a machine that would independently create unique representational paintings, very few people believed that he would end up creating art. Yet his computer program AARON has done exactly that: it creates drawings and paintings which have been exhibited in numerous places. The work has been analyzed by art critics – unaware of the fact that a computer generated the art work – who decided that the art work was probably made by artist Harold Cohen, thus referring to the machine as a pupil of a master.



- painting by computer program AARON, created by Harold Cohen

All of these drawings are supposedly unique. AARON has received a limited knowledge of the world from his creator; yet within this world he is able to endlessly generate random images, constantly depicting variations of the same elements until his creator inserts a new object in his program.[29]

Just like one would teach a child, Harold Cohen had started to 'teach' his pupil what a potted plant was, what different types of plants there were. In the same way he has taught the apprentice how parts of the body connect to each other. He has given AARON a range for every body part wherein the program can vary. Every drawn object is derived from a conceptual primitive programmed into AARON.

Why is this relevant in a discourse on random? Although AARON knows a small number of components, he is not only able to generate images independently, but using random variations within these components generates seemingly *unique* drawings. No two drawings are identical, which has led critics to call AARON to be the only creative program they know of. Whether it is or is not the only creative program is of course of no relevance. What is intriguing is that the use of randomness is associated with creativity.

All AARON can do is pick some of the objects (such as woman, man, plant, and table) in his catalogue and select the values to the variables associated with the primitives (such as color, size, and position). Harold Cohen has created quite a spectacular program, but it still is a closed circuit, incapable of changing its own catalogue of usable primitives.

Considered in one way, there is no input to AARON, the computer simply generates a painting, regardless of context or situation. On the other hand, Harold Cohen has entered a highly sophisticated grammar into the computer first. Indeed, the input-process-output paradigm is in itself susceptible to interpretation, depending on what part one is interested in.

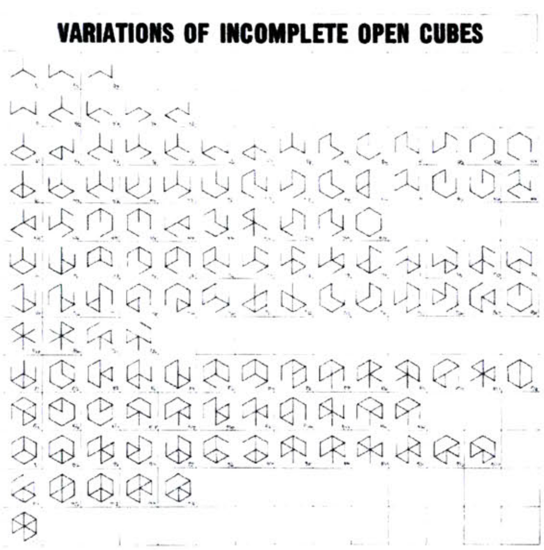
In one way, the randomness within the program makes each painting unique, in another, all outcome are copies.

INTENTION ≠ EXPECTATION

The idea becomes a machine that makes the art.[30] *–Sol Lewitt*

Sol LeWitt's *Variations of Incomplete Open Cubes* from 1974 could be taken as an accurate sketch of contemporary use of computational design in architectural practice: a geometrical system – an incomplete cube – is set up, and a clear command – compute all possible variations within that single system – is assigned.[31] As an analogy for the imperfection of an architectural idea and the perfection of the closed series, the scientific rationality of *Incomplete Open Cubes* was a wry premonition of what computational design has become several decades later: it is now in a compulsive obsessive state of finding all solutions to an arbitrary system.[32]

Where this scientific rationality machines itself into an intriguing series of works of art, it becomes evidently problematic in an architectural practice when the initial concept of the incomplete cube excludes any other event from happening. Without a doubt the systems set up in architectural context are more complex, but in general it is indeed about choosing a specific set of constraints and calculating every single or the single best possibility within that system.[33] Finding all solutions to a single system is exactly what a computer does best; however, this obsessive calculation separates the artist from the creative moment. That separation is exactly what LeWitt was after: the creative aspect for LeWitt is in the idea, not in the calculation. For LeWitt the calculation is the end of the project. For a designer, however, it is (or it should be) a means to an end – opening up the entire realm of possibilities to an idea.

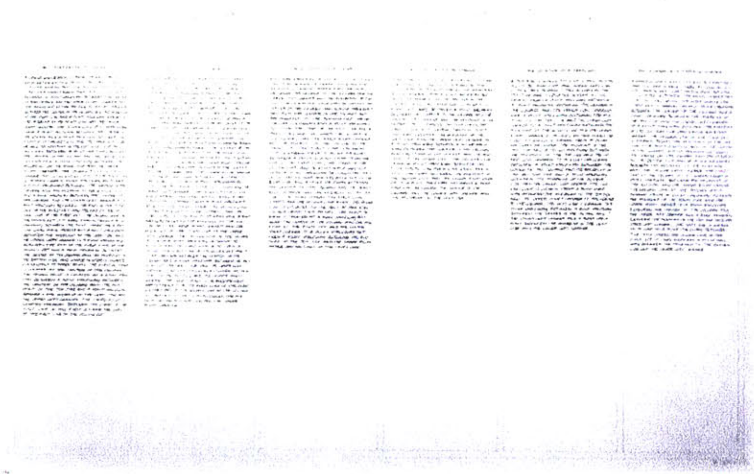


- Variations of Incomplete Open Cubes (1974), Sol LeWitt

In the calculation of the *Incomplete Open Cubes* LeWitt has given divergence a very straightforward, yet intriguing face. All the cubes share cubeness as common denominator; yet, one cannot help to attempt finding the systematic within the series that is beyond *being incomplete cubes*. As every viewer wonders whether LeWitt may have missed a solution to his system, the system itself proves to be incomplete. So, what is the use of calculating all possibilities to a complex set of architectural constraints, if all possibilities to a simple idea such as *Incomplete Open Cubes* is consistently read as being incomplete?

In the Wall Drawings LeWitt issues instructions as *Ideas that generate art*, similar to the *Incomplete Cubes*. Yet where the cubes ended in divergence, the wall drawings move through divergence, the instructions, to convergence, the physical wall drawing.

The role of instructions in the Wall Drawings by LeWitt demands a closer study in terms of their analogy to contemporary architectural practice, where both architect and computer scientist engage in a designing dialogue. This is based upon the communication of intention and/or expectation on the architect's side and interpretation and/or responsive action on the computer scientist's. The nuance of communicating from intentions or from expectations will become evident from the work by Sol LeWitt.



- The Location of Six Geometric Drawings, 1973, Sol LeWitt

In the titles to his drawings LeWitt makes an argument that a verbal language is not precise. Starting from verbal descriptions of the shape and its location that accompany the drawn shapes in *The Location of Six Geometric Drawings*, 1973, LeWitt later ventures into the merging of both instructions and the outcome to these instructions in *Lines to Specific Points*, 1975. Although the titles indeed represent the core idea in the drawing, they do not manage to determine the drawing. The titles are open-ended instructions that can produce the drawing, among many variants. The precision of the text accompanying the 1973 work of art, and embedded in the 1975 work of art, illustrates the verbal complexity inherent to a visually evident drawing.

Strangers to the artist and, to some extent, to his work would execute instructions for a work of art (the early wall drawings); at first sight this mode of production resembles issuing commands for a computer. Yet, the nuance is already embedded in the vocabulary used. Commands for a computer need be precise, whereas LeWitt allows his instructions to be open-ended. He deliberately renders decisions to those producing the actual wall drawing. In *141. short straight lines, not touching, drawn at random, and evenly distributed over the area* it is up to the draftsperson to determine the eventual randomness of the wall drawing.

Over time, his language of forms and shapes used in the instructions evolved into a very personal language. The continued issuing of wall drawings forced LeWitt to reconsider his method of production. His language – in both the instructions and in the drawings – had evolved such that only his own people were able to execute his work. Whereas initially the drawings were intended to externalize the actual production to random people, LeWitt has reduced the agency within his system by turning to his alter ego-like crew of assistants. His working with selected and art-educated personal assistants, begs the question whether the recent wall drawings are still about the instructions as an idea as a system.

In his later work LeWitt drops the verbal instructions altogether in favor of a graphic representation on paper. LeWitt no longer has to issue a set of quasi descriptive geometrical instructions; working with his own production team has allowed him to move into an area of messier and vaguer instructions, now shifting from intention to expectation. The instructions no longer describe an idea sent out into the world, but an image that needs to be returned to LeWitt by his staff, according to his expectations. His turn to personal assistants is thus an impoverishing act in terms of having the idea be the system that generates a wall drawing. While random people producing the wall drawing can be considered unaware of LeWitt's intentions beyond the written word, thus filling in the blanks in the instructions according to their own interpretation, the studio assistant will rather assume intention according to previous experiences than interpret the instruction itself which comes without context.[34]

The surprising quality of the wall drawings depends on the interpretative capacity of the receiver of the instructions and the assumptions under which he or she works. The clean instructions that accompany the early wall drawings may seem to be reductive in terms of their possible outcome, yet, considering that these instructions are executed by one time only draftspeople unrelated to LeWitt, these geometrically contained wall drawings may have been very well be the works whose outcome Sol LeWitt had least anticipated.

MECHANODIGITAL FUZZINESS

It seems to me that the modern painter cannot express this age, the airplane, the atom bomb, the radio, in the old forms of the Renaissance or of any past culture, each age finds its own technique.[35] *–Jackson Pollock*

The machine of our age is neither the airplane nor the atom bomb, but the computational device and the intricate web it is weaving. Its current potential to create and solve complexity has not yet been fully explored while its continuing expansion is stupefying.

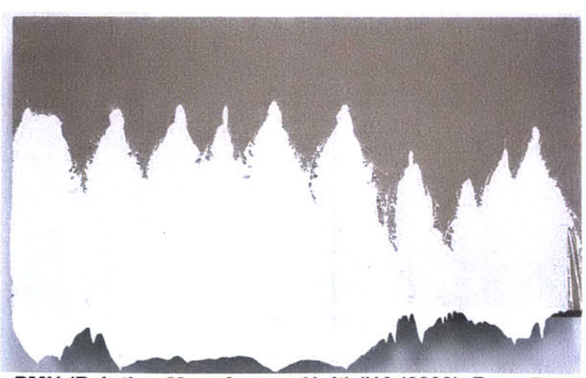
Although these devices are based upon a rational concept of pure logic, art now ventures into machines producing works of art that do not simulate human touch, but that express their own mechanodigital nature. This nature is visibly not nature, yet natural to the production unit, not deterministic yet programmed. Paradoxically, it is the demanding precision of the digital medium that creates the opportunity to exploit the inaccuracies inherent to a mechanical medium. While most of the world tries to gain infinite control over mechanodigital devices, the reversal of direction of evolution – the loosening of control – gives way to *mechanodigital artistic expression*.

The artist is not motivated by a nihilistic desire to destroy our foundation of knowledge. Instead, he strives to make us aware of some of the changes that have come with our digital age.[36] *–Joseph D. Ketner*

Very early in his career, Paine was intrigued by the notion of setting up a fuzzy mechanical system that is and produces the work of art. The most exemplary of that is Displaced Sink (1993), in which a leaking faucet hung from the ceiling slowly erodes a carefully placed stack of soap bars located underneath – turning a manmade work of art into a natural process of uncertain transformation. This process of dripping water to produce "soap scum puddles" [37] provided for Paine the intended tension between organic and industrial, and between artist/controlled and nature/uncertain. A similar game of an organic effect caused by machine can be found in Viscous Pult (1990). In this work brushes sling ketchup, white acrylic paint and motor oil from pans and a baking form onto the window; the final product is a mechanical performance, rather than a Pollock painting on glass.

Even the most perfect reproduction of a work of art is lacking in one element: its presence in time and space, its unique existence at the place where it happens to be.[38] *–Walter Benjamin*

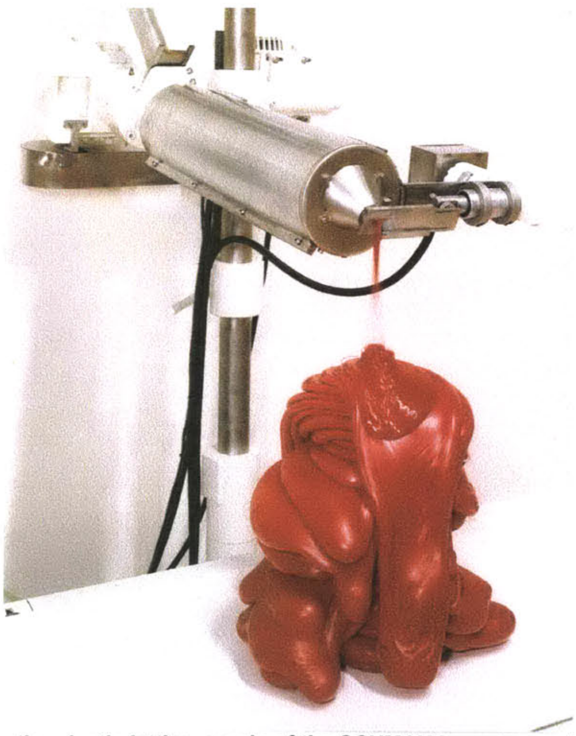
The introduction of mechanodigital production allows the artist to outsource uniqueness associated with manual labor to a machine set up to perform acts of imprecision. Even though Benjamin argued machines erase identity from the (re)production process, the detailed uniqueness that is manufactured by the Painting Manufacture Unit (PMU from now on) and Auto Sculpture Maker (SCUMAK from now on) are prime examples that overturn Walter Benjamin's fear of mechanical flatness. The suggestion that a machine could express its own material individuality surpasses from the Benjamin trope into one of humanoid creation. Benjamin thought of machines as copy makers. Roxy Paine presents us with machines that make copies without originals, copies that are originals. By loosening up the fabrication process each sculpture exactly expresses its time and space.



- PMU (Painting Manufacture Unit) #13 (2003), Roxy Paine

I wouldn't describe it as a cyborg. It's more a collaboration between me and nature.[39] *–Roxy Paine*

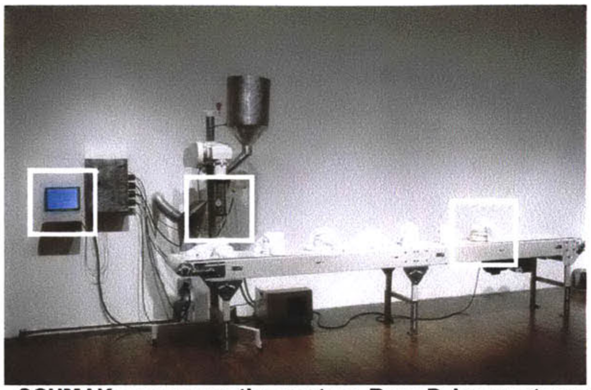
The use of polyethylene – used for both plastic throw-away shopping bags and high-end prosthetic implants – in the SCUMAK is once again a fuzzy paradox that exemplifies Roxy Paine's struggle to come to terms with the human yet artificial qualities of his machines. The so-called binary of permanence/temporary (prosthetic hip/shopping bag), encapsulated in slowly dried mechanical uncertainty, illustrates the machined meticulousness associated with manual labor in Roxy Paine's contraptions. The painstaking slowness at which the *PMU* and the *SCUMAK* construct paintings and sculptures refers for Paine to natural processes of erosion of rock formations. Having this double reference to manual labor and to natural processes, is an example of his dismissal of binary either/or thinking over the use of a fuzzy and/and vocabulary.



- the plastic jetting nozzle of the SCUMAK is engineered not to be fully controllable

It seems as if creating a material portrait, rather than a specific form, is the intention. Roxy Paine's code has the urge to become a sculpture, without defining which one. Paine sets the direction while permitting the consistent inaccuracies of the system to affect that intention. There is no sense of imitating nature, but rather an acknowledgment of the possibility of a mechanodigital device having human qualities usually associated with artistic expression.

The machined yet natural characteristics found in Roxy Paine's sculptures and paintings do not comprise a return to nature, but the *loosening* of the machine in order to release its modest – because the artist is still present – humanoid qualities.

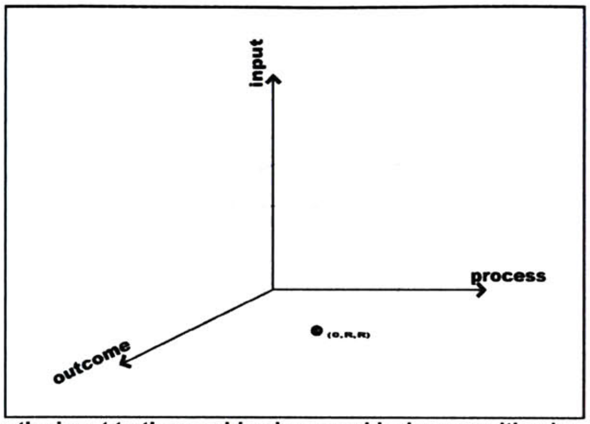


- SCUMAK as a generative system, Roxy Paine creates an input on the computer, which is executed by the machine imprecisely, and results in the organic sculptures

Although Gregory Volk argues that all subjectivity has been removed from Paine's machines, the artist's intentions are still hitting the gas pedal while the machine is steering itself. [40] Whatever Roxy Paine codes, becomes a dripped painting or sculpture blurred and altered by a layer of unforeseeable variation that resides in the machine. Even though Volk would like to erase the artist – turning the PMU #13 into a work of art produced solely by a machine – it is still very much the effect from the program caused by the artist that just left the room (as suggested by the chair next to the machine). Paine was sitting in the chair next to the machine a moment ago, working on the still present common personal computer – instead of an industrial equivalent which might have emphasized the industrial over the personal.

Roxy Paine himself also attributes the disappearance of the hand of the artist to the Scumaks[41], yet at the same time he does acknowledge that every Scumak largely relies on his input, while an identical input only produces fraternal Scumak twins, visibly familiar, yet unique.[42] But more importantly, even though Paine likes to promote the SCUMAK as an independent machine-artist, at the end of the day his personal software guides the machine. Although Paine uses randomness – in the material and the machine – to generate unique sculptures, the machine itself has not yet shed its toolness, and is a mechanodigital extension of the artist.

As a generative system, Paine enters a string of instructions that are executed by the machine. Because of the engineered freedom of the plastic spraying nozzle, the sculpture is somewhat disconnected from Paine's intentions. Yet even though indeed the form-making has a degree of randomness – the artist rendered some control over the form to the material – Paine interacts little with the outcome of his instructions.



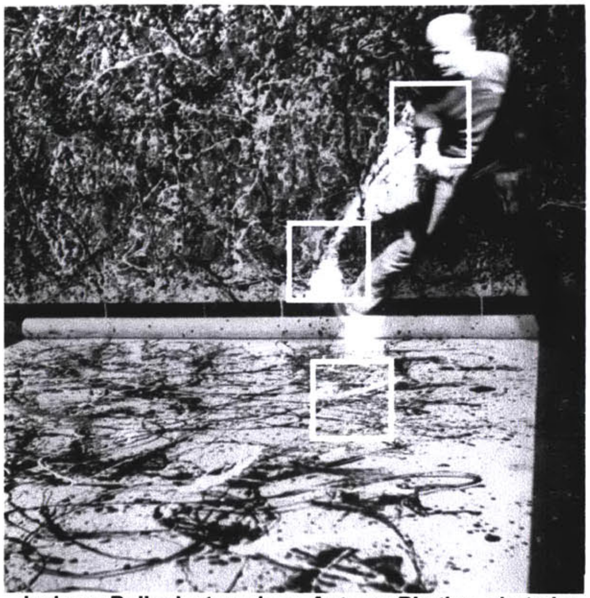
- the input to the machine is a graphical composition by Paine, indicating some intentions. Yet the production unit is deliberately set up not to be fully controllable, which adds a layer of randomness to each sculpture

The machine executes commands, and contributes to the form of the sculpture, yet the entire process is considered as a single string of commands that do not allow being interrupted by the artist. Obviously it is Paine's immediate intention that the machine works as independently as possible, yet at this point it is merely an execution of Paine's intentions. Disregarding the freedom in the nozzle, it is rather similar to any industrial car manufacturing robot. At no point does either the process of making affect the initial intentions for the sculpture.

SEQUENCE OF PERTURBED INTENTIONS

I don't use the accident – 'cause I deny the accident.[43] *–Jackson Pollock.*

Pollock did not use brushes in a conventional manner, he used them as sticks to launch the paint towards the canvas without touching it. Pollock did not use common artist supplies at all; he created his personal world of materials and methods, all different from how the world had romantically come to accept how an artist should paint.[44]



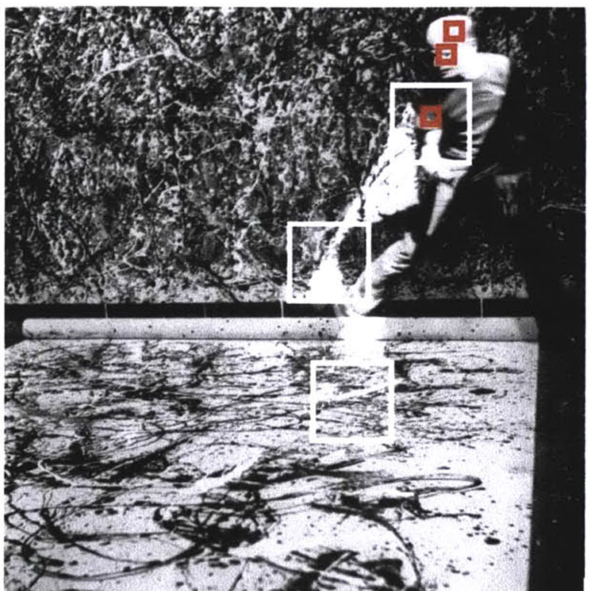
- Jackson Pollock at work on *Autumn Rhythm*, photo by Hans Namuth, as a generative system. input = gesture; process = physical system; outcome = mark

What was initially read as randomness was the agency given to his tools. Even though he had an intention where to apply his next stroke, or how his next gesture would follow the previous one, Pollock had no complete control over the final mark on the canvas. While many artists experimented on the implementation of chance and randomness in works of art, in the paintings of Pollock randomness is not treated as a final product. In the paintings randomness becomes a generative principle that continuously inspires the ensuing performance. Accepting this model of dialectics – of continuously assessing the uncertain outcome of your own intentions – creates a new paradigm for artists to work with.

This dialectics of responding to a system that is beyond the artist's full control introduces not only a new language of painterly forms and shapes in art, but also creates a new way of thinking about making art, and what is essential to art.

Chaos. Absolute lack of harmony. Complete lack of structural organization. Total absence of technique, however rudimentary. Once again, chaos.[45] *–Bruno Alfieri*

While Bruno Alfieri in TIME magazine, 1950, still refers to the Jackson Pollock paintings as *Chaos, Damn It*, research by James Coddington at the MoMA shows that these chaotic looking, all-over paintings actually have a structured basis of straightforward and bold gestural marks.[46] That initial layer enables Pollock to have visual complexity and randomness emerge from a well defined structure. Yet, even though these emergent properties are intentional, they are by no means planned, only evoked.



- alternative view on Pollock as a generative system
input = looking; process = mind; outcome = gesture

The embedding of nature in the work of Jackson Pollock has been demonstrated by physicist Richard Taylor, who concluded that some of the Pollock paintings were highly fractal.[47] The myriad of painterly lines and spots in the drip paintings is thus of a complex geometrical character, similar to nature. This fractal aspect of the paintings is however radically different from for instance a Mandelbrot series, which is purely mathematical and a generalization of nature's fractal character. Pollock's fractalness is the complexity found in nature.[48]
The well-defined initial structure in the Pollock drip paintings is continuously layered over by increasingly more gestures. As the painting evolves, Pollock immerses deeper into the painting, gets closer to the physical canvas, and narrows his frame of interaction. This results in a free scattering of tiny marks intended towards a very specific location, on top of very sharp lines less intentional in location. Thus the manifestation of *randomness* in the paintings

moves from form (the lines) to scattering (the spots). The randomness of the marks is complicated by the merging of marks, diffusing the distinction between marks. The merging of marks depends largely on material properties and the degree the paint has dried on the canvas. Although reaction between materials can be anticipated, the ultimate outcome is uncertain. Pollock does not fully control the variables affecting the interactions of marks on the canvas; yet, their behavior does influence the further evolution of the painting.

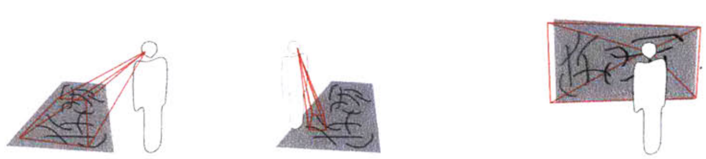
SEEING MATTERS

My ideal would be that you would see a piece differently every day.[49] *–Roxy Paine*

The all-over qualities to a Jackson Pollock painting that make it a Jackson Pollock painting are only part of the story. As Matthew Rohn argues, the microstructure of the painting is equally important. It is not at all simply about the painting, but also about the tiny details.

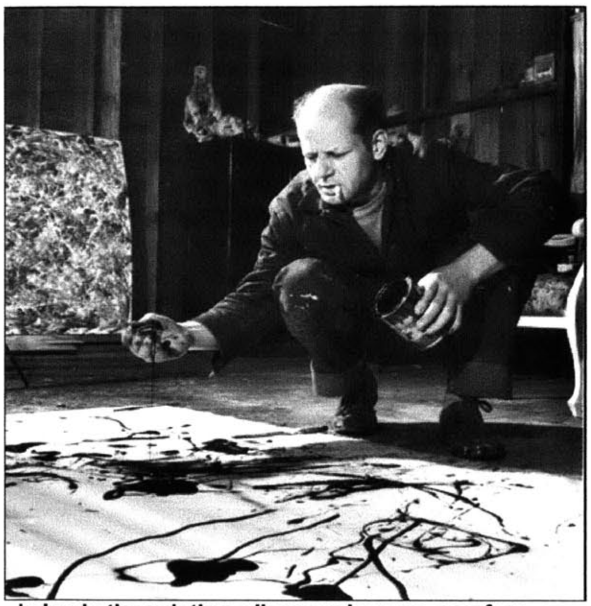
I don't work from drawings or color sketches. My painting is direct. I usually paint on the floor. I enjoy working on a large canvas. I feel more at home, more at ease in a big area. Having a canvas on the floor, I feel nearer, more a part of a painting. This way I can walk around it, work from all four sides and be in the painting, similar to the Indian sand painters of the West. [50] *– Jackson Pollock*

Even though Jackson Pollock is often referred to as *Jack the Dripper*, his decision to lay canvases flat on the ground can be considered as a way to limit or control the dripping of the paint.[51] Indeed, the paint sent towards the canvas becomes a mark instantaneously, which allowed Pollock to immediately assess his gesture. This instantaneous aspect turns the complex and dynamic mid-air form-finding into a nearly static process of becoming on the canvas.[52] Yet the process of interpreting – looking at – the mark is nevertheless dynamic.



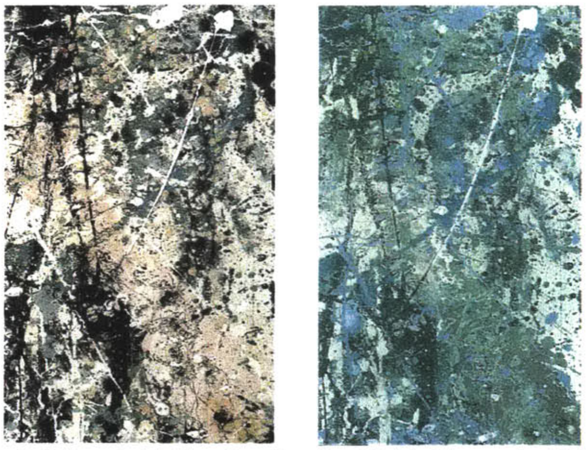
- a different relation to the canvas changes the perception of the marks on the canvas

At this point it is crucial to realize that indeed Jackson Pollock looked at his paintings from all different distances, yet it was impossible to assess the full canvas from a distance. The furthest Pollock could remove himself from the canvas while painting was standing up straight, looking down on the canvas. That said, it is somewhat of an illusion to assume Pollock never saw his paintings from afar when working on them. There are several indications that Pollock would return to paintings after having the painting stored in a vertical manner in his studio for some time. Assuming that Pollock would only see the entire canvas when hung from, or placed against a wall does imply that the microstructure, rather than indeed the all-over structure drives Pollock while painting.



- being in the painting a line may become a surface, a surface partly dried, and the canvas curvy rather than flat

Looking closely at how the splashes of paint interact, whether they form visually a single mark, or whether they repel each other thus becomes an important issue. It has been shown by James Coddington that Pollock was a master of visual deception. Marks in Lavender Mist that seem to have happened in sequence, appear to be completely different types of paint when studied under ultraviolet light.[53] Other tools of analysis show that indeed Pollock used many different types of paint and that each had a different behavior in forming gestures into marks.



- Detail, and detail under ultraviolet light of Lavender Mist #2 (1950), research by James Coddington

It is unlikely that Pollock could fully anticipate how the paint would hit the canvas and interact with the previous marks. The canvas is not homogeneous, some parts have been primed, some parts have dried. Some marks where made with highly liquid paint, others had sand embedded to give the paint more structure.

As there is an unpredictability to consider in the materials and in the interaction between materials that depends on both the material and the originating gesture, Pollock can only *control* the course of the painting by systematically making sense of the painting.

Rather than considering the distance to the canvas as determining how much of the painting one sees, it determines how what aspects of the painting one perceives. Being *in* the painting permits to look at the microstructure as a three-dimensional construct of individual marks; standing over or walking around the canvas allows the composition to be perceived as composite marks.

SHAPES ARE EVERYWHERE

Pollock himself saw no randomness in his paintings; he is quoted saying there is *no accident* in the making of the paintings. He agrees that there is no plan a priori beyond making a painting. Regardless of his claim, I consider his drip paintings to be prime examples of real-life computations, and will use these as an illustration of how randomness can be used as a generative principle in rule-based design.

The vehicle for thinking about Jackson Pollock as a computation, is shape grammars. A shape grammar is a computational formalism that manipulates shapes on an IF-THEN basis: IF shape A THEN shape B. All that happens in shape grammars is expressed through *rules*. A rule is a transformation '→' that replaces shape A by shape B. A → B [54]

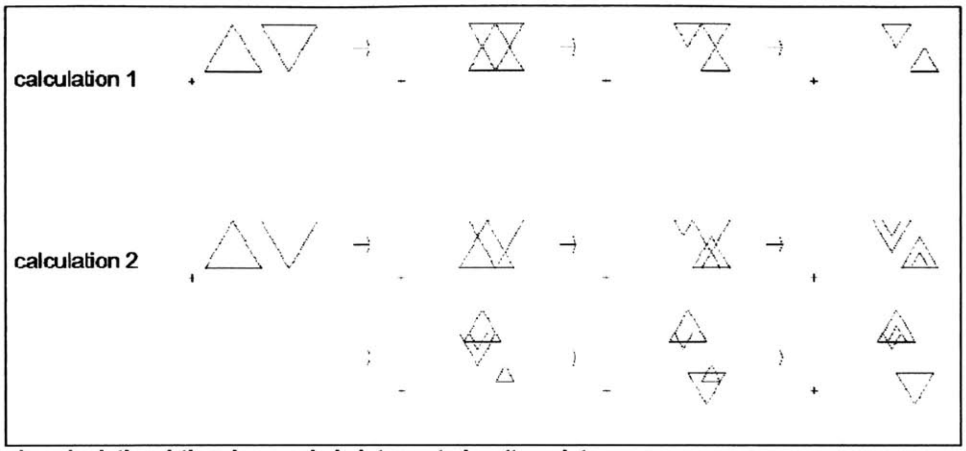
shape rule

- shape A is replaced by shape B

What the arrow in this rule indicates is that the square on the left side of the arrow (situation A) becomes the square on the right of the arrow (situation B). The input is a shape, the process a translation, and the result the same shape in another place.

As shape grammars are a visual enterprise, they allow for visual interpretation as well. Either one can assume that the spatial relation is exact, or one can interpret what the rule implies. The former uses tracing paper approach to embed a shape – find it – erase the original shape and replace by exactly tracing shape B. The other approach would be that the rule only implies that a shape A is translated up and to the right, without caring too much about the distance the rule might imply. If stretching this interpreting of rules even further, not a square, but a rectangle or even simply a shape is translated. Obviously it is up to the shape grammarist to make the rule as explicit as needed, but in essence, it is a visually ambiguous system.

The generosity of shape grammars lies in the fact that they are based primarily on what the user sees. What the viewer sees in the drawing is there. Thus it is irrelevant how anyone else thinks of the presented shape. Whether the A → B figure consists of two squares, of eight lines, or four angles does not change what happens visually. Obviously a computer can be instructed to think of a shape in multiple ways, however the point is that to a designer the definition of the shape is dynamic. Any shape is only defined after the shape was created. It is hard to predict that by moving one of two triangles four triangles appear, or even nine. A designer is not restricted by the definition of a shape, but can easily discard that earlier definition and continue with that same shape as an entirely different thing because it is still visually the same shape, it is only treated differently. It is this flexibility of defining what we see in shape grammars that make it a valid language for analyzing the work of Jackson Pollock. At the same time Pollock's method of looking at the painting to see what the mark has become makes him a valid subject to study in terms of shape grammars.



- in calculation 1 the shape rule is interpreted as 'translate triangle over a distance equal to its side to the right'. In calculation 2 the rule is interpreted as 'translate a triangle to the right'

A DRIP GRAMMAR

Even in its visual complexity, a Jackson Pollock painting can be considered the result of a limited set of rules. There may not be two identical marks in the entire oeuvre of Pollock paintings, yet there is a finite set of gestures that form the core of how Pollock approached painting his large scale projects between 1947 and 1950, with a focus on *Alchemy*, *Autumn Rhythm*, and *Number 27, 1950.*[55]

Although most art historians make a distinction between the paintings before and after he started dripping – asserting that this constitutes a period of time – one can also distinguish two radically different approaches across Pollock's career based upon the relation between looking at the painting and reacting to that looking. The common strategy would be to think of painting – or designing in general – as a sequence of actions and evaluations: a mark is made on the canvas – whether dripped or not – and then that action is looked at. This approach can be found in Pollock's conventional paintings such as *Stenographic Figure*, and *Blue (Moby Dick)*, but also in drip paintings such as *Alchemy*. The other approach would be the continuous painting, where action and looking happen simultaneously. This is evident in *Number 23, 1948*.

- Blue (Moby Dick), 1943

- Alchemy, 1947

- Number 23, 1948

In the context of generative systems, the focus will be on the sequential work that has a clear distinction between input, process, and outcome. Even though it is intriguing to think of digital design as a continuous system of actions and evaluations, as a dialogue of two superimposed voices, for the sake of clarity of the argument the shape grammar developed here focuses primarily on the paintings that are constructed in turns.

- the overlooked image, Pollock looks at his work

The intention for making the shape grammar was on the one hand to argue that simple rules are capable of creating complexity, and that designing with intentions rather than expectations is a viable strategy.

The knowledge for designing this shape grammar is based on two separate sources. On the one hand an analysis of finished paintings, on the other hand an analysis of the 1951 film by Hans Namuth that shows Jackson Pollock working on a painting. Frame outtakes from the film have been published in a wide variety of articles on Pollock; many of these frames focus on the painter, rather than the painting. However, in 1998 Pepe Karmel published the findings of his close readings of the Namuth film. For that research he collaged film frames together to build composite images of the paintings Pollock was working on at that time.

These images, and the findings of Karmel, are an invaluable resource to get a grasp of how Pollock actually treated the blank canvas.

In studying the published photographs and film fragments of Pollock in action, it has become clear how influential the Namuth photographs have been on how art history has come to view Jackson Pollock. Harold Rosenberg, for example, wrote the 1952 essay *Action Painting* only after seeing some of Namuth's photographs. Also, there are few published images that show Pollock looking at his work. Most of the images reprinted show Pollock in full action in his arena of paint and canvas. This seems to indicate that indeed most attention is spent on Pollock's actions, where this grammar posits that the looking part is every bit as important.

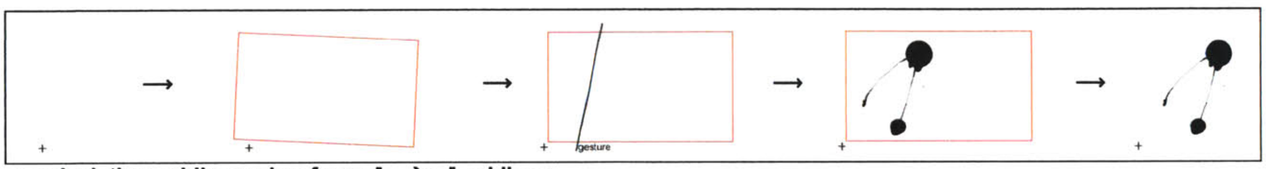
The rules and schemas presented here are based upon a narrow selection of Pollock's work. Yet at the same time, the schemas are general enough to suggest how other paintings by Pollock could be constructed.

In essence, Jackson Pollock's method of painting can be captured by four schemas. Quite obviously, these four schemas allow for much more than what Pollock did. The schemas are therefore the backbone to what constitutes the Pollock method, and are complemented by assignments and clarifications that define more clearly what, at specific times, was going on. The assignments and clarifications limit the generative power of the schemas according to the findings in the limited, yet telling sources. This shape grammar does not attempt to cover all – nor only –Pollock marks, gestures, or figures. Rather, it is geared at making a statement how, using a limited set of rules can result in the visual complexity of a Pollock painting, and what the implications are of working in an uncertain medium, and exploiting that unpredictability.

- schema 1 $y \rightarrow y + x$
- schema 2 $x \rightarrow t(x) + s$
- schema 3 $y \rightarrow y$
- schema 4 $x \rightarrow$

- y is the collection of marks within the view frame x, within x something s is added, a view frame is erased

Schema 1 [**y → y + x**] describes how Pollock chooses the area **y** (a collection of paint marks on the canvas) he will work on next, placing a view frame **x**. At this point it remains undetermined what drives that choice, later specific instances will illustrate some of the selection criteria. Schema 2 [**x → t(x) + s**] indicates adding something **s** to a transformed view frame **x**. Although Pollock's paintings are referred to as *drip paintings* they also include marks directly applied to the canvas. Therefore a distinction is made in the grammar between gestures **g** and figures **f**, generalized in schema 2 as **s**. Schema 3 [**y → y**] evaluates the effect of schema 2 on the collection of marks **y**. In the case of adding a figure **f** this evaluation or looking is somewhat redundant because of the direct relation between action and outcome. Yet the real power of Pollock lies in his embracing of the physical world as an unpredictable generative system when adding gestures **g** to his view frame **x**. The uncertainty inherent to any gesture is thus balanced by schema 3, which evaluates the outcome of the gestural intention. Schema 4 removes the view frame, and leaves Pollock with the choice whether or how to continue the painting.



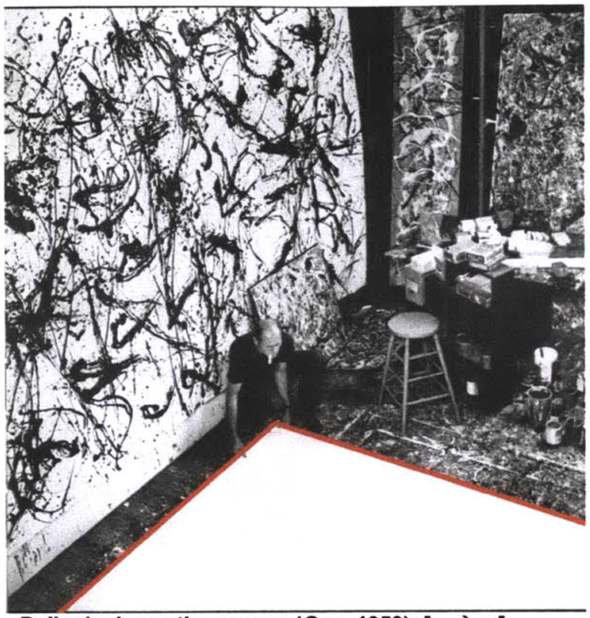
- a calculation, adding a view frame [→ x], adding a gesture to that view frame [x → x + g], looking at the mark [y → y], removing the view frame [x →]

In principle, Pollock goes through the four schemas in the given sequence over and over again. Each sequence would then add a view frame to the canvas, place a gesture or figure, evaluate its outcome and remove the view frame.

Where this shape grammar radically differs from many other shape grammars is that it only deals with the artist's interaction with the painting. The grammar does not tell in any way how a gesture finds its form on the canvas. It only emphasizes the necessity to make sense of the entire painting by including the identity transformation as a schema after making a gesture. The grammar essentially represents the action of the painter, rather than the form finding of that action. Whereas every rule in a shape grammar embodies an action, in this grammar the action is the grammar. By not engaging in the matter of the gesture form finding the essentially two part nature of Pollock's method is emphasized: there are actions (gestures) towards the canvas, and there is a return from the canvas (looking at the marks on the canvas).

Analyzing, or reconstructing a particular painting would result in specifying each of the elements in the schemas and a record-keeping of the sequence of schema applications.

A first clarification of the schemas involves including the placement of the initial view frame. Schema 1 allows the assumption that there is no collection of marks yet [**y = 0**]. This results explicitly in [→ **x**].

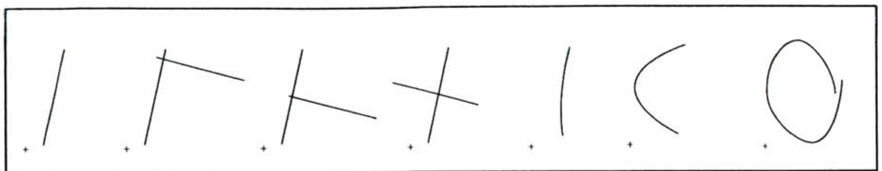


- Pollock places the canvas (*One*, 1950): [→ x]

The second clarification distinguishes between gestures **g** and figures **f**. Figures are marks that are representational (humanoid shapes), calligraphic (numbers), or applied directly onto the canvas with a brush (strokes). Pollock's catalogue of figures includes anthropomorphic shapes, hand prints, cigarette butts, numbers, asterisks, and a she-wolf. Important to figures is that they act independently from each other and the past marks. In a sense, they are applied simultaneously, in parallel.

The gestures in Pollock's paintings are ambiguous. Often a mark is read or perceived as the result of a single gesture, though the research of both James Coddington[56] and Pepe Karmel[57] indicates that Pollock often creates this illusion by superimposing mark upon mark, or by connecting independent gestures. From a formal point of view there seem to be two main categories of gestures: straight or curved. By recursively adding gestures Pollock creates local spatial relations.

By elaborating straight line on top of straight line, allows forming planes as the liquid paint starts to blend. In a sense, one can think of these superimposed lines as identical gestures, that each have closely related yet differing outcomes. By altering the straight gesture, he builds a vocabulary of V-, T-, and X-shape marks. Altering a single curved gesture gives a range from (-shape over C-shaped to O-shaped. Obviously both types of gestures can be combined, but hardly ever does the composite mark seem to be composed out of more than two composite – multiple gestures – elements.



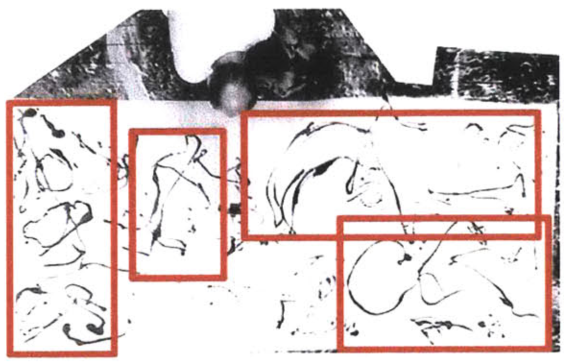
- spatial relations of a straight gesture, evolution of a curved gesture

As a rule governing the relation between gestures and figures, it seems important to Pollock that all pictorial acts are to be veiled by abstract gestures. Karmel's extensive analysis of the black and white film by Hans Namuth shows clearly that at least painting *Number 27, 1950* contains figures as fields of departure.

In the following images – composites of the 1950 Namuth film frames – red rectangles have been added to indicate what part Pollock was looking at. In terms of the shape grammar this is considered to be the view frame x, or t(x).

- film frame shows Pollock adding a humanoid figure to the blank canvas: [x → x + f]

- film frame shows an independent (dripped) figure developing next to humanoid figure: [x → x + f]



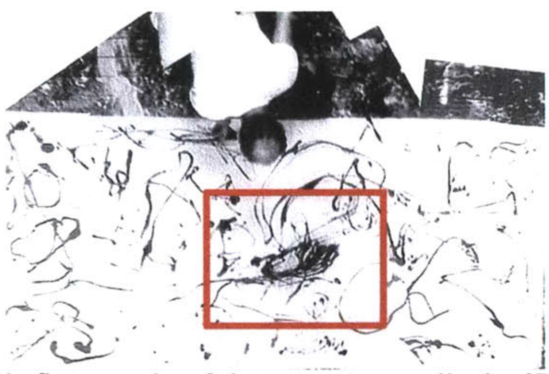
- composite of film frames shows the first campaign of *Number 27, 1950*. The humanoid figure is visible in the lower right corner. [x → Σ (t(x) + f]

In *Number 27, 1950* Pollock started off by drawing independent figures on the canvas. Karmel recognizes in this early stage several humanoid figures, and a female dog/wolf, in *self-contained configurations.*[58] Yet there is little to no interaction between the various view frames. This is why, rather than thinking of this calculation as a sequence of transforming the view frame and adding a figure [**x → t(x) + f)**], the grammar incorporates these parallel developments as [**x → Σ (t(x) + f)**]. After the first layer of figures is placed, to Pollock's satisfaction [**y → y**], this campaign is ended, by completely removing the view frame [**x →**] Summarizing the calculation for *Number 27, 1950* so far:

- schema 1 : $\rightarrow x$
- schema 2 : $x \rightarrow \Sigma(t(x)+f)$
- schema 3 : $y \rightarrow y$
- schema 4 : $x \rightarrow$

- a view frame is placed, transformed into Σ view frames + Σ figures, the view frames were removed

The first campaign of abstract gestures – curve shaped – connects two of the independent figural elements in the painting, placing a view frame in the surrounding the interstitial space. **[y → y + x]** This first bridging mark is actually composed of several *identical* gestures. Schema wise this implies the recursive application of **[x → x + g]**, applying the same gesture to the same view frame over and over again. The gesture in this specific case would be a gentle curve. However, applying the same gesture over and over again in that same location has now generated a new form that is more surface-like than line-like, yet it has not lost its line-likeness.



- the first campaign of abstract gestures on *Number 27, 1950* is begun, bridging independent figural elements. Schemas applied: [y → y + x] ; [x → x + g]

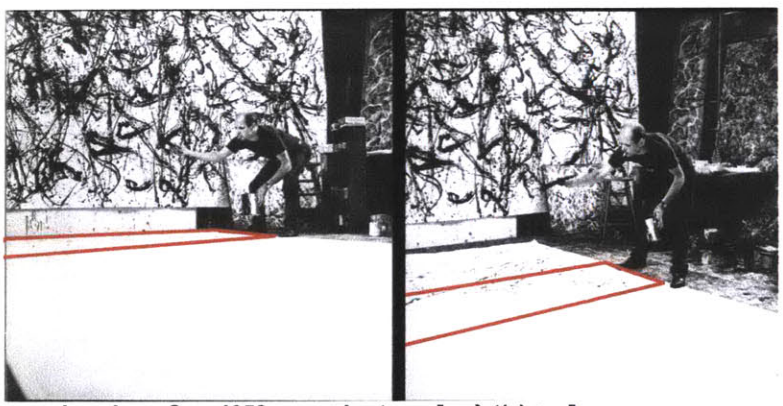
The grammar does not explain what exactly defines the eventual form of a gesture. The grammar does not go into details how Pollock achieves his repertoire of extremely thin lines, splotches, circular drips, spots. That *calculation of randomness* is left to the physical environment, yet present in every mark that is not applied directly to the canvas by a brush.

At the same time the grammar does suggest how Pollock constructs visual randomness by overlaying unrelated patterns through an automatism of mark and view frame propagation (this requires a recursive application of **x → t(x) + g** without evaluating the outcome).

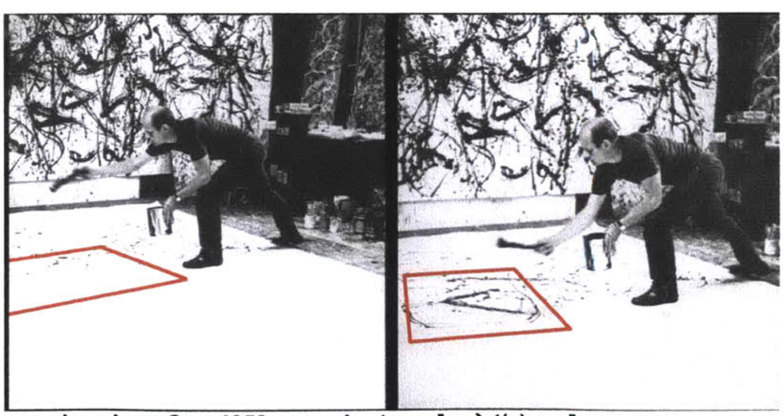
- schema 1 :
- schema 2 : $x \rightarrow t(x) + g$
- schema 3 :
- schema 4 :

- recursive application of schema 2 results in an arbitrary view frame propagation

What prevents Pollock from getting too involved with the microstructure and material unpredictability in his paintings is the use of an automatism that generates rhythmic marks. Adding gestures to the canvas without looking immediately at their outcome, allows Pollock to quickly create an entire field of unanticipated mark interactions on the micro scale, while still maintaining an all-over impression. In the automatism lies a second layer of randomness that gives the paintings bursts of energy, even though they may be followed by a close and controlled looking after that campaign is finished.

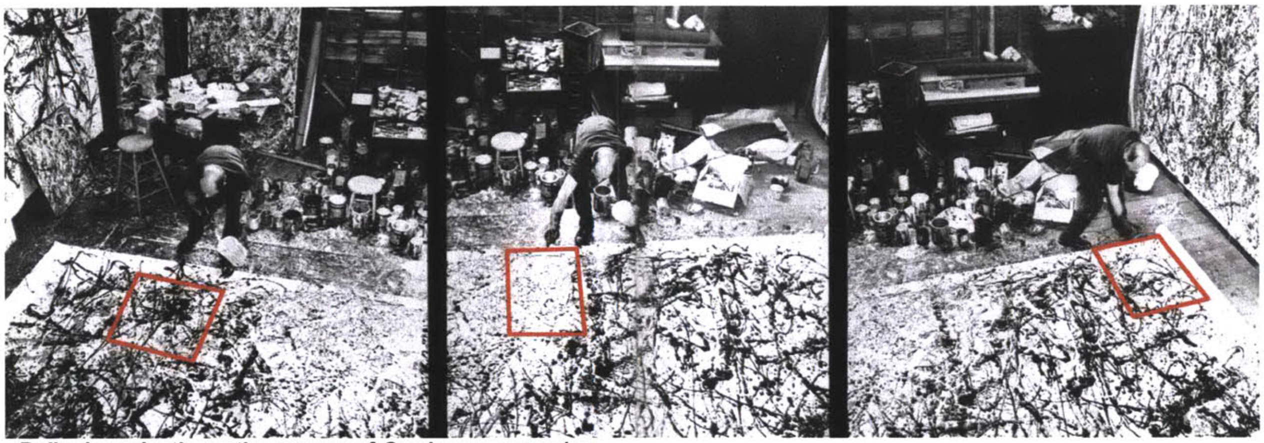


- moving along *One*, 1950, an early stage: [x → t(x) + g]



- moving along *One*, 1950, an early stage: [x → t(x) + g]

The photographs of Pollock laying the first layer of *One* show clearly how he moves along the canvas. [**$x \rightarrow t(x) + g$**] Stepping into the canvas reduces the size of the view frame temporarily. While standing next to the canvas Pollock has little control over the paint, resulting in marks that have a high degree of randomness. However, as soon as Pollock moves – literally – into the canvas, he also moves closer to the canvas – the distance between brush/stick to canvas has been reduced to half – which indicates a higher degree of control over the mark. This level of control is reflected in the shape grammar as the size of the view frame, and the speed of the view frame transformation.



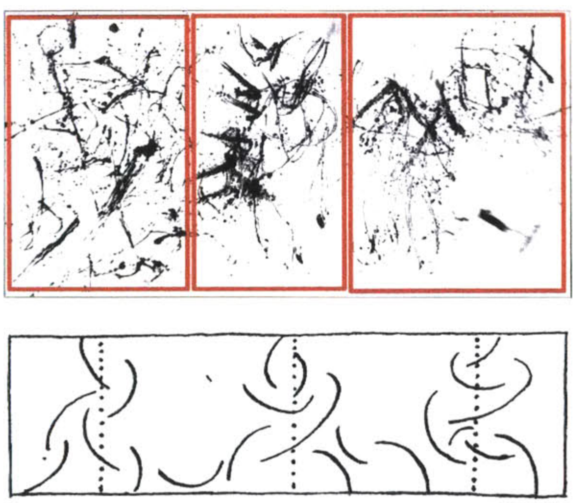
- Pollock works the entire canvas of *One* in one campaign.
[recursively ($x \rightarrow t(x) + g$]

In the above series of photographs Pollock moves along the entire canvas adding large gestures in a late stage of the painting. These finalizing large marks – often in aluminum paint – seem to have to unite the painting. Whereas this specific painting started off as a series of large – somewhat – lateral marks, Pollock finishes this painting on that same level. This presents us thus with a layer of marks that is highly visible, but may be independent from the structure underneath.

Studying Karmel's photograph composites illustrates the close relation of *Autumn Rhythm* early structure to the compositional diagrams by Thomas Benton, regardless whether the initial marks are figural or gestural. Again, in the middle frame one can clearly recognize a standing humanoid figure.

- ***Autumn Rhythm (Number 30)*, 1950, as it can be seen in The Metropolitan Museum of Art**

The intermediate stage of Autumn Rhythm shows three independent fields of marks. When analyzing the final painting however, this structure has been veiled in favor of an all-over impression, although some of these initial marks can still be retrieved from the final painting.



- **a parallel structure, visible in *Autumn Rhythm*, diagram by Thomas Benton. [$x \rightarrow \Sigma\ (t(x) + f)$]**

The composite image of *Autumn Rhythm* also shows that indeed Pollock created a series of marks, not based upon his movement along the canvas, but along an absent pole. Each of the V-marks can be considered to be constructed from multiple gestures, a recursive application of [$\mathbf{x \rightarrow x + g}$] and [$\mathbf{y \rightarrow y}$]. The view frame is then moved, without changing its size, and the next gesture added to the new view frame: [**x → t(x) + g**]. At that point the earlier recursion of making a composite mark is applied.

Judging from Karmel's composite image, this routine is repeated at least five times in this part of the painting.

- view frame location in *Autumn Rhythm*, [y → y + x], and adding a V-shaped mark without changing the view frame, by recursively applying [x → x + g]

- view frame location in *Autumn Rhythm*, [x → t(x) + g]; and adding a V-shaped mark without changing the view frame, by recursively applying [x → x + g]

- view frame location in *Autumn Rhythm*, [x → t(x) + g]; and adding a V-shaped mark without changing the view frame, by recursively applying [x → x + g]

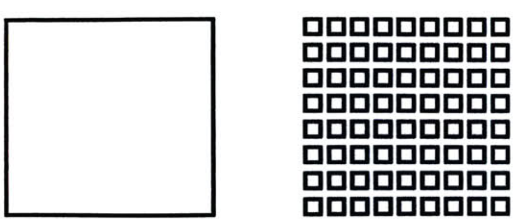
- recursive application of [$x \rightarrow t(x) + g$] + [$x \rightarrow x + g$]

A close analysis of any of the drip paintings will show marks that are indeed produced by a rhythmic automatism, that are part of a limited catalog of marks. Yet the most important part – and Pollock differs greatly from other artists discussed – is the scattering of the calculation throughout the making of the painting.

– schema 1 : $y \rightarrow y + x \; ; \quad \rightarrow x$
– schema 2 : $x \rightarrow x + g \; ; \; x \rightarrow t(x) + g \; ; \; x \rightarrow \Sigma\,(t\,(x)+f)$
– schema 3 : $y \rightarrow y$
– schema 4 : $x \rightarrow$

- 4 schemas, now distinguishing between adding a gesture or a figure

The smallest part in the suggested schemas explaining a Pollock painting is a gesture, followed by looking at the actual form of the mark on the canvas. This approach to art – or design – is radically different from the Roxy Paine and Sol LeWitt approach. Each of these artists/designers differs from Pollock in their own respect, yet the difference relevant to randomness is the relation between intention, outcome, and response.

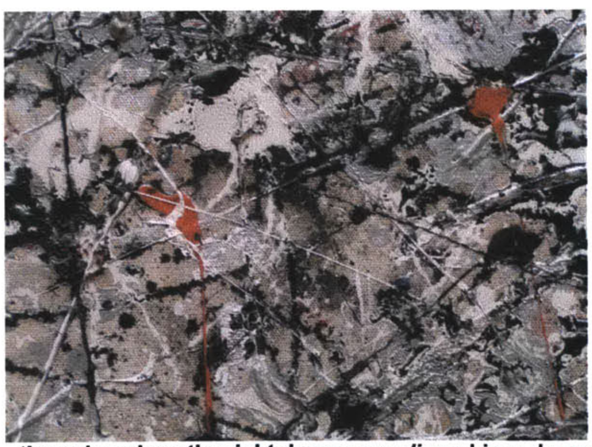


single iteration **indefinite iterations**

- left, design as a massive computation
- right, design as a scattered computaton

In the case of Sol LeWitt the instructions to a wall drawing (the intentions) are issued to a set of draftspeople (the process). In the earlier wall drawings these could be *random* people, in the later ones his studio assistants. The evaluation of the outcome by LeWitt has caused the artist to return to a studio model of art production because his personal assistants are capable of executing more vague or incomplete instructions while still achieving LeWitt's expected outcome. Yet within the production of a single wall drawing there is no or little dialogue that changes the course of the project. It is a purely sequential process without dialogue: LeWitt does not revise his instructions because of the production process of a draftsperson. The SCUMAK and PMU are similar in this respect, after sending the commands to the production unit Paine has no more influence, and is not influenced either. One point of difference would be that Paine exhibits all sculptures as they are being made, and without final alterations. LeWitt on the other hand does not exhibit this process of making, and sometimes makes final changes – in the form of instructions, obviously – to his wall drawings.

In neither of these models the randomness of the process affects the designers, primarily because the randomness is contained in the production process, which is disconnected from the conception of the idea.



- the red mark on the right drapes over *lines*. Lines drape over the red mark on the left. Detail of *Number 1, 1948*

In the case of Pollock's drip paintings, each action however is affected by what the marks on the canvas end up looking like. This presents a computation that has indefinitely many points in the production process that may affect the course of the project as a whole. Therefore, it cannot be emphasized enough that the [**y** → **y**] rule is actually the one that separates Pollock from the current computational approach. Pollock assesses the evolution of the computation tiny step by tiny step, nevertheless allowing the generative system to have a huge impact on his intentions.

Each mark or gesture is influenced by a number of variables either controlled or affected by Pollock such as the liquidity of painting, the presence of sand in paint dried paint on stick. Yet an equally complex web of interrelated variables is present on the canvas. Each mark has a past of its own that determines its behavior when hit by a new gesture. This past will determine whether the new mark is superimposed, whether it blends, whether it repels.

The behavior of these individual collisions is too complex to predict. At the same time it is the eliciting of specific material behavior that characterizes Pollock. The subtle play of lines and surfaces that drape over each other are the drivers for Pollock's paintings.

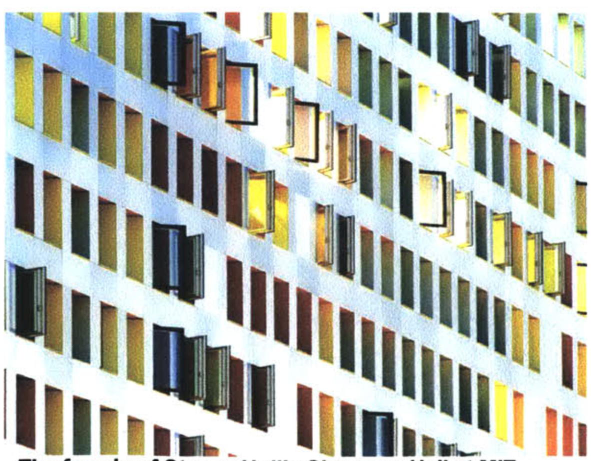
- Jackson Pollock looks at the result of his gestures on the canvas [y → y]

INTENTIONAL/PERCEPTUAL

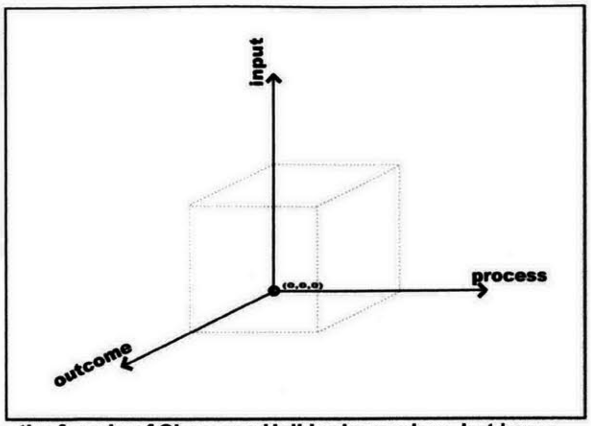
There are numerous examples in architecture that showcase randomness as a final result. Through a conscious design process a random – or visually random – pattern is attained for the sake of visual pleasure. In these projects randomness is a goal, rather than a generative process.

- Federation Square, Melbourne, Australia, by LAB architecture studio

In the Federation Square project by LAB architecture studio a geometrical construct – a pinwheel grid – allows the architects to generate a seemingly random pattern. Yet the pattern only seems to be random, as the two designers claim each had a signature style of randomness, marking the effect of *not knowing* on the part of the visitor on the perception of randomness. Yet it is quite possible that studying the different patterns that at first seem to be equally random results in recognizing indeed two different hands to them.



- The facade of Steven Holl's Simmons Hall at MIT



- the façade of Simmons Hall looks random, but has a direct relation to the structural logic of the building

In Steven Holl's Simmons Hall project, a structural drawing led to a color coded façade indicating reinforcement of the façade. Yet to a visitor the pattern simply looks random. Whereas the Federation Square project intended a *personal* random pattern, the coloring of the window framing in Simmons Hall precludes the architect making choices for the entire façade. Rather than coming up with rules that could produce an interesting field of colors, this is a single rule that determines the entire façade, but does not seem to stem from a single rule.
However, both projects employ randomness as a pattern – LAB architecture studio consciously aimed for a random pattern, Steven Holl did not mind the rational pattern being perceived as being irrational – and not as a contribution to the creative process of designing these façades.

LOOKING AT AN UNCONSCIOUS LINE

Coop Himmelblau is known for the use of the unconscious in architecture as a way to shun common solutions to a design situation. As a way of getting the design started, Wolf Prix and Helmut Swiczinsky would think of the initial drawings as psychograms: quick drawings they would build.
Regardless of what Coop Himmelblau jots onto the page from the unconscious, one could say that they thus liberate themselves from the horror of the blank page. Yet, as in Hans/Jean Arp's work, this only constitutes the start of the design, providing 'external' stimuli the architect needs to pick up. But exactly as Arp's *Collage with squares arranged according to the laws of chance*, all pieces had been put into place, only to be rearranged lightly.

- Coop Himmelb(l)au, rooftop renovation in Vienna

Where Arp is clear about using chance as an instrument that enables him not to start off from the blank page, Himmelblau is equally clear that the psychogram needs to be read. It needs an interpretation.

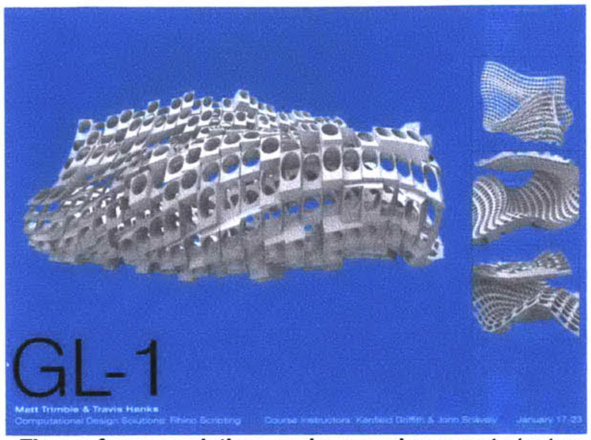
Coop Himmelblau would not define these psychograms being random – whether they are, is irrelevant – what does matter is their status in the design process. The drawings are created in an unconscious manner, independent from clear reasoning. The designers do not really know what generates these drawings, nor do they care. After the drawings are made, the designer then determines how that image will be built. In other words, after the facts, the designer determines what line represents structure, what becomes glass, what becomes shading.

AN EXPERIMENT OF WHATEVER

Many designers (both students and professionals) are preoccupied nowadays with the creation of fluid, continuous shapes. Yet where Marcos Novak was still looking for continuity in his Liquid Architecture fantasy[59], many design experiments have now ventured into the assumption of a continuous shape while looking for ways to populate the surface.[60]

During the final review of a crash course of programming for designers Matt Trimble and Travis Hanks presented a formal experiment of shape population that illustrates the Arp approach to computational design.

The students had created several fluid – somewhat random[61] – surfaces to be experimented on with shape population. The original surface shape had to be somewhat random, to their opinion, to prove that their script could indeed work for any surface. However, a shape was created that would fill the rectilinear grid on the surface. Yet at that point they felt they got stuck. What relations would they introduce between neighboring shapes? All they knew was that the surface was not to be *boring*. So they coded each object to be of a *random* height within a certain range. Assigning random values to the height of the primitive – an oblong with a circular hole – assured the emergence of combinations not thought of before.



- The surface population employs randomness to 'get an idea of what relations to continue with'

RANDOM FORM GENERATOR

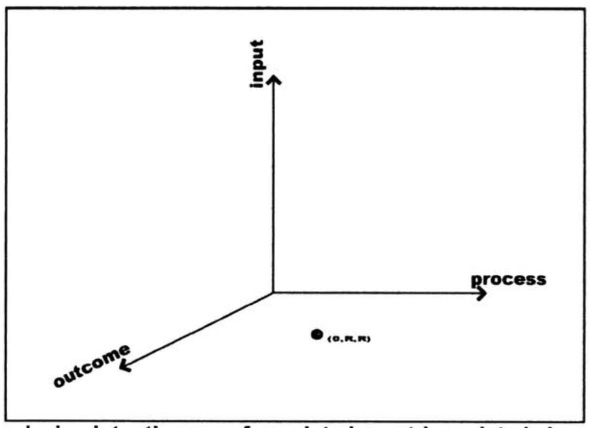
However, when transformations are applied iteratively in random order and at random locations in the design, the grammar defines an infinite language of structural shapes for single-layer space trusses.[62] *–Kristina Shea*

Kristina Shea uses randomness as a solid part of the generative process. She is interested, literally, in using randomness as a generative principle within the framework of a shape grammar to break open common notions of form and structure.

Shea starts from the notion that geodesic domes (popularized by Buckminster Fuller) can be represented in a simple shape grammar by assigning the right geometric constraints to the grammar. The constraints thus reduce the generative power of the general grammar to a specific range of forms: geodesic domes.

According to Shea the use of randomness in the grammar is directly connected to her intention to create a non-deterministic system. Even though the algorithm is geared towards the creation of structurally sound compositions, she feels strongly that *weaker designs* should nevertheless be explored. In terms of design exploration, a *weak design* is as interesting as any other.

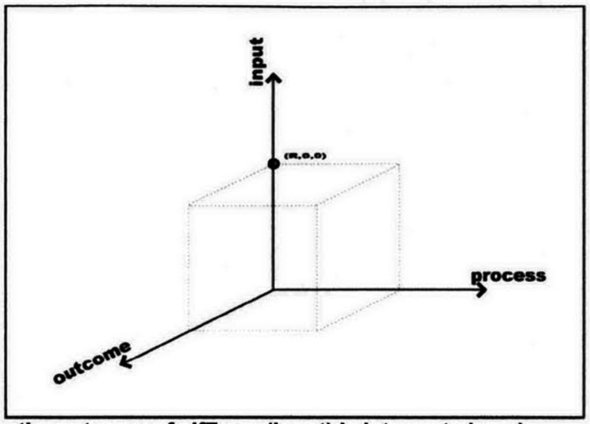
Shea's program, eifForm, starts from an initial surface triangulation with edge constraints, and then proceeds by calculating the structural performance of the entire structure when replacing a random element by random alternatives. The *best* random alternative then replaces the original element. This replacement of elements – lines in a triangulated three dimensional surface – is then repeated until the designer feels a satisfactory result has been reached. This point of satisfaction can obviously be expressed as a mathematical goal (maximum weight of the entire structure, minimum surface area, uniformity of the structural members), or simply left to the visual, aesthetic pleasure of the designer.



- design intentions are formulated as a triangulated shape (input), eifForm then transforms random elements (process) into a random form (outcome)

Rather than being a manipulator of geometry, the designer in the computational process has to interpret the geometrical outcome as a whole to determine whether the program has the design evolve in a wanted direction. The interpretation of these forms – assign meaning to the overall shape – then leads to the questioning and revising of the basic design intentions. These revisions take the form of geometry manipulations – outside the algorithm – and use the revised form as input to eifForm.

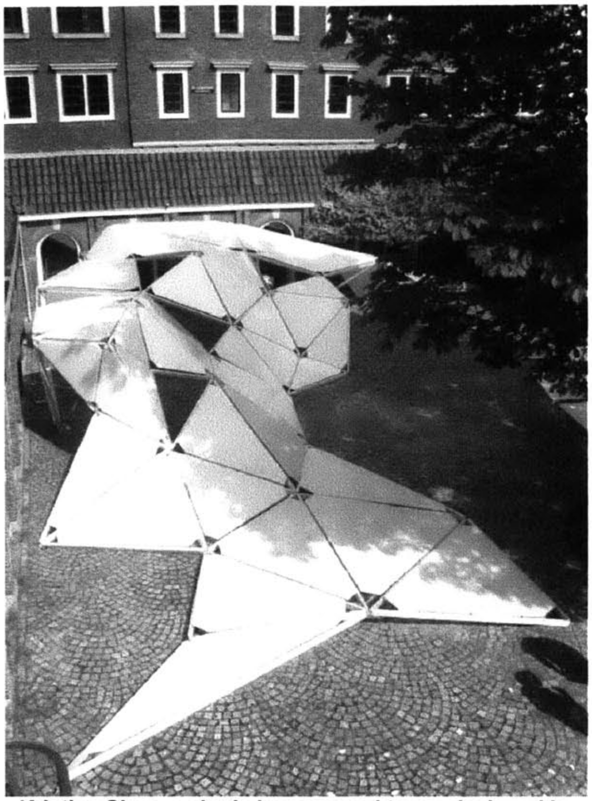
Every time eifForm calculates a form, the shape intentions can be revised by the designer – the designer can change, add, or remove constraints. Hence, the eifForm program presents a design process that has as many designer-system interactions as the designer feels necessary: at any given point the eifForm application can be halted or frozen, which allows the designer to lock or unlock part of the form from the further design evolution. Yet eifForm itself cannot affect the constraints or limitations. There are no rules that allow eifForm to randomly change constraints as it can change structural members.



- the outcome of eifForm (input) is interpreted, and modifications are made (process), this altered form (outcome) then becomes the input to eifForn.

In one way this computational model closely resembles how Pollock approaches painting: the point of departure can be independent from the outcome and there is an indefinite number of designer-system interactions that allow the change of design intentions based upon what is presented to the designer at that moment. At the same time, however, the application works in a single interpretation realm of the design. The entire form is always transformed as construct of lines, not engaging in the potential interpretation of the shape as a construct of planes. Shea also concludes that to enhance the creative potential of eifForm, it should handle shape ambiguities.[63]

The eccentric shape created with eifForm illustrates that randomness as a generative principle closely coupled with designer interpretative actions can lead to unanticipated design solutions that make full use of the computational power at hand.


- Kristina Shea, a single layer spacel truss, designed by using a shape grammar based approach injected with randomness

REDUCTIVE DESIGN

The quest for systems generating designs stems from architecture's struggle to come to terms with the subjectivity inherent to the act of designing. Where modernism attempted to create a house as machine, contemporary practice has set its mind on creating a logic machine that designs. Generating form from mathematical formulae gives the design process a scientific twist that allows the design to present itself as the outcome to a rigorous and objective process.

Greg Lynn's approach to design in the Port Authority project can be compared, to some extent, to that of the Roxy Paine PMU or SCUMAK. The likenesses are remarkable, if one disregards for a moment the difference in scale of both projects. Both Paine and Lynn set up a system that defines the rules of the game, which is a personal piece of software for Paine, and simple physics equations within existing software for Lynn; both come up with a series of actions – setting time intervals of spraying and drying polyethylene in the case of Paine, and determining the initial velocity and direction of the bouncing particles in the case of Lynn. Yet, Paine has the luxury of ending in a divergent state, allowing multiple versions to co-exist, whereas Lynn needs to favor one single solution. Even though Lynn claims his architecture is based on a theory[64] of complexity – irreducible and multiple – that denounces simplicity, his actual design strategy is one of simplexity, simplicity disguised as complexity. The sculptural forms created by Greg Lynn Form reveal little of their generative design principles – which are of an incredibly simplistic nature: warping form-determining balls[65] into virtually stripped space. The velocity, speed, direction, and initial position determine univocally the course of the particles. Lynn's so-called complexity resides in the manipulation of the entries to the system in order to get to the intended solution. Thus the system – this is where the Lynn approach differs from Paine – is not used to generate form, but rather to validate it in a so-called objective manner.

The system of ballistics takes into account friction, motion, and gravity. Yet the entire system is based upon linear laws of physics, taking ideal materials for granted. This idealization of the environment prevents any surprise – from the uncertainty of *real* materials – to sneak into the system. Only the initial conditions were susceptible to change in the design process: tweak that force field, elevate that starting point, and hit the start button again. These values determine rather than generate the form. The *so-called generative* system, in a sense, does not generate the form at all: the initial values *are* the form. Possible imperfections in materials are excluded by mathematically precise calculations. The messiness inherent to the real world is thus traded for a mathematical simulation of an ideal world.

Another problematic aspect of Greg Lynn's system is its single concept approach – bouncing balls deliver the form – to architecture. Even though at this point incredibly complex, life-like systems can be created, in order to allow the designer to manipulate this virtual world it is reductive rather than expansive. Right at the start – when a 'generative' system is created – the designer needs to determine where and how that system can act on the design intentions. Right at the beginning the designer specifies what part of the physical world his virtual world will deal with. This decision of machine-design interaction is left to chance in the Roxy Paine and Jackson Pollock approaches. Neither Pollock nor Paine has full control over the environment's impact on their intentions. Context correlates their intentions to the outcome. Pollock's drips are affected by a sudden breeze through the barn. The drying cycles in Paine's sculptures depend on room temperature fluctuations. Only in a fuzzy way they know what may come out. Compared to the open-ended nature found in the early LeWitt wall drawings, in the PMU and SCUMAK, and the all-over drip paintings by Pollock, the impenetrable and definite nature of the Port Authority Gateway 'generative' system seems a retreat from design as an exploratory act.

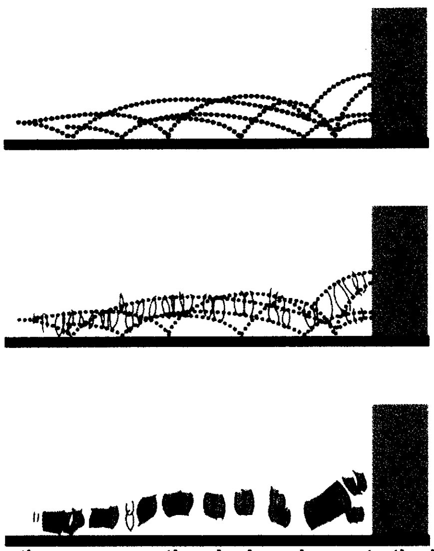
RANDOMNESS AS A GENERATIVE PRINCIPLE

The New York Port Authority Bus Terminal competition entry by Greg Lynn dates back from 1996. Various forces of movement and flow on the site were considered as shaping architecture. Time has passed, and designers have adopted new design techniques that take full advantage of the increased computational power.

Yet being preoccupied with technologies and techniques that facilitate designing complex shapes and curves has not presented us with more intuitive design strategies at all. If anything, the process to create these voluptuous shapes has become hyperconscious in nature on the one hand and less ambiguous on the other. Both may seem to imply a progress since the advent of computers. However, when hyperconscious means that one needs to be hyperconscious of the built-in limitations and methods of the design environment, this is actually a step back from ink on paper. When less ambiguous implies that the design environment does not tolerate ambiguity either, one needs to worry about bringing the actual design process into that design environment.

Both aspects are present in the Port Authority project. The project has a three part hierarchy: there is a primary structure of tubular beams, a secondary of tubular frames connecting the beams, and a tertiary tensile structure stretching between the frames.[66]

The form determining technique was to create force fields that would affect the particles launched from within the bus terminal. The particles have elasticity and density, in a gravitational environment. Thus, the initial location, direction, and speed of launching these particles determine directly the outcome of this computational process. Even though the animation sequence presented in *Animate Form* shows the particles bouncing through their modeled world at the same time[67], the particles are isolated from each other. They are launched simultaneously and avoid literally bouncing into each other. At the same time the balls pretend to be physical, by purporting they have density and elasticity, yet they follow perfectly predictable paths. I encourage everybody to try to predict the path of a physical bouncing ball, even under hypercontrolled conditions, let alone launching several bouncing balls at the same time.



- three consecutive design phases to the Port Authority project, in the Lynn approach

In the Pollock approach to the Port Authority project one would first of all use particles that have actual material properties, which results in complex behavior only be partially understood or predictable. At the same time, none of the particles launched would be identical. The paths of a particle launched twice from the same location under seemingly identical conditions would not be identical. Each path would be predictable to a certain extent; just as Pollock could predict the shape of a drip of paint he had no full control over the microstructure of the paint.

Instead of iteratively defining the right combination of particle paths, one could imagine launching a particle quasi randomly into virtual space and simply proceed from that path on. [→ **g**] Launching the next particle [**y** → **y** + **g**] would then result in a collision of sorts between the existing path **y** and the bouncing particle – result of a gesture in Pollock's approach – affecting the final path of the particle. Because of the full spectrum of material properties both the path and the particle have, this interaction is quite unpredictable, and requires the designer to look at the outcome. [**y → y**]

Whereas the Lynn approach to computational design was strictly top-down – from determining the primary structure, to bridging primary elements with a secondary structure, to filling in the secondary elements – Pollock approached his paintings in a rather rhizomic manner where every design decision is related to a range of other actions without definite hierarchy.

This rhizomic design thinking leads us to apply structures locally or globally according to perceived opportunities, rather than according a pre-determined plan. [**y → y + x]** Yet in the Pollock approach, there do exist campaigns that keep the process from becoming a sequence of singular events. Repeat [**x → t(x) + g]**.

Applying [**x → t(x) + g**] recursively in an automated manner – by skipping [**y → y**] – results in novel and unanticipated situations, as indicated by Kristina Shea in the design of the single layer space truss. The superimposition of unrelated layers of design decisions potentially takes the design into a realm that Arp would consider inaccessible by the conscious self.

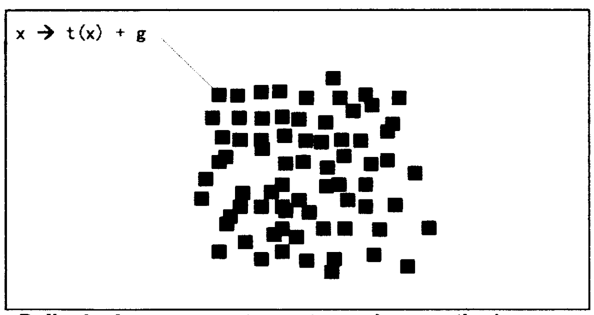
After a series of automated/random calculations the designer interprets the outcome, and at that moment generates its meaning – regardless of its actual history. It forces the designer to make sense of the presented situation rather than that the course of the design process determines – or biases – its interpretation. While acknowledging the importance of Pollock looking at the evolving design, it is equally important to acknowledge that he also proceeded on automatism to assure emergent events.

By applying these rules and recursions an indefinite number of times, the initial structure to the design gets veiled, erasing the importance of the initial line. At the same time, it allows to either emphasize or conceal emerging structures, rather than having to erase emerging properties. Critical to these emerging properties of the design however is recognizing them on the one hand, and being able to respond to them on the other. Both are dealt with in the Pollock approach by the sheer indefinite amount of designer-system interactions. In a sense, Pollock can only deal with the unpredictability of the complexity of the physical system that materializes in every mark, by dealing with it after each gesture.

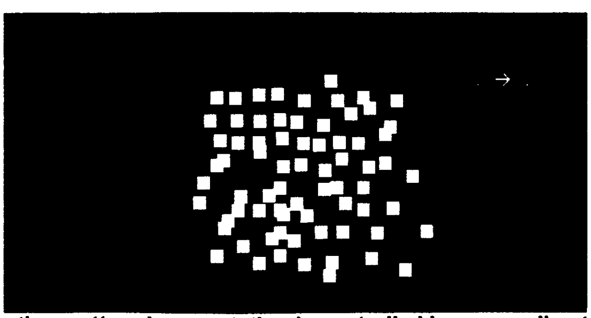
The unpredictable nature of material – be it real or virtual – thus offers the designer an external voice in the design process, but by being unpredictable it also forces the designer to interpret each step involving randomness and uncertainty.

SCATTERED COMPUTATION

What many architects have failed to recognize is the importance of the sheer indefinite human-system negotiations between the uncertainties of paint being flung with the artist's intention that went into every single Jackson Pollock painting. Pollock's method was not simply about the dripping or pouring itself. It was about *seeing* where to do so. By removing expectation from the act of painting, the seeing was brought to the foreground. The fuzzy intention of location is thus complemented by a structure of chance and randomness inherent to nature. The actual merit of Jackson Pollock, from a computational designer's point of view, lies in his contrasting of the artist's agency to the agency of the system he operates in.



- Pollock gives agency to gesture g in a continuing computation



- the scattered computation is controlled by responding to the numerous sub-computations

Instead of deciding what to respond to once, twice or even ten times, Jackson Pollock interacted thousands of times, mark after mark, leaving every single one present. It is this complex web of decisions and chance which may be the place to look for the computational complexity that contemporary architecture is in search of. Pollock's construction of visual randomness[68] is fundamentally different from the complexity found in both the work of Sol LeWitt and Roxy Paine. This difference can be best described as the difference in the artists' vocabulary. LeWitt issues *his verbal instructions*, Paine graphically creates *a string of commands*, yet Pollock engages in *a dialogue*. While both LeWitt and Paine effectively are involved in a generative dialogue – one with human drawing machines, the other with human-like machines – their generative conversation is limited to a single statement and response. Each recursion of that process produces a new work of art. The contemporary digital designer is similarly engaged in a dialogue consisting of a single statement that is tweaked in order to get the intended singular response. Yet Paine's single iteration is affected to a large extent by material properties, LeWitt's wall drawings by independent interpreters. Each of these external voices holds their systems from becoming reductive and predictable. When turning to Jackson Pollock we need to acknowledge that some of his paintings look similar to noise. Looking closer at this *noise*, however, brings out complexity generated through randomness, rather than plain chaos: thousands of little voices are responded to by the artist.

Critical to the Jackson Pollock approach is the presence of unpredictability and ambiguity in every single step of the process. The current computational models resist this continuous (re)interpretation. Only the input to the generative system is continually revised, in order to produce the entire design from the push of a button. In this regard these architectural design systems are not all that different from Roxy Paine's approach to sculpting. Each change to an initial value requires the re-calculation of the entire system of dependencies. The system evolves, but the design can only be generated after fully creating the system.

In architecture the system generates its formal complexity from a single designerly input – three points determine the generation of an entire building – and the negation of reality's uncertain nature – bouncing particles are predictable. This generalization has become an opaque entity of its own, which allows to be approached from many sides, yet only reveals a single result at the very end: all actions and decisions collapse into a single major computational event.[69] Opposed to this system of collapse stands a painterly system that reveals step by step the *becoming of*, rather than concealing the becoming of over the mythification of the final revealing.

Although architecture claims to be looking for complexity, given the size and thickness of the clouds that hide the process even from the designer, architecture may very well only find skin-deep perplexity. In the quest for shapes and forms derived from mathematical formulae beyond the designer's comprehension or even plain mathematical impossibilities, one has to wonder how long the collapse of decision-making into one system will keep amazing – or interesting for that matter – the critical viewer.

-Kenny Verbeeck, May 2006

NOTES

[1] The napkin sketches by Frank O. Gehry are famed for their after the fact nature, supposedly drawn from looking at the final design

[2] John Maeda in a roundtable discussion of "010101", quote found on wirednews.com, [http://www.wired.com/news/culture/0,1284,41972,00.html]

[3] At a Generative Components/SmartGeometry workshop at MIT, 4-6 November 2005, the preliminary parametric model for the DIFA project was informally presented by Kohn Pedersen Fox. The location of three points supposedly determined the entire three dimensional façade to the skyscraper.

[4] This argument of system purity is heard often when asked as an excuse not to take up the challenge and opportunity found within the system, yet well beyond the current system's capabilities.

[5] For the sake of simplicity and the fact that this essay builds upon the notion that architecture and art share methods of production, I will allow the words artist, architect and designer to be interchangeable without going into the discussion whether a clear distinction should be made between art and architecture.

[6] Nearly every design software package relies on mathematical equations to generate form, ranging from simple linear algebra to high level calculus. Researching which architects actually truly understand the mathematical depth of the formulae behind their whimsical shapes and forms would possibly be revealing the true role of contemporary architects in their pet peeve projects; yet unfortunately this is beyond the scope of this research.

[7] James Steele, in Architecture and Computers, Laurence King Publishing, London, 2001, p.98-107

[8] Branko Kolarevic, "Digital Morphogenesis", in Architecture in the Digital Age: Design and Manufacturing, Spon Press, New York, 2003, p. 20

[9] The article on random number generators and their relation to shuffling a 52 card deck is quite astonishing, illustrating the vast calculation power and a seed from a physical source, uncontrollable by players, needed for shuffling decks. [http://www.paradisepoker.com/shuffling.html] [last visited on 04.29.06]

[10] The same argument can be found in Martin Davis, 'Mathematical Logic and the Origin of Modern Computer', in The Universal Turing Machine, ed. Rolf Herken, pp.149-174, Oxford University Press, 1988

[11] the random number generator can be found on [http://www.random.org/nform.html] [last used on 02.02.05]

[12] some of these examples were retrieved from [www.random.org/essay.html] [last visited on 01.19.05]

[13] some of these examples were retrieved from [www.random.org/users.html] [last visited on 01.18.05]

[14] Stephen Wolfram, 'A new kind of science', chapter 8, Wolfram Media Inc., 2002

[15] the most famous cellular automaton is the 'Game of Life' by John Horton Conway, it first appeared in 1970 in an issue of Scientific American in a column about "Mathematical Games".

[16] from 'Theoretical interlude-What is randomness? My definitions', by Gregory J. Chaitin, in 'Exploring randomness', pp.111, Springer-Verlag London Limited, 2001

[17] Marvin Minsky, The society of mind, New York, Simon & Schuster, 1988

[18] N. John Habraken, Mark D. Gross, et al., Concept design games, Cambridge, Mass., Dept. of Architecture, Massachusetts Institute of Technology, 1987

[19] From Philip Galanter, 'What is Generative Art? Complexity Theory as a Context for Art Theory', 2003, [http://www.philipgalanter.com/academics/index.htm] [last visited on 04.29.06]

[20] 'Art from randomness. How Inverso uses chance, to create a Haiku', by Matthew J. Koehler & Punya Mishra, Michigan State University

[21] Thierry de Duve, 'Given the Richard Mutt Case', in The Definitively Unfinished Marcel Duchamp, Cambridge, MIT Press, 1991, p.190

[22] P.B.T. (Marcel Duchamp) in The Blind Man, no.2, May 1917, in Thierry de Duve, 'Given the Richard Mutt Case', in The Definitively Unfinished Marcel Duchamp, Cambridge, MIT Press, 1991, p.199

[23] John Cage, "Experimental Music", in Silence, 1973, Wesleyan University Press, Middletown, p10

[24] John Cage, "Experimental Music: Doctrine", in Silence, 1973, Wesleyan University Press, Middletown, p14. This article first appeared in 1955.

[25] Line Form Color, Ellsworth Kelly, 1999, Harvard University Art Museums

[26] from 'Art from randomness. How Inverso uses chance, to create a Haiku', by Matthew J. Koehler & Punya Mishra, Michigan State University

[27] Similar poetry experiments can be found in the dada movement, most famous is Tristan Tzara's recipe for random poem composition from news paper clippings. See also Rosalind Krauss, Passages in Modern Sculpture, Cambridge, Mass., MIT Press, 1977, p. 105

[28] from 'Artificial Evolution for Computer Graphics', by Karl Sims, in 'Computer Graphics', Volume 25, Number 4, July 1991

[29] from 'What is an image?', by Harold Cohen, 1979, on [http://crca.ucsd.edu/%7Ehcohen/cohenpdf/whatisanimage.pdf] [last visited on 02.24.04]

[30] Sol LeWitt, "Paragraphs on Conceptual Art", in Conceptual Art: a Critical Anthology, ed. Alexander Alberro and Blake Stimson, MIT press, 1999, p. 12

[31] Sol LeWitt, Incomplete open cubes, Nicholas Baume, ed., with essays by Nicholas Baume, Jonathan Flatley, and Pamela M. Lee. Hartford, Conn.:

Wadsworth Atheneum Museum of Art ; Cambridge, Mass. : MIT Press [distributor], 2001

[32] Credit to Rosalind Krauss for describing the *Variations of Incomplete Open Cubes* in 'LeWitt in Progress', 1978, as *a 'system' of compulsion, of the obsessional's unwavering ritual, with its precision, its neatness, its finicky exactitude, covering over an abyss of irrationalism.*

[33] Another great example of LeWitt's obsession to find all solutions to an idea is his book Lines in two directions and in five colors on five colors with all their combinations, Minneapolis, MN, Walker Art Center, c1988

[34] Though it is arguable that by now, because of Sol LeWitt's omnipresence in art history, very few people involved with making a LeWitt wall drawing would not have seen any of his previous work.

[35] Jackson Pollock, Interview with William Wright, 1950, in Jackson Pollock: Interviews, Articles, and Reviews, ed. Pepe Karmel, New York, MoMA, 1999

[36] Joseph D. Ketner, "Introduction", Roxy Paine / Second Nature, 2002, Contemporary Arts Museum, Houston

[37] Lynn M. Herbert, "Interview with Roxy Paine", Roxy Paine / Second Nature, 2002, Contemporary Arts Museum, Houston, p.15

[38] Walter Benjamin, "The Work of Art in the Age of Mechanical Reproduction", in Illuminations, ed. Hannah Arendt, Schocken Books, New York, 1968, p.220

[39] Roxy Paine in "Medium Isn't the Message; Art Is ", Jason Spingarn-Koff, WiredNews, Mar. 02, 2001

[40] Gregory Volk in "Dreams and Mathematics", Roxy Paine / Second Nature, 2002, Contemporary Arts Museum, Houston, p.35

[41] Roxy Paine refers to the machine as the SCUMAK, but to the sculptures as Scumaks.

[42] Roxy Paine in "Conversation/ Roxy Paine and Allan McCollum", Roxy Paine / Bluff, 2002, Public Art Fund, New York, p.26

[43] Jackson Pollock, Interview with William Wright, The Springs, Long Island, New York, Late 1950. Broadcast on Radio station WERI, Westerly Rhode Island, 1951, in Pepe Karmel, Jackson Pollock, Interviews, Articles, and Reviews, New York, MoMA, 1999, p.22

[44] Ironically, the persona of Jackson Pollock has now very much become the romantic notion of what a modern painter is.

[45] Paraphrasing the Bruno Alfieri review from the November 20, 1950 TIME magazine article. Alfieri reviewed the paintings shown at the 1950 Venice Biennale.

[46] James Coddington, in "No Chaos Damn It", in Jackson Pollock, New Approaches, ed. Kirk Varnedoe and Pepe Karmel, MoMA, New York, 1998, p.101-115

[47] from 'Pollock, Mondrian and Nature: Recent Scientific Investigations', by Richard Taylor, invited article for 'Art and Complexity', a special edition of 'Chaos and Complexity Letters',

[48] from 'Fractal Expressionism', by Richard Taylor, Adam Micolich & David Jonas, in 'Physics World', October 1999, Volume 12 no 10

[49] Lynn M. Herbert, "Interview with Roxy Paine", Roxy Paine/ Second Nature, 2002, Contemporary Arts Museum, Houston, p.19

[50] Voice over by Jackson Pollock in the color film by Hans Namuth and Paul Falkenberg, 1951

[51] This notion of controlling the dripping paint can also be found in Pepe Karmel's "Pollock at Work: The Films and Photographs of Hans Namuth", in Jackson Pollock, Kirk Varnedoe, Pepe Karmel, New York, MoMA, 1998

[52] There are however paintings that show 'runnings', such as *Lucifer*, that indicate that marks were applied to the canvas in a vertical position.

[53] James Coddington, "*No Chaos Damn It*", in Jackson Pollock, New Approaches, ed. Kirk Varnedoe, Pepe Karmel, New York, The Museum of Modern Art, 1999, plates p.128

[54] Further literature on shape grammars can be found in:
George Stiny, Shape: Talking about Seeing and Doing, 2006
George Stiny, "*Introduction to Shape and Shape Grammars*", Environment and Planning B, 7, 1980

[55] Matthew L. Rohn, Visual Dynamics in Jackson Pollock's Abstractions, Michigan: UMI Research Press, 1987, p14

[56] James Coddington, "No Chaos Damn It", in Jackson Pollock, New Approaches, ed. Kirk Varnedoe, Pepe Karmel, New York, The Museum of Modern Art, 1999

[57] Pepe Karmel, "*Pollock at Work: The Films and Photographs of Hans Namuth*", in Jackson Pollock, Kirk Varnedoe, Pepe Karmel, New York, MoMA, 1998

[58] Karmel, 1998, pp. 108

[59] Marcos Novak, "*Liquid Architectures in Cyberspace*", in Cyberspace: First Steps, ed. Michael Benedikt, 1992

[60] Just walking through the SMArchS room indicates this shift from continuous shape to continuous shape-population. Models are focusing on the relation between morphologically relative yet unique units on a 'whatever/however' surface. In the Generative Components (design software) project by Bentley shape-population has already been nicknamed *the GC prostitution*. Because our tools now allow for the swift population of surfaces, that is were the designs seem to focus.

[61] The project was about experimenting with programming and design environments, without setting a definite context. Nearly by definition this resulted in random looking surfaces shapes, this is nor surprising, nor problematic.

[62] From 'Directed Randomness', in Digital Tectonics, ed. Neil Leach, David Turnbull, Chris Williams, (Hoboken, NJ : Wiley-Academy, 2004), p.91

[63] Shea, 'Directed Randomness', p.99

[64] It needs be pointed out that Greg Lynn is renowned for his architectural writings (An Advanced Form of Movement, 1997; Animate Form, 1998) that

justify setting up these systems of particles and force fields to determine architectural form.

[65] As all depends on straightforward linear equations, the trajectory of the balls determines form, rather than *finding form.*

[66] Greg Lynn, Animate Form, (New York: Princeton Architectural Press, 1998), pp.102

[67] Lynn, 1998, pp 108

[68] Randomness or complexity, the term only depends on the viewer's interpretation of there being guiding principles underneath. If Jackson Pollock saw no relation between the mark on the painting and his next gesture, one has to conclude his paintings are indeed random.

[69] In many of the used methods there are plenty of things visually happening on screen. Yet they are only animated entertainment for an easily impressed audience, as they do not allow any intervention by the designer. Thus all actions within this black box of generative design are pre-calculated, all possibilities have been foreseen or excluded from being possible. More often than not, the computational design is based upon a pre-cognitive model, this turns an architect not in a master-builder, but into god-programmer, he who foresaw all. For a further elaboration on this argument, see also: Helen Castle, Editorial to 'Architecture + Animation', in Architectural Design, vol. 71, No. 2, 2001

SELECTED READINGS

- Reyner Banham, Theory and Design in the First Machine Age, Cambridge, MIT Press, 1980
- Roland Barthes, *The Death of the Author*, Image, Music, Text, essays selected and translated by Stephen Heath, New York, Hill and Wang, 1977
- Walter Benjamin, *The Work of Art in the Age of Mechanical Reproductio'*, in Illuminations, Hannah Arendt, ed., 2nd ed., New York, 1988
- Deborah J. Bennett, Randomness, Cambridge, Mass., Harvard University Press, 1998
- John Cage, Silence, Middletown, Wesleyan University Press, 1973
- Kathleen Carter, *Computer-Aided Design: Back to the Drawing Board*, in Proceedings of Creativity and Cognition, 1993
- Gregory J. Chaitin, Exploring randomness, Springer-Verlag London Limited, 2001
- Marcus Chown, *Random Reality*, in New Scientist, February 26, No. 2227, 2000
- James Coddington, *"No Chaos Damn It"*, in Jackson Pollock, New Approaches, ed. Kirk Varnedoe and Pepe Karmel, MoMA, New York, 1998

- Harold Cohen, What is an image?, 1979, can be retrieved from [http://www-crca.ucsd.edu/~hcohen/cohenpdf/whatisanimage.pdf] [last visited on May 21, 2006]
- Harold Cohen, Coloring without Seeing, a Problem in Machine Creativity, 1999, can be retrieved from [http://www-crca.ucsd.edu/~hcohen/cohenpdf/whatisanimage.pdf] [last visited on May 21, 2006]
- Thierry de Duve, ed., The Definitively Unfinished Marcel Duchamp, Cambridge, MIT Press, 1991
- Manuel De Landa, A thousand years of nonlinear history, New York, Zone Books, 1997
- B.H. Friedman, *An interview with Lee Krasner Pollock*, in Jackson Pollock: Black and White, New York, Marlborough-Gerson Gallery Inc., March 1969
- Philip Galanter and Ellen K. Levy, Complexity, Art and Complex Systems, Samuel Dorsky of Art, 2002
- Philip Galanter, What is Generative Art? Complexity Theory as a Context for Art Theory, paper presented at 2003 Generative Art Conference in Milan, Italy, can be retrieved from [http://205.212.176.98/academics/index.htm] [last visited on May 21, 2006]
- Clement Greenberg, *'Avant-garde and Kitsch'*, in Art and Culture: Critical Essays, Boston: Beacon Press, 1961
- N. John Habraken, Mark D. Gross, et al., Concept design games : a report submitted to the National Science Foundation Engineering Directorate, Design Methology Program, Cambridge, Mass., Dept. of Architecture, Massachusetts Institute of Technology, 1987
- Lynn M. Herbert, Roxy Paine / Second Nature, Houston, Contemporary Arts Museum, 2002
- Rolf Herken, ed. , The Universal Turing machine: a half-century survey, Oxford, New York, Oxford University Press, 1988
- Wassily Kandinsky, Point and line to plane; contribution to the analysis of the pictorial elements [Tr. by Howard Dearstyne and Hilla Rebay] Ed. and prefaced by Hilla Rebay, New York, Pub. by the Solomon R. Guggenheim Foundation for the Museum of Non-Objective Painting, 1947
- Pepe Karmel, ed., Jackson Pollock: Interviews, Articles, and Reviews, New York, MoMA, 1999
- Ellsworth Kelly, Line Form Color, 1999, Harvard University Art Museums
- Terry Knight, *Either/Or -> And*, in Environment and Planning B: Planning and Design, volume 30, 2003
- Terry Knight and George Stiny, *Classical and Non-classical Computation*, in arq, Information Technology, vol 5, no 4, 2001
- Matthew Koehler and Punya Mishra, *Art from Randomness. How Inverso uses Chance, to Create Haiku*, Michigan State University

- Branko Kolarevic, Architecture in the Digital Age: Design and Manufacturing, New York, Spon Press, 2003
- Rosalind Krauss, Passages in Modern Sculpture, Cambridge, Mass., MIT Press, 1977
- Donald B. Kuspit, Clement Greenberg, Art Critic, Wisconsin, The University of Wisconsin Press, 1979
- Charles Lachman, *"The Image Made by Chance" in China and the Wesy: Ink Wang Meets Jackson Pollock's Mother*, in The Art Bulletin, Vol. 74, No. 3 (Sept 1992)
- Ellen G. Landau, Jackson Pollock, New York, Abrams, 1989
- Bryan Lawson, How designers think: the design process demystified, Oxford, Boston, Architectural Press, 1997
- Neil Leach, David Turnbull, Chris Williams, eds., Digital Tectonics, Hoboken, NJ, Wiley-Academy, 2004
- Sol LeWitt, Incomplete open cubes, Nicholas Baume, ed., with essays by Nicholas Baume, Jonathan Flatley, and Pamela M. Lee. Hartford, Conn.: Wadsworth Atheneum Museum of Art ; Cambridge, Mass. : MIT Press [distributor], 2001
- Sol LeWitt, Lines in two directions and in five colors on five colors with all their combinations, Minneapolis, MN, Walker Art Center, 1988
- Sol LeWitt, "Paragraphs on Conceptual Art", in Conceptual Art: a Critical Anthology, ed. Alexander Alberro and Blake Stimson, MIT Press, 1999
- Sol LeWitt, "Sentences on Conceptual Art", in Conceptual Art: a Critical Anthology, ed. Alexander Alberro and Blake Stimson, MIT Press, 1999
- Greg Lynn, Animate Form, New York, Princeton Architectural Press, 1999
- John Maeda, Design by Numbers, Cambridge, MIT Press, 1999
- B.B. Mandelbrot, The Fractal Geometry of Nature, San Francisco, Freemann, 1983
- Thom Mayne, Morphosis, London, New York, Phaidon Press, 2003
- Malcolm McCullough, William J. Mitchell, and Patrick Purcell, eds., The Electronic design studio : architectural knowledge and media in the computer era, Cambridge, Mass., MIT Press, 1990
- Marvin Minsky, The society of mind, New York, Simon & Schuster, 1988
- William J. Mitchell, The Reconfigured Eye: Visual Truth in the Post-photographic Era, Cambridge, MIT Press, 1992
- Hans Namuth, essais de Rosalind Krauss & Francis V. O'Connor, les textes de Jackson Pollock, L'atelier de Jackson Pollock, Paris, Macula/Pierre Brochet, 1978
- Hans Namuth, photographs, Barbara Rose, ed., Pollock painting, New York, Agrinde Publications, 1980

- Marcos Novak, "*Liquid Architectures in Cyberspace*", in Cyberspace: First Steps, ed. Michael Benedikt, 1992
- Kas Oosterhuis, Architecture Goes Wild, Rotterdam, 010 Publishers, 2002
- Kas Oosterhuis, Hyperbodies : toward an e-motive architecture, London, Momenta, 2003
- Roxy Paine: Bluff, New York: Public Art Fund; available through D.A.P./Distributed Art Publishers, 2002?
- Ivars Peterson, The Jungles of Randomness: a Mathematical Safari, New York, John Wiley & Sons, 1998
- Matthew L. Rohn, Visual dynamics in Jackson Pollock's abstractions, Ann Arbor, Mich., UMI Research Press, 1987
- Donald Schön, Educating the reflective practitioner, San Francisco, Jossey-Bass, 1987
- Kristina Shea, *Directed Randomness*, in Digital Tectonics, N. Leach, D. Turnbull, C. Williams, eds., Hoboken, NJ, Wiley-Academy, 2004
- Herbert A. Simon, *Alternate Views of Complexity*, in The Sciences of the Artificial, Cambridge, MIT Press, 1996
- Karl Sims, 'Artificial Evolution for Computer Graphics', in Computer Graphics, Volume 25, Number 4, July 1991
- James Steele, Architecture and Computers, Laurence King Publishing, London, 2001
- George Stiny, *'Ice-Ray: a Note on the Generation of Chinese Lattice Designs'*, in Environment and Planning b, volume 4, 1977
- George Stiny, *Introduction to Shape and Shape Grammars*, Environment and Planning B, 7, 1980
- George Stiny, Shape: Talking about Seeing and Doing, Cambridge, Mass., MIT Press, 2006
- Richard Taylor, Adam Micolich & David Jonas, *'Fractal Expressionism'*, in Physics World, October 1999, Volume 12 no 10
- Sherri Turkle, *The Triumph of Tinkering*, Life on the Screen, 1995
- Kirk Varnedoe, Pepe Karmel, Jackson Pollock, New York, The Museum of Modern Art, 1998
- Kirk Varnedoe, Pepe Karmel, eds., Jackson Pollock, New Approaches, New York, The Museum of Modern Art, 1999
- Gregory Volk, *Dreams and Mathematics*, Roxy Paine / Second Nature, 2002, Contemporary Arts Museum, Houston
- Frank Werner, Covering + Exposing: the Architecture of Coop Himmelb(l)au [translation, Michael Robinson], Basel, Boston, Birkhäuser, 2000
- Stephen Wolfram, A new kind of science, Wolfram Media Inc., 2002

LIST OF ILLUSTRATIONS

Unless otherwise noted, the images and diagrams are by the author. Due to the transient nature of the internet it is unclear who created or owns some illustrations.

All images are attributed in order of appearance in the document.

- p.7: advertisement from [http://www.apple.com/ipodshuffle/] [last visited on May 23, 2006]
- p.9: photograph by Hans Namuth, c.1950
- p.13: Greg Lynn FORM, image from James Steele, Architecture and Computers
- p.18: Stephen Wolfram in New Kind of Science
- p.19: image from [http://www.csit.fsu.edu/~burkardt/f_src/table_uniform_noise/table_uniform_noise.html] [last visited May 23, 2006]
- p.20: image from [http://www.csit.fsu.edu/~burkardt/f_src/table_uniform_noise/table_uniform_noise.html] [last visited May 23, 2006]
- p.27(top): Anthony Gormley, *Field for the British Isles*, 1993, image from [http://www.chaplog.co.uk/blog/wp-content/Gormley1b.jpg] [last visited on May 23, 2006]
- p.27(bottom): Anthony Gormley, *Field for the British Isles*, 1993, image from [http://www.georgetown.edu/faculty/irvinem/CCT794/Images/] [last visited on May 23, 2006]
- p.28: Jeffrey Ventrella, screenshot from *Gene Pool*
- p.29: Roxy Paine, *Abstract no.6*, 2000, from Roxy Paine/Second Nature, 2002
- p.30: Robert Rauschenberg, *Dirt Painting (for John Cage)*, c.1953. Dirt and mold in wood box. 15 ½ x 15 x 2 1/2 in. Collection of the artist. New York
- p.32: Marcel Duchamp. American, born France. 1887-1968). *Three standard stoppages*, Paris 1913-14. . Wood box 11 1/8 x 50 7/8 x 9" (28.2 x 129.2 x 22.7 cm), with three threads 39 3/8" (100 cm), glued to three painted canvas strips 5 1/4 x 47 1/4" (13.3 x 120 cm), each mounted on a glass panel 7 1/4 x 49 3/8 x 1/4" (18.4 x 125.4 x 0.6 cm), three wooden slats 2 1/2 x 43 x 1/8" (6.2 x 109.2 x 0.2 cm), shaped along one edge to match the curves of the threads. Katherine S. Dreier Bequest. © 2006 Artists Rights Society (ARS), New York / ADAGP, Paris / Estate of Marcel Duchamp
- p.33: Marcel Duchamp. (American, born France. 1887-1968). *Network of Stoppages.* Paris 1914. Oil and pencil on canvas, 58 5/8" x 6' 5 5/8" (148.9 x 197.7 cm). Abby Aldrich Rockefeller Fund and gift of Mrs. William Sisler. ©

2006 Artists Rights Society (ARS), New York / ADAGP, Paris / Estate of Marcel Duchamp

- p.34: John Cage, *Fontana Mix*, 1958
- p.36: Jean Arp (Hans Arp). (French, born Germany (Alsace). 1886-1966). *Collage with Squares Arranged According to the Laws of Chance*. (1916-17). Torn-and-pasted paper on blue-gray paper, 19 1/8 x 13 5/8" (48.5 x 34.6 cm). Purchase. © 2006 Artists Rights Society (ARS), New York / VG Bild-Kunst, Bonn
- p.37: Ellsworth Kelly, *Black, Brown, White*, plate 35, Line Form Color, 1999, Harvard University Art Museums
- p.39: image from [imej.wfu.edu/articles/2002/1/03/images/fig1d.jpg] [last visited November 19, 2004]
- p.40: image from Karl Sims, *Evolving Creatures*, in SIGGRAPH '94 proceedings, fig.7&8
- p.41: Harold Cohen, AARON painting, image from [http://www.m-cult.org/read_me/press.php] [last visited on May 23, 2006]
- p.43: Sol LeWitt, Cat.65 schematic drawing for incomplete open cubes, 1974, from printed four page announcement for the exhibition *wall drawings and structures: the location of six geometric figures/variations of incomplete cubes,* john weber gallery, new york, 15x15", in <u>Incomplete open cubes</u> /edited by Nicholas Baume
- p.44: Sol LeWitt, The Location of Six Geometric Drawings, 1973, in <u>Sol Lewitt drawings, 1958-1992</u>, Susanna Singer, ed., The Hague: Haags Gemeentemuseum, 1992.
- p.47: Roxy Paine, *PMU #13*, 2003
- p.48: Roxy Paine, *SCUMAK No.2*, 2001, from <u>Roxy Paine/Second Nature</u>, 2002
- p.49: Roxy Paine, *SCUMAK (Auto Sculpture Maker)*, Extruder, cooling system, Teflon, electronics, stainless steel, polyethylene. 163" x 81 7/8" x 55 7/8". 1998. Image from [http://www.grandarts.com/art/SCUMAK.jpg] [last visited on May 23, 2006]. Three white squares added.
- p.51: photograph by Hans Namuth, c.1950. Three white squares added.
- p.52: photograph by Hans Namuth, c.1950. Three white + three red squares added.
- p.54: photograph by Hans Namuth, c.1950
- p.55: detail of Jackson Pollock, *Lavender Mist*, by James Coddington
- p.58 (top): Jackson Pollock, *Blue (Moby Dick)*, c.1943, gouache and ink on composition board, 18 ¾ x 23 7/8 in. In the collection of Ohara Museum of Art, Kurashiki
- p.58(middle): Jackson Pollock, *Alchemy*, 1947. Oil, aluminum (and enamel?) paint, and string on canvas, 114.6 x 221.3 cm. Peggy Guggenheim

Collection. Jackson Pollock © 2003 The Pollock-Krasner Foundation/Artists Rights Society (ARS), New York. In the collection of Guggenheim New York.

- p.58(bottom): Jackson Pollock, *Number 23*, 1948. Enamel on gesso on paper, support: 575 x 784 mm frame: 651 x 861 x 42 mm. Presented by the Friends of the Tate Gallery. In the collection of the Tate Gallery.
- p.59: photograph by Hans Namuth, c.1950
- p.62: photograph by Hans Namuth, c.1950
- p.63: film frame from 1951 black and white film by Hans Namuth
- p. 64(both): film frames from 1951 black and white film by Hans Namuth
- p.65: film frame from 1951 black and white film by Hans Namuth
- p.66(all): photographs by Hans Namuth, c.1950
- p.67(all): photographs by Hans Namuth, c.1950
- p.68(top): Jackson Pollock (American, 1912–1956). *Autumn Rhythm (Number 30)*, 1950. Enamel on canvas; H. 105, W. 207 in. (266.7 x 525.8 cm). George A. Hearn Fund, 1957 (57.92). ©1999 Pollock-Krasner Foundation/Artists Rights Society (ARS), New York. In the collection Metropolitan Museum of Art
- p.68(bottom): composite of film frames by Pepe Karmel from film footage from 1951 black and white film by Hans Namuth. Diagram by Thomas Hart Benton.
- p.69(all): composite of film frames by Pepe Karmel from film footage from 1951 black and white film by Hans Namuth
- p.70: composite of film frames by Pepe Karmel from film footage from 1951 black and white film by Hans Namuth
- p.72: photograph by Hans Namuth, c.1950
- p.73: LAB architecture studio, Federation Square, Melbourne, Australia, image from [http://perso.wanadoo.fr/bbbtd/melbourne/federation%20square2.JPG] [last visited on May 24, 2006]
- p.73: Steven Holl, M.I.T. Simmons Hall, Cambridge, Massachusetts, image from [http://www.stevenholl.com/images/173WE03.jpg] [last visited on May 24, 2006]
- p.75: Coop Himmelb(l)au, Vienna, Austria, deconstructivist office extension
- p.76: Matt Trimble and Travis Hanks, in Computational Design Solutions, January 17-23, 2006, Department of Architecture, M.I.T.
- p.77: Kristina Shea, image from *Digital canopy: high-end computation/low-tech construction*, arq, vol6, no.2, 2002