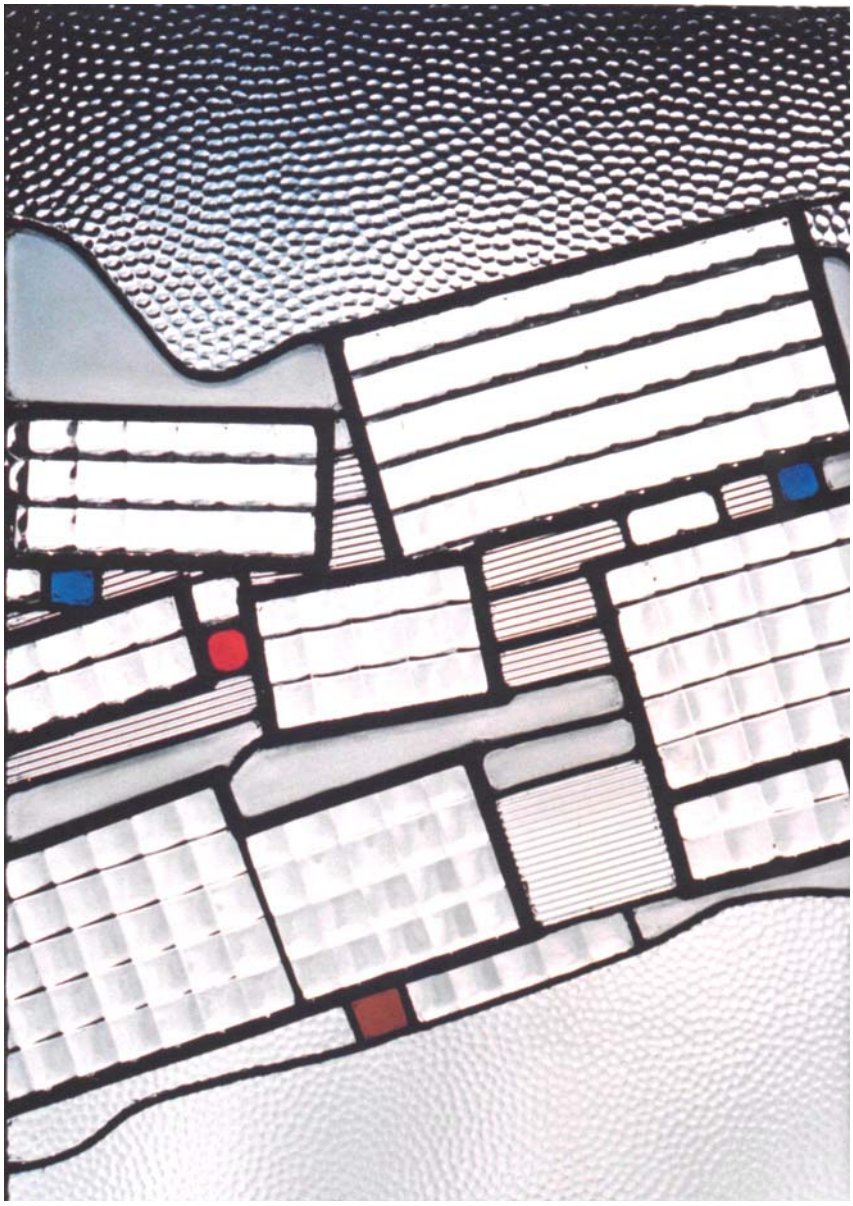
The Nature of Architecture:

The Art & Science of building with Chaos and Fractals



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Draft Essays by Aron Faegre

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1. Chaos, Fractals, and Architecture

This booklet provides a series of short essays – or perhaps they would better be thought of as poems – on architecture. They explore the possibility that with the changing of the century, and the knowledge that has come with it, our way of building can change dramatically from that of the last century. There is a new science, and a new poetics, that is founded on new answers to questions such as "what is nature," and "what is man's place in nature?" Architecture can delightedly join with this revolution of understanding.

The terms "chaos and fractals" are used many times in these essays. These words began as mathematical terms, but quickly have lead to a vast and exciting modern field of geophysics. Geophysics is a science (and art) that is every day making new discoveries about the origins of the universe, while simultaneously solving complex local hydraulics of watersheds, swamps, and wetlands – and relating these seemingly small local issues, at times, back to big issues such as potential global climatic change! In one joint US-Russian study currently under way, it is hypothesized that peat wetlands in northern Russia may play a role in absorbing CO^2, and then perhaps 20,000 years later releasing it, as part of the force behind the earth's cycle of ice ages[1]. The big and the small are being found to be interrelated in fundamental and profound ways.

Our understanding of the universe we live – this science of geophysics – provides the true basis for architecture. Most of the discoveries of geophysics are appropriate for direct or parallel use in the design fields of architecture, engineering, and landscape architecture. Thus, these essays could easily touch on many things besides "chaos and fractals." In fact, I had hoped to have specific essays about architecture as it relates to: sprites, elves, blue jets, spider lightning, metastable eutectic thermodynamic equilibrium, diffusion-limited aggregation, gravitation models, climate-biosphere links, Pacific Decadal variability, string theory, pulse chorus, biophony, bioengineering, viral family trees, volcanic geodesy, tree ring data, tsunami prediction, quantum entanglement, substorm current wedges, bow shock waves, substorm onsets, near earth neutral line models, Jovian lava fountains, cavitation, linear elastic dynamic analysis, fractal cell phone antennas, acoustic bandgaps, quantum spinor liquids, and the paramagnetic meissner effect. However, my editor said that readers would be bored by most of those subjects.

What follows are a series of essays about how a few of these new understandings shed light on a new way for architecture. Apologies are made that these essays are rough and flighty at times, and in many ways unfinished. The author works most of each day in the trenches of "real" architecture, where one's boots are muddy most of the time. It has taken a great effort to get these few essays finished. Hopefully, the bones of the ideas make it through to the reader and expose the skeleton of some new ways of doing architecture. It is hoped that there will be time to further flesh these ideas out – or that this will be accomplished by others who have more time than is currently available to the author.

2. Man, Nature, and Architecture

Man lives in nature, but is strangely not quite part of nature. This is the duality of all human life. As children we build a fort in the area under our bunk bed, using sheets and blankets to form the enclosure. Our creative abilities are rich in content, and our imagination allows us to inhabit grass fields, trees, and swamps, as if that is the most ordinary thing in the world. A child leaps through the rushes and jumps over a shallow stream, just as does the deer or coyote. One guesses that all children have this innate sensibility. We are all born into the world as part of nature.

Then, as a person grows older, they settle into a way of life that is different from that of childhood. Each culture has evolved ways of living that become norms to follow and fit into. In America now, the majority probably live in suburban houses on square plots of land that are lined up along asphalt paved streets. Each house and lot is owned separately, and the owners use automobiles that are parked on the lots, to drive on asphalt streets hither and yon to accomplish a multiplicity of work and pleasure activities.

But that is just the current dominant American way. There are as many other ways of living as their other cultures. In some cultures the way of life is intensely urban, while in others an ancient nomadic way of life continues, where tents or campers are used as a daily abode. And in contrast to the American cultural model of single-family ownership, there are places where multiple families prefer to share ownership in their dwellings.

The architecture of a culture is interesting to examine and conjecture about, because it is a physical manifestation of the way of life of the people of that culture. Architecture tells us something about those people. People talk about themselves by storytelling, writing books, giving lectures, arguing with neighbors, and a host of other verbal and non-verbal messaging systems. However, it is with architecture that people talk about themselves more honestly – since they are not constructing buildings or landscapes with immediate intent of "saying" something. In this respect, architecture becomes a measuring stick for examining how a peoples resolves this duality of being born of nature, but not remaining wholly a part of it.

"Landscape architecture" is included in this discussion. Constructed landscapes tell as much about a people as do constructed buildings. A farmhouse means little without the farmyard, fences, pastures, and fields. Similarly, the suburban house means little without the connecting roads, parks, playfields, boat ramps, and parking lots.

In fact, architecture has a certain duality within itself as well. A people builds in a certain way – with traditional forms, materials, relationships between uses, and so forth – yet once a building is constructed and inhabited it then in turn forces the inhabitants to see the world in a certain way – through that building's "windows." Living in a tent causes one to become very aware of wind and rain storms, to feel the transitory and cyclical nature of life. Living in a stone house causes one to see the world through a rectangular window with less concern for wind! If the stone house were constructed by your great-grandfather, the stones may even engender your ability to see yourself within the context of your lineage.

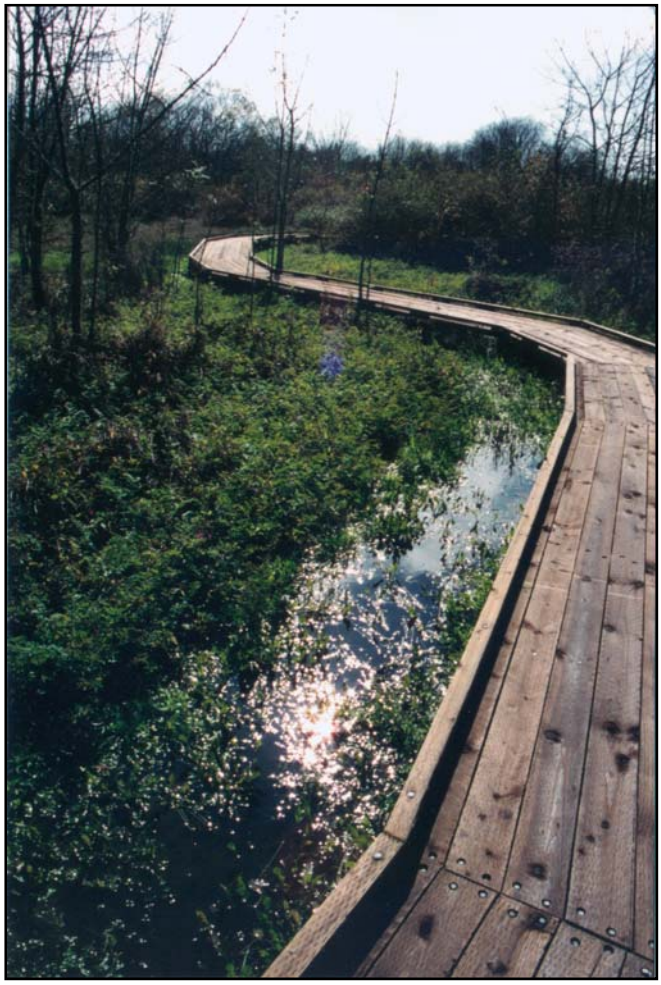

Figure 1: Jackson-Frasier Wetland Walkway

Surprisingly, this duality of architecture also means that those who "make" architecture can use this knowledge in reverse. Through examining architecture as an artifact of a peoples life, we then gain the power to use this same knowledge to create buildings that help people live a kind of life they desire. This is an exciting opportunity.

There are many people today – especially in the United States – who would like to live a life that is closer to

nature. There is much evidence that our current way of life is causing great harm to other parts of natural life. Our culture has created an "Endangered Species Act" to try to prevent the loss of whole families of animals and plants, is attempting to save and restore "wetlands" being lost at an alarming rate, is watching an "ozone hole" widen at the southern pole, and is attempting to forecast whether mankind's activities are causing a melting of the icecaps which may in subsequent years cause a rise in sea level and a flooding of our greatest cities.

Within this context, there is the possibility that our architecture might be designed to promote a way of life that is more in harmony with the ways of nature. With that goal, this paper is written for practitioners, builders, and users of architecture. It presents a new theory of architecture, but it is not presented for theorists. It is intended for those who work in the field,-- those who are knee-deep in the problems of designing a building that an owner wants to use. It is for those who get the planning and building permit approvals, and work on the nitty-gritty with the contractor so that it is built on time and on budget. It is for those who enjoy going back, and experiencing the successes and failures of their projects.

The creation of a single piece of architecture, unlike a single piece of sculpture, requires the convoluted interaction of countless people and agencies. Building design is by its nature a complex and chaotic process. As the 21st century begins, most architects lament this complexity, and feel that their power and control is being diminished. This paper provides a framework for understanding that chaos is fundamental to the creation of architecture — not just now, but throughout all of history. The recently created sciences of chaos and fractals now provide powerful tools and a framework for understanding this complex side of architecture. Thus, perhaps, a time has finally arrived for the architectural side of our way of life to be better integrated with the natural world. If we imagine the architectural history of man as beginning in caves and tipi's, and getting all the way over to "modern" high rise glass towers – then one might imagine that we've been given a key that lets us find a tipi within the glass tower. Those who wish to live a life more in harmony with the ways of nature can through chaos and fractals find help in buildings and landscapes that share nature's innate vitality and life.

Figure 2: Columbia Center

3. Architecture as a Union of Art and Science

Architecture since Roman times, and probably from long before, has been practiced as a combination of art and science. It is often heard today that the artistic side defies scientific definition, by its nature, while the scientific portion follows the available detailed knowledge of mathematics and materials available at the time. Thus for the Romans, the "Roman arch" — a self-supporting masonry arch opening up a solid wall – represented a major scientific and technological advance, while the artistic component was best exemplified by a style of sculptural friezes and paintings on the architecture.

A strongly surviving architectural theory dating to the Roman era was expressed by Vitruvius in his oft quoted phrase from the *Ten Books on Architecture,* that architecture should provide "Commodity, Firmness, and Delight." That phrase – which is still popular today – embodies a kind of Platonic idealization of architecture as having three fundamental forces that are identifiable, that interact with one another, and which an Architect can work with to achieve superior architecture. This may have been the first early European recorded attempt to try to find a "formula" for architecture.

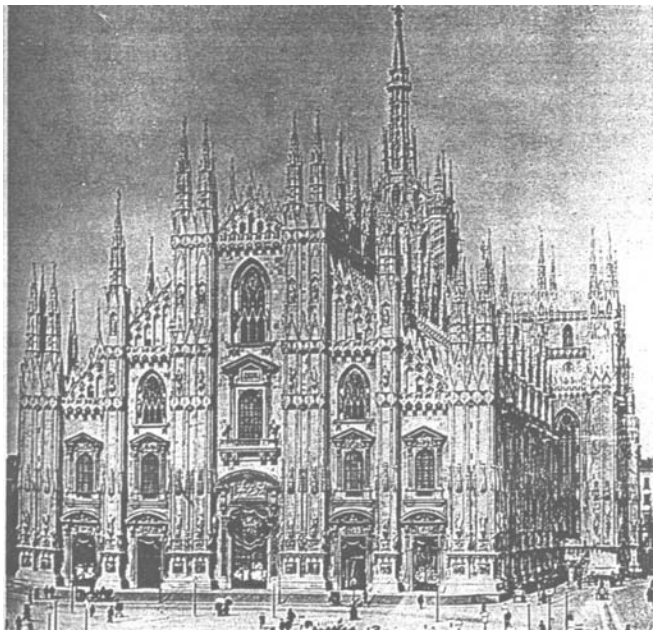

Figure 3: Milan Cathedral Elevation

In the case of the cathedral builders of the Middle Ages, the flying buttress, the wood roof truss, and tall masonry sculpted towers represented the high point of conjunction, for the art and science of architecture of that era. The culmination of this concept, that there must be a balanced union between art and science in architecture, is well stated in the record of the famous conference of cathedral builders at the Cathedral of Milan, Italy, held in May 1392. There, a group of Master Builders was trying to resolve why the cathedral was failing during construction. The group's analysis was carefully recorded in eight volumes of papers, and included discussions of everything from Pythagoras to waterproofing of roofs. The recorded[2] grand conclusion of the meeting was: "Ars sine scientia, nihil est." [Art without science is nothing]. The point was that there needed to be a science of building to accompany the artistic knowledge — the cathedral was just not going to stand up because it looked artistically good. In the case of the Milan Cathedral a structural science existed, and was being ignored for art's sake.

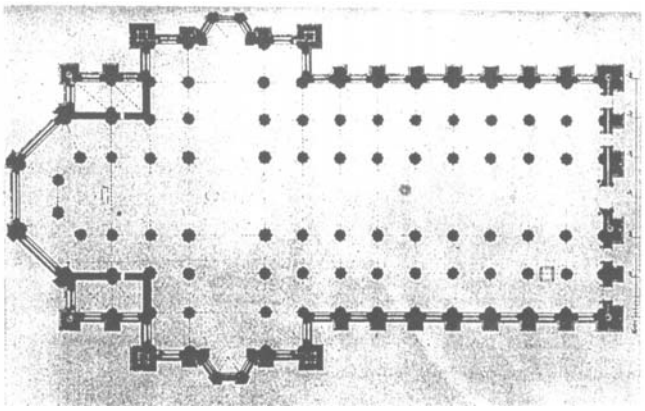

Figure 4: Milan Cathedral Plan

Leonardo Da Vinci (1452-1519) represents a person who explored buildings (and other things) as a combination of art and science, but for which the enabling science was sorely lacking to execute his ideas. In his notebooks he drew pictures of inventions that combined art and science but were at the time considered fantasy. His famous Galata Bridge design of 1502 for crossing the Golden Horn Inlet in Istanbul, with a span of 1,155 feet was considered unbuildable in his own time. Only now, 500 years later, versions of this bridge are planned for construction in Norway and the United States. In this case Da Vinci had an intuitive sense of science that exceeded what was possible at the time. Da Vinci's design was exquisite, but there was no scientific method available to validate it, so it was considered fantasy art and never built. Thus, also remained his flying machines, which only 500 years later are the primary means of long distance travel for all the world's peoples.

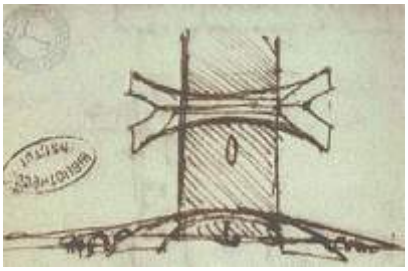

Figure 5: Leonardo's Galata Bridge Drawing
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The so-called "Modern Movement" of the mid-20th century attempted to find an architectural aesthetic based on the new materials and technologies of the day, — steel, aluminum, and steel reinforced concrete. The artistic friezes and decorations were stripped away from the building and architectural theorists talked about "form follows function." Of course there still was an artistic aesthetic used, some of which mimicked the clean aluminum industrial skin that might be found on an airplane, while others used large expanses of glass as the primary exterior artistic material.

With the advent of computers, today's science has opened up a whole new world of study called chaos theory. The older classical science easily developed mathematical equations describing the forms and motions of objects in the natural world. But the equations were so complicated that they were, per se, unsolvable. So to approximate solutions to the complex formulas, they were by necessity simplified, truncated and adjusted. Thus the complex physics of life was reduced to the simpler physics of billiard balls, something that could be calculated.

Even with that simplicity there were many amazing discoveries, such as Einstein's theory of relativity and the atomic world of quantum mechanics. But science still could not begin to predict or explain why things in nature took the everyday, visible forms they did. Thus the meander of a river, the branching structure of a tree, or the curved lobes of a cloud remained indescribable in terms of physics. Scientists could say that they knew the formulas that predicted these things, but they had no way to solve the formulas.

Earlier scientists from the late 1700's recognized that there were form similarities between natural objects which were interesting and should be studied. Goethe is best know as a poet, but his scientific studies – especially "The Metamorphosis of Plants" (1790) – provided the groundbreaking basis for much of the form studies that have lead to the discovery of fractals. One could almost guess that he was talking about fractals when he said in the opening paragraph:

> "Anyone who observes even a little the growth of plants will easily discover that certain of their external parts sometimes undergo a change and assume ... the form of the parts adjacent to them." (*The Metamorphosis of Plants*, Introduction, Paragraph 1).

The Englishman D'Arcy Thompson in the late 1800's spent a whole lifetime working on how organic form evolves. His *On Growth and Form* (published 1917) provided a vast compilation of this work about form as it is derivable from nature. He finds the form origin of a waterborne jellyfish in the forms that water droplets make when plashing. He develops a graphic method to show how one form of animal species can be shown as evolved from another. The fish morph below is from page 1064. On pages 1082 through 1086 Thompson shows how even to morph from human skull to chimpanzee, to baboon, to dog!

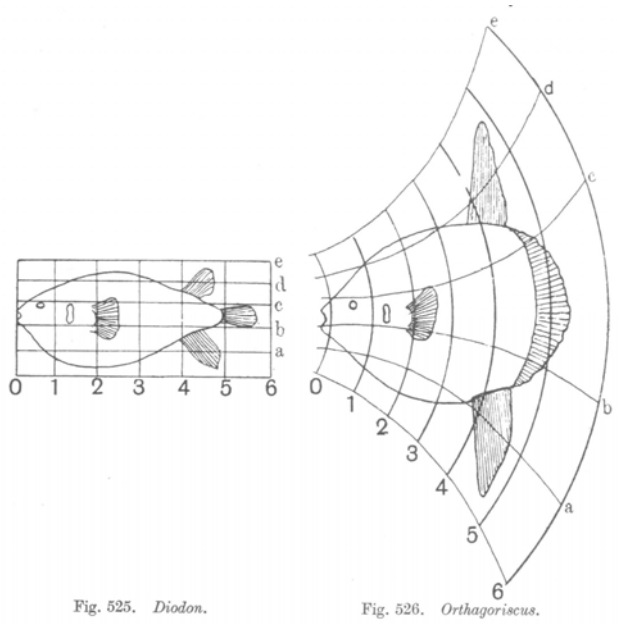

Figure 6: Morph of Porcupine Fish to Sunfish

Thompson credits Goethe with the creation of the term "morphology," and says that this new graphic analysis method is to be the basis for a "wider Science of Form which deals with the forms assumed by matter under all aspects and conditions ... the Book of Nature is written in characters of Geometry." Though no great body or school of scientific work has continued on with his study of organic form, the book is still in print today, pointing to the powerful common understanding that there is something important here to be further examined. Who will carry this work forward? With the use of fractal geometry, there are many new chapters waiting to be written!

The French geographer Elisee Reclus in his 1890's encyclopedic writing *A Universal Geography: the Earth and its Inhabitants* went so far as to recognize that the continents of Africa and South American "fit together" into a single form – thus understanding the geological concept of plate techtonics long before that science came into being! And there is the German scientist Theodor Schwenk who in his book *Sensitive Chaos: The Creation of Flowing Forms in Water and Air* (first published 19xx) studied eddies in rivers and developed theories about complex fluid motion in air and water during the mid-1900's. long in advance of the "creation" of chaos theory as a science. Somehow this earlier method of using "form" as a basic tool for science was lost for many years, as there is a discontinuity from those works to today's science. They are not listed as part of the established scientific lineage, yet.

But it was not until the advent of modern computers, and the development of chaos theory and fractals, that science has been able to now fairly easily describe complex natural objects such as rivers and trees and clouds. Using these new chaos theories, complex objects[3] are not only describable, but can be described with relatively short formulas. One might think it would take a tree's worth of paper to describe the twists and turns of a trunk, the fabric interlocking nature of the roots, the vast number and shapes of leaves. But fractal formulas can create very complex objects which begin to look very much like trees, using only a couple of lines of numbers and letters.

Until now architecture has been limited by the boring rectilinearly of Sir Isaac Newton's billiard ball science. The engineering behind most current architecture is largely based on the old physics which does not include or allow for the complexity of nature. If the International Building Code (which in various forms governs most buildings constructed today) were utilized to design a maple tree, it would come out looking more like a telephone pole, than a delicate structure of fine twigs and leaves. A western red cedar or sequoia would probably end up being a large concrete or steel structure in the shape of a cone — or with some professional help might even be constructed as a pyramid!

With a knowledge of fractals, a complex fern or tree-like structure such as that shown in the illustration on the next page can be defined by several short lines of mathematical code as shown beside the image. This fractal code is in contrast to Euclidian geometry methods such as are used by current architectural and engineering CAD software, which to define the same image would require a file of numbers approaching infinite size. There would be no disk large enough!

In the fractal method, numbers are used by the computer to take a simple graphic image and then iteratively copy, rotate, or scale its size per the set list of code instructions, and then repeat the instructions for several generations. It is a little like taking a xerox copy of a xerox copy of a xerox copy – where each iteration takes a line in the drawing and re-draws it with certain rules

4. What are Fractals & Chaos Theory?

At the end of this paper are provided some detailed references to elementary books on chaos theory and fractals. If the reader has at least some modest understanding of those terms, it is recommended that he or she proceed on with this paper. However, if the reader feels unable to proceed, without gaining a more specific understanding of those terms, then the reader may wish to get one of the reference books before proceeding.

However, this paper is intentionally presented with a loose organization that should be understandable to the new-comer! It is written a little bit from the perspective of a person who is "thinking out loud," rather than as presenting a finished product or theorem. What is the future of architecture and modern science in the new millennium? This is indeed an open question. It is an unanswerable question. None-the-less, this paper will explore, probe, and attempt to project the architecture profession along this pathway into the future, though it is not yet traveled. The meanings of the terms "chaos" and "fractal" will undoubtedly change as this field of study is further refined and explored. So to read on without a firm definition of chaos and fractals is not necessarily a bad thing. You may arrive at better definitions or meanings than have yet been created by others.

	Translations		Rotations		Scalings	
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1	0.0	1.6	-2.5	-2.5	0.85	0.85
2	0.0	1.6	49	49	0.3	0.34
3	0.0	0.44	120	-50	0.3	0.37
4	0.0	0.0	0	0	0.0	0.16

Figure 7: Barnsley's Fern Code[4]

This is the simple formula that a computer turns into the complex image in the next figure.

Figure 8: Barnsley's Fern Image

5. Fractal Geometry

"Geometry" from an etymological standpoint is the "measurement of the earth." "Geo" means earth, and "metry" means measure. And so, with circles, squares, lines, triangles — Euclidean geometry — we have measured the earth for millennia. We have gridded the earth with latitude and longitude. Our third President, Thomas Jefferson, purchased the wild and unknown west, and then gridded it with Townships and Sections – without having the slightest idea of what was actually out there. It was a tool for discovery and documentation of an unknown land. Until now these are the only earth measurement tools that man has had. But with fractals we now have a "geometry of nature." The originator of the word "fractal", Benoit Mandelbrot, titled his major book about the subject *The Fractal Geometry of Nature*. As he showed in his book, fractal geometry — unlike Euclidean geometry — provides a dynamic geometry that can describe the complex forms found in nature. Fractal geometry speaks more to what Lewis and Clark found, than the linear river across the country that Thomas Jefferson was hoping to find. In hind sight, it is of course fortunate that Jefferson's hope was not confirmed. America's diversity and strengths come in part from the geographical complexity of our land.

The fundamental concept of fractals is that a form can be identified which occurs in both small and large sizes, and that furthermore, the larger size form is made up of pieces which are self-similar to those of the smaller size. Thus, as one looks at a fractal geometric image, if one "zooms in" and enlarges a piece of the image, the image is different, but surprisingly similar to the previous image. If one "zooms out" the same result occurs.

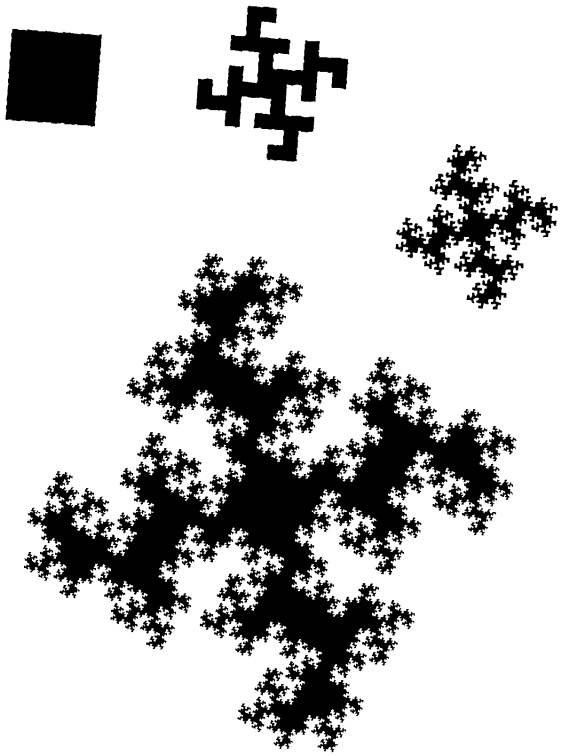


Figure 9: Fractal Geometry of Nature[5]

6. Fractals and Architecture

-- "No architect has yet had the notion of passing off his palaces as mountains and woods." Goethe[6]

What do fractals have to do with architecture? The fractal geometry of nature is directly visible to an observer when traveling in mountainous regions. One often can not tell for sure if a peak is close or far, a mountain very tall or only somewhat tall. Where there is no scale to measure the landscape, it can be very big or very small. Part of the incredible inherent beauty in Frank Lloyd Wright's small houses is precisely this fractal quality. Small form details in the trim, furniture, and masonry, repeat at larger sizes and in some cases even in the diagrams of the floor plans and sections. He even experimented with letting the forms extend into the landscape to some extent.

One could say that a fractal house design would have a quality that when you looked at the forms and shapes in the details of the building, they were mimicking or similar to the larger forms of the rooms. And of course if a building related to the landscape of the site, it might well pick up on forms and shapes inherent in the landscape and then find ways of working with those similar forms in the building.

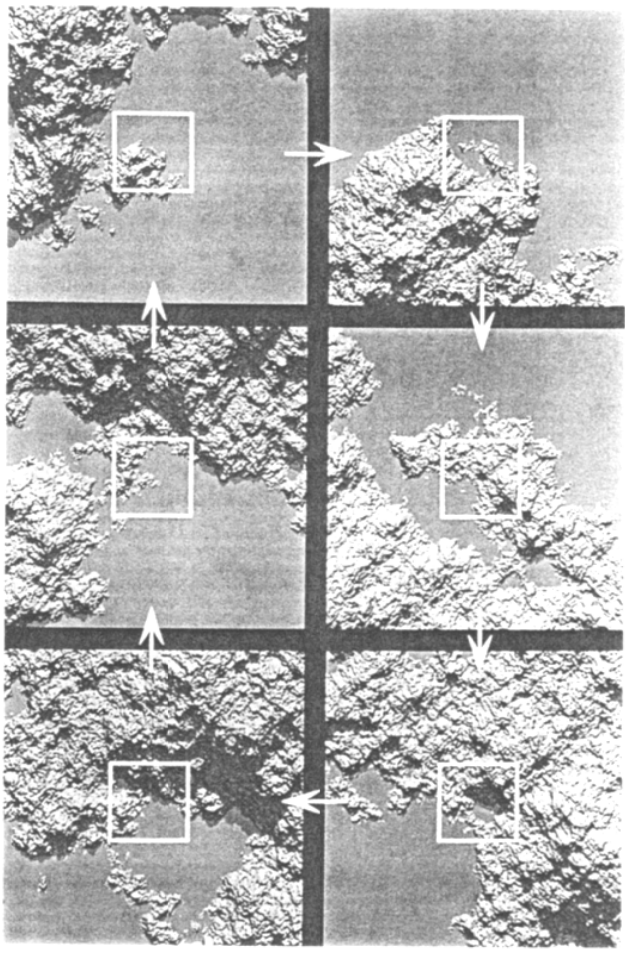
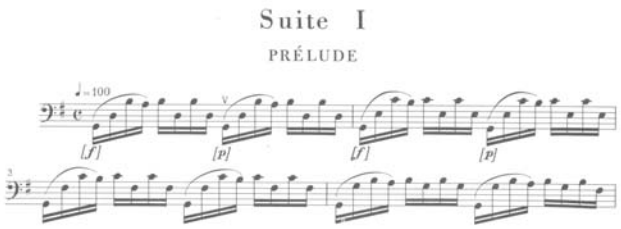


Figure 10: Fractal Coast with 6 Magnifications by Voss[7]

7. Music, Architecture, Chaos, and Fractals

Music provides a good example to use when considering the study of chaos and fractals in art. Much of J. S. Bach's music when deconstructed is found to have fractal forms throughout it. The music establishes certain phrases or forms, and then chronologically reverses them, or inverts them, or changes their time signature or key. Likewise, the bass line and the treble line are playful with each other, with a kind of complexity that relates to what we call fractals in today's science. Some historians have expounded on observations that in Baroque times the decoration of the architecture has a quality to it which is similar to that of the music.



Some would say that the attractiveness of "jazz" music is for similar reasons. There is a playfulness and spontaneity in the taking of a figure and improvising on it. The result is music with a complexity which is astoundingly beautiful, if not quite understandable or repeatable. There are composers today who are exploring the creation of modern music using mathematical fractal generators. Samples of this music can be found at one internet site www-ks.rus.uni-stuttgart.de/people/schulz/fmusic/index.html. Those compositions do capture the baroque quality of Bach.

In 1973 the Zimmermans invited our string quartet to visit and play in their Frank Lloyd Wright House in Manchester, New Hampshire. It is one of the best know of Wright's Usonian Houses. The Zimmermans said that many people had commented on how Frank Lloyd Wright's best houses (their own included) were like a piece of Bach music. It is this sense of initiating a simple form and repeating it and varying it in scale, texture, and size, which Frank Lloyd Wright's work is such a genius at accomplishing. For the owners who lived in the house, our playing of Bach in their home just carried their love affair with the house to an even higher level, where the physical form and live music with a similarity of form interpenetrated each other.

Music has always been a more fluid and alive form of the arts than architecture. In both Baroque and modern times improvisation has been an important central element of music composition and performance. In Baroque times the bass line played by the cello, gamba, or continuo (harpsichord) was only loosely written out so that the performers could invent the part as they went along. In addition, the solo parts (violin, flute, cello, or harpsichord depending on the piece or movement) could embellish the basic notes that were written down and in the case of cadenzas were expected to create a whole new "piece." Thus each performance was intended to have newness and spontaneity.

Recent studies have indicated that the brains of children who learn to play music have a different physical structure than those who do not learn music. Thus, music as a form of complexity may be more than enjoyable, it may be essential to the creation of a healthy human. The complexity of the music is somehow absorbed into the musician. Is there somehow a fractal relationship between the music itself and a human brain that intensely experiences it?

Figure 11: Multi-Bell Coronet, 1852[8]

8. Fractals and the Future of the Science of Architecture

Under the new science of chaos we are able to study the natural world and scientifically describe the forms of plants as they grow, the changing hydro-dynamics of water flow in a river, and the dynamics of weather systems as they move across the country. In the case of architecture, there have as yet been very little corresponding changes in the buildings to reflect the changing abilities of the science of the day. The much-heralded Museum at Bilbao by Frank Gehry has only been possible through the use of computerized modeling. Its design of curves was beyond what normal sheets of paper could explain. But that in itself does not necessarily imply more than that it was complex.

Figure 12: Rice Retreat -- Black Poplars

9. Architectural Drawings as Fractals of the Architecture

In one sense, the methods of architectural design which have been used for centuries of time by architects, are based on a fundamental fractal relationship. Buildings of hundreds of feet in dimension are designed on paper that is typically 2 feet by 3 feet in size. There are floor plans, elevations, sections, and details of the various parts of the building. What is the relationship between these drawings and the actual building? The drawings are in some form a smaller version of the actual building. We never inhabit the drawings, but they serve as a way that humans can understand and develop the actual building. Through the drawings, people imagine that they are inhabiting the building. The drawings are the real building, in this dream-world of design time.

One aspect of fractals is that they can contain an enormous amount of information in a small formula or package of rules. In this sense, a set of architectural drawings and specifications are a fractal of the larger building. What is described on perhaps 10 sheets of drawings and 50 pages of specifications, through a year's labor of 100 people ends up being a building. Whereas in physical reality we can experience only one part of a building at a time, the drawings allow us at one sitting to comprehend the whole of the building. A builder takes the set of drawings and uses them by cross-referencing between plans, sections and details to effectively expand his knowledge through a construction process that results in the finished whole building.

Figure 13: Rice Retreat -- Red Alder

10. From Architectural Drawings to Buildings: A Fractal Process

Scientific theory describes two types of chaos -- deterministic chaos and indeterministic chaos. The former is a system in which the place where an action changes from a linear response to a non-linear response can be known. For example, in a car, when driving at 100 mph, if the steering wheel is rapidly turned beyond some angle, the car will lose controllability and begin sliding and spinning in an unknown way. The point of change from control to non-control can be determined to some degree. Indeterministic systems are ones which appear to always be unknowable in this regard. It would be as if the amount of change in the turn of the steering wheel to achieve uncontrollability is different each time. Perhaps there is ice on the road and strong winds which randomly blow first from the left and then from the right. Now the system becomes completely indeterministic. Of course, if we could know exactly from which way the wind is to be blowing at each point on the road along with the location of every patch of ice, maybe we could turn this into a deterministic chaos! But this kind of absolute knowledge seldom exists in the real world.

There is an enormous, gigantic, and all pervasive indeterminacy in the normal construction of a building. As a building takes form, the owner of the building may decide that there are special views out of windows that they want to capture which only could be understood from standing on the floor of the partially finished building. Windows might be moved to the left or to the right to capture a special opportunity. Sometimes a builder makes a mistake and builds the building differently than it is drawn. The mistake may never be caught, adding a certain chaos that is only discovered later (or maybe never discovered). Alternatively, the builders "mistake" might be based on better knowledge than the architect's, so that it results in a better building than was drawn on the paper. In this respect, Builders save architects' lives every day. Every architect has laid out a building where a pipe ends up supposedly going through the middle of a room, where in fact it can't. It is only through the innate complexity of the construction process that the building actually becomes a beautiful reality.

Figure 14: Rice Retreat – Oregon Oak

11. Architecture, Seeds, and Fractals

During much of the last hundred years architecture has been viewed as an object. It has been called a "machine" for living in, it has been classified into "styles", and in our modern-day American world, a good citizen aspires for a "McMansion" to go along with the fancy car, power boat, and big screen TV.

We view architecture as a thing, that is being constructed or is finished or that needs repair. There is an assumption that it has some kind of perfect form — for each person or organization there exists a "piece of architecture" that fits that person or organization.

Books on the history of architecture have sometimes emphasized this static quality, by distinguishing "architecture" from "building" which may be constantly changing and is thus less important (or simply less describable). Just as a plant grows from a seed, one might study a specific piece of architecture as growing from an architectural fractal. We have considered that the architectural drawings are in some form a fractal seed of a building that comes into being. In the case of Frank Lloyd Wright's buildings, there often was an actual underlying form that he used to help generate the building. Even the chairs Wright designed specifically for each house mimicked forms from other parts of the same house design, thus creating a fractal relationship to sit in. Unfortunately, the fractal relationship did not typically result in a chair that was comfortable it sit in!

Fractals give us a new mechanism and language for understanding architecture. In using a fractal geometry for architecture, we immediately begin looking at and understanding the complexity of architecture, and how the forms regenerate at different sizes and locations.

12. Fractals in Architecture: the self-similarity of all architecture

There is a sense in which all architecture is more similar than different. For humans, architecture at its root creates a sense of nesting or dwelling. Through a combination of enclosure and openness there is created in architecture a place to receive man's spirit and body. An enclosure with a warm fire within, warms the body; an enclosure of a home and a warm bed creates the place of dwelling for the human spirit.

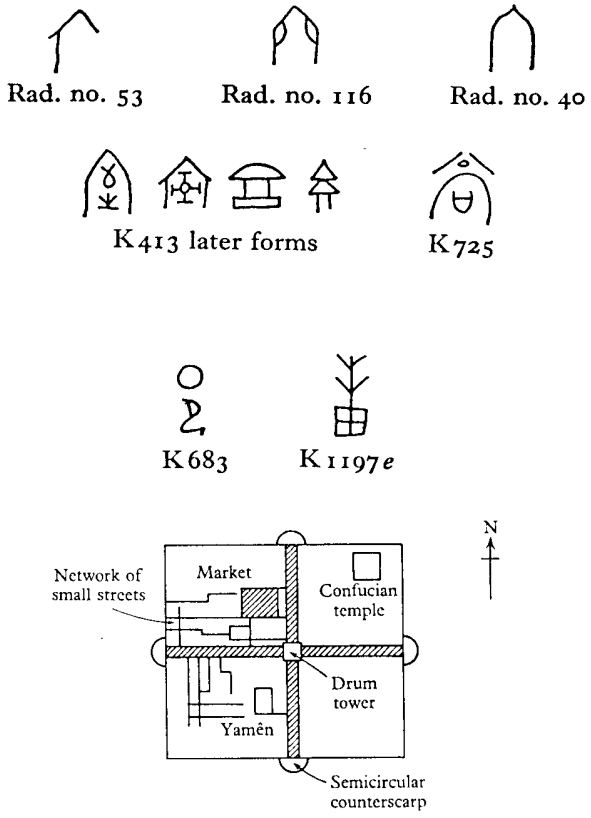


Figure 15: Chinese Character Roots

There is a sense in which this kernel, or seed, of architecture can be tracked as the form giver for all architecture. The Chinese written language provides a visual history in its characters for architecture or building. In 1974 I was fortunate to be able to meet with the scholar Joseph Needham to discuss Chinese architecture and landscape. He noted that there are three radicals which express the origins of building and architecture[9]. The first, Radical 53 *yen*, represents a lean-to shelter against a cliff. The second, Radical 116 *hsueh*, represents a cave or pit-dwelling in rock or soil, and the third, Radical 40 *mien*, which represents a simple gable roof.

In all cases there is a sense of an enclosing roof at the root of the Chinese sense of building. A similar analysis of the Chinese characters for "city", are based on a person kneeling before a circular walled enclosure, or branched paths leading to a square-walled enclosure with major internal cross-streets (Needham, page 72).

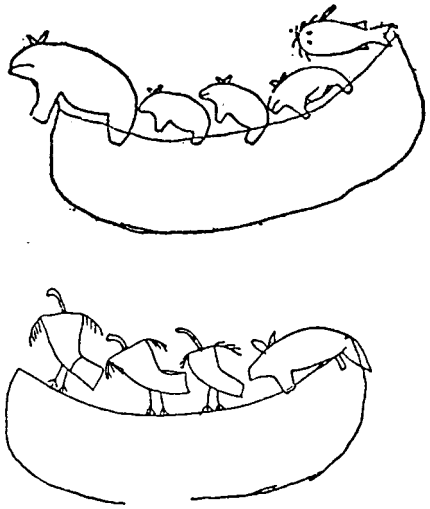


Figure 16: Ojibwe Birchbark Canoes[10]

Looking at other ancient writing systems, this Chinese example might be contrasted with that of the Ojibwe Indians (*Anishnaabeg*) who in their written language (rock art) don't seem to show enclosures. The primary human built form is image of a canoe with paddlers. For hunters and gatherers there is less of a sense of architecture; the basic ability for transportation to move throughout the world is more important than an individual building within it. The primary transportation mode for the American continent for the 6,500 year period 5000 BC to 1500 AD was by canoe.

However, as to a sense of "dwelling", we note the use of the symbol of a Mide' pole and stone, which represents the song with the repeating words "On the center of a peninsula; I am standing." This and the city with branching paths above, have an obvious form similarity, and one can feel a similarity in the importance of "place." Perhaps the sense of a ceremonial tree on a central rock, is truly the origin of the sense of city.

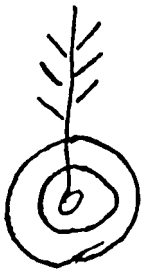


Figure 17: Mide' Pole and Rock[11]

It would be interesting to perform an analysis of the history of architecture, using fractals as a measurement and descriptive methodology. The simple hut which Rykwert considers in his book *On Adam's House in Paradise: The Idea of the Primitive Hut in Architectural History* may be this fractal origin. This seed then grows more and more complex – as exemplified in its extreme by medieval cathedrals and pueblo cliff dwellings – or is made even more simple and linear by Philip Johnson in his famous glass house.

Figure 18: Tipi on Willamette River, 1998

13. What is Chaos Theory?

By the use of computers and ingenious software, scientists are now able to find solutions to extremely complex mathematical equations. The computers are programmed to simulate the scientific event being studied. Just as most kids today spends hours each week on the computer playing graphics games – Playstation, Diablo2, Mario Brothers, Nintendo, etc. – for scientists the computers are modeled to simulate weather systems, biological communities, cosmological events, earthquakes, and architectural structural systems.

Prior to the availability of computers, scientists could generate the complex equations that were believed to describe these phenomena. But there were no ways to find solutions to the equations. There often were so many different equations that interacted with each other that it would have taken lifetimes with a paper and pencil to figure out what the answers might be. With the new science of complexity, these interconnected formulae are solved through trial and error, utilizing the capability of the modern computer which can perform millions of calculations per second.

Let's walk through an example, to give a sense for how the science of chaos works. Suppose an extremely complex formula were developed to predict the temperature – call it "T" – at Chicago, Illinois on August 15, 2005 at noon. The computer might simply guess 90°F, which would be an average noontime temperature for that city at that time of year, and plug that value into T in the equations and see whether it is the answer. Undoubtedly it did *not* solve the formula exactly (it was simply a guess). Then the computer would repeat the same calculation with T = 91° and T = 89°.

If the computer determined that T = 89° was getting closer to the correct answer (as with elementary school division, the "remainder" was getting smaller) then the computer would go to 88°, 87°, and 86°. Perhaps by the time T = 86° was computed, it was found that the remainder instead of continuing to decrease was now increasing. Then the computer would start looking for an answer in between 86° and 87°. In this way the computer iteratively, step-by-step, searches for an answer to a complex problem.

Where chaos theory gets interesting, is when that same formula is tested for solutions, values of T, beyond the normal expected range. Suppose the computer starts marching on down 80°, 70°, 60°, and finds a solution to the complex equation at 0°F, and then even a third possibility of a temperature at -100°F.

Our first inclination would be to say that these other two answers are absurd! How can the temperature in the middle of the summer in Chicago, Illinois be -150°F? But what appears to be ridiculous chaos may in fact help us understand the chaotic nature of reality. For example, suppose the 0° answer represented the geological era of an ice age, when ice covered the earth to the 45th degree parallel. Suddenly this number might make sense. Or, consider that there may be a stable climate on the earth for which the earth is covered with ice and snow, and it is so white and reflective of sunlight, that it can never heat up. Then that negative -150°F might make some sense.

Years ago, the author was involved in developing computer models of the earth's climate that showed chaos such as described above. It is interesting that this same research has continued on in the years since. There are now more interesting simple earth climate models that include dynamic feedback mechanisms that cause a kind of oscillation of the earth's climate. For example, Michael Ghil has developed a "cryothermodynamic" model[12] that recognizes that at lowered temperatures there is not much moisture in the air, yet in the summer the ice mass continues to melt, reducing the amount of "white" snow-ice reflecting away the sun's heat – thus allowing more heat from the sun to stay at the earth and raise the earth's temperature. His model develops regular oscillations at time periods that match the 100,000 regularity of periodic ice-ages during the last 2 million years of the earth's geologic history. Thus, in Ghil's hypothesis, the earth is a kind of musical instrument, with oscillating "tones" of characteristic frequencies that a human will never hear, but which we look at the geologic record and see the visual results – in northern America – as the principal force carving our landscape.

Scientists commonly solve complex non-linear problems with a computer by guessing answers and searching iteratively for an actually correct answer. When the computer starts to zero in on a place where a solution seems to exist, we say that we are in the domain of a "Lorenz" or "Strange" attractor. The first term honors Edward Lorenz, a meteorologist from MIT who was one of the earliest scientists to recognize meaning in what at first appeared to be chaotic results. The concept of "attractor" indicates that as if by gravity, the computer seems to be getting pulled closer and closer to a solution.

Another way to imagine a strange attractor is to imagine a physical example. The search for an attractor might be imagined to be like a floor of a large room, where the floor has many dips and rises to it. If one rolled a ball back and forth all over that floor, one would find that at the low spots the ball would tend to start circling around and staying within that area. The force of gravity would

tend to trap the ball at the low spots, while rolling it faster away from the high spots. Finding the domain of a strange attractor would be similar to moving a ball carefully around a floor until an area is found where it tends to keep rolling in a spiral closer and closer to a low spot.

Every practicing architect knows that chaos comes with the territory of architecture. After a few years of practice every architect has a book full of stories about the madness that can occur during a design project. Early in my practice I had a project of renovating a run-down old building that involved first putting it on the National Historic Register, and then doing major repair and restoration. The building was accepted as being of national significance, and the restoration design was approved by federal officials. One day while renovation was under way, I was on one of the weekly inspections at the building, which overlooks the Pacific Ocean. We started on the fourth floor, examining the work room by room, and continued on like this through the 3rd and 2nd floors. Finally we arrived at the bottom of the stairs on the ground floor. I looked up to find that the entire north exterior ground floor wall was *missing*. The contractor, who could have mentioned this at the start of the meeting, said he had no idea what had happened. With some prodding, he finally confessed that on finding it fallen down when one of their trucks backed into it, *he had thrown it away*. Now, under the Secretary of Interior's required standards for landmark buildings, which as the architect I was sworn to uphold, the preservation of existing materials is the prime directive. So now we had to explain how one of the historic walls of building had been lost during construction! *O mighty chaos did it*.

14. Architecture as a Chaotic Process in Search of a Strange Attractor

The process of design and construction in architecture is chaotic in many ways. It is an iterative process that begins with a desire or a need for a building. The designer (who might be anything from an owner to a professional) makes a few marks on the back of an envelope that initiate the form and shape of the building. Consultation with friends or a husband or wife (or looking at other buildings) results in a next generation of the design. Initially it is a sketch with no dimensions or scale. After some refinement it may gain dimensions and have a specific place designated on the site. Fine tuning of the design may ensure a building to have good access from a street, or a good view of a river, or may ensure that rays of morning sun come through a window on the solstice to light a particular room.

Often the changes from one step of the design to the next are minor and consist only of little refinements. Other times they may result in a big change to the building, such as the adding of a new wing to the building, or another floor, or the breaking of the building into two buildings. When the building changes are relatively small from step to step, that is a sign that the building design has reached a certain stability. In terms of chaos theory, we would call this reaching the domain of a strange attractor.

Once the design is in the domain of a strange attractor, the iterative changes begin clearly refining themselves to more and more detail for the same general project. Doors are added and windows are added but the direction of door swing or the type of window may still be changing. However, the overall form of the building is stable. As time goes on even the windows and doors are now fairly stable and it's a matter of whether the floor surface is wood or carpet or linoleum or rock.

As with chaos theory, even though we think we are in the domain of an attractor there is always the possibility that the iterative process will enter a chaotic region for which the entire design is forced to radically change. This is comparable to science fiction where wormholes exist and there is a complete lack of spatial continuity. Unfortunately wormholes do exist in architecture.

For example, let's suppose the building plans are virtually complete and submitted to a local building department for a building permit. The building department may determine that due to a new law, no building is allowed on that site because it is an "environmental zone", a "wetland", or a "geologically unstable" site. Or legislatively a planning department or other political entity re-zones what was allowable on a site, to be abruptly not allowed on a site.

Less disastrous, the company which makes the windows and doors you have selected goes bankrupt, and you have chosen unique sizes which are now no longer available. Another common problem is that the size or topography of the property on which the building is placed is found to be different than was shown on surveys used for the design. Suddenly the entire design has to have one wing taken off or the building mirrored to create a different configuration. These kind of things happen quite often in architecture.

At the time of writing this paper, in 2000 in Oregon, the newpapers regularly discuss a house being built on a bluff overlooking the Columbia River Gorge. The house is 80% complete, yet the local building department has placed a "stop work order" on the entire project because it may be in violation of planning rules for the National Columbia River Gorge National Scenic Area. So here is a project that will likely have a major change to it after it was largely thought to be completed. The options are demolishing the building, moving the building, painting the building green, and/or trying to create a dense buffer of trees and shrubs in front of it. The agency in charge is leaning toward requiring demolition, a worm-hole worse even than dreaded carpenter ants!

When we train apprentices how to have success in design and architecture, we should tell them that these are the norm and not the exception. Today's cultural world has become so complex that virtually every job has some major form of discontinuity and chaos such as are being described here.

It's important to realize that this chaotic process is natural. Just as there are windstorms and floods that determine the general landscape that we live in, so in our buildings and architecture they are formed with equally cataclysmic events. Fortunately for most buildings, the major determining events though abrupt and often upsetting, are resolvable after several days or weeks of problem-solving and creative design.

In some ways this is the true work of the architect or designer, -- how to create a successful, healthy, good building within the context of the chaos and disruption of the design and construction process. It is a little bit like Goethe's revelation that Newton's theory of gravity is interesting, indeed it is remarkable — but what is even more astounding is to try to figure out how the apple got up in the tree in the first place.

15. Architecture: the History of Man vs. Nature

-- *The study of geometry is the study of man's relationship to nature.*

For Native Americans and most indigenous cultures, the geometry of architecture is quasi-circular in shape. Historians and anthropologists have long debated whether house form is simply a product of building technology or worldview. Obviously, the easiest building forms are of such elementary construction as the stacking of sticks around a central point to create a tipi or kiva, and then spreading animal skins or birch bark over the surface. But anthropologists have long known that the inside space has traditionally been described as a microcosm of the universe. The door often opens in a prescribed direction, the four cardinal directions relating to sunrise, sunset, and their ninety degree midpoints are often related to certain gods. There is often a male side, a female side, a place of honor (opposite the door), and so forth. In some sense, the rounded shape is a mimicking of the 360 degree arc of the celestial sky.

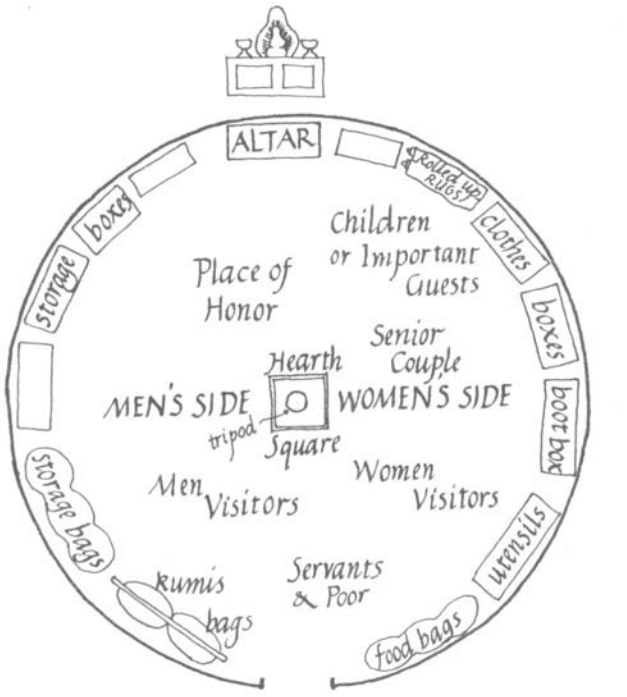


Figure 19: Yurt Interior Space[13]

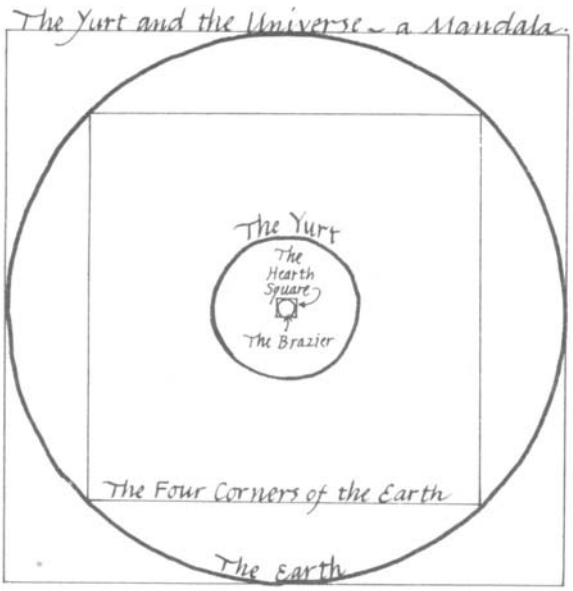


Figure 20: Yurt & Universe

The celestial circles of sun and moon are copied in man's drawing of a circle as our first ideogram — it depicts nature idealized. Clarence Glacken's wonderful book *Traces on the Rhodian Shore: Nature and Culture in Western Thought from Ancient Times to the End of the Eighteenth Century* takes its title from Vitruvius's preface to the sixth book of *De architectura* which describes how the Socratic philosopher Aristippus lands on a wilderness sea shore and finds on the beach, scratched into the sand, the lines of regular geometrical shapes. From this he knows that man is present.

Figure 21: Modern/Ancient Yurt

HARVARD COLLEGE LIBRARY

Frontispiece of David Gregory's edition of Euclid's *Opera* (Oxford, 1703) illustrating the shipwreck of Aristippus as related by Vitruvius in the Preface to Book VI of his *De architectura.*

Figure 22: Geometry of Man

My friend J re-enacted this experience 2500 years later. Walking along a beach on Sauvie Island, 15 miles north of Portland, Oregon, along the Columbia River, he noticed a circle etched into the sand. He reached down and found it was a 6" diameter rock that had been exposed after recent flooding.

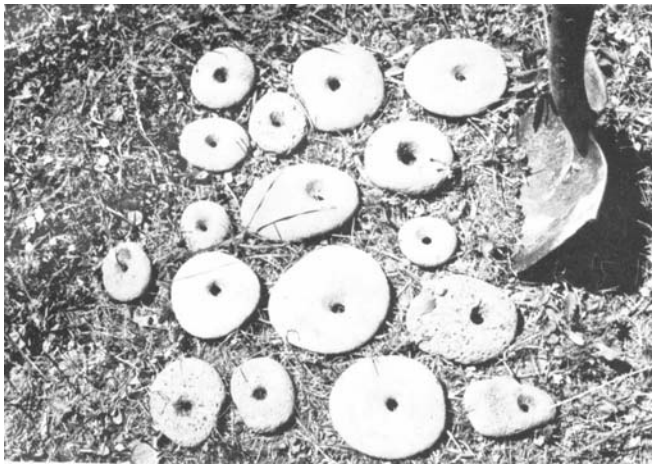


Figure 23: Chinookan Perforated Fish Net Sinkers[14]

The rock had been carefully ground into a donut shape by Native Americans for use as a fishing net weight. Was it 2500 years old? Perhaps more, perhaps less. Most importantly, it was a sure sign of humans. A geometrically perfect circle, created by the spinning and grinding of one rock on another, by human hand.

The Greek temple is a celebration of rectilinear geometry in plan and elevation. However it is interesting that the design of smaller elements like columns are finely fluted and detailed – many architectural historians believe – to represent bundles of sticks and to have a taper based on an organically defined curve. Thus, beneath the Euclidian architectural geometry of the Greeks is found a more natural geometry reference.

Mound building represents right from the start a more fluid geometry. Objects often appear to be representations of animals or organic natural beings of some sort. The diagram below is located near Prarie du Chien, Wisconsin. In many parts of northern United States and Canada ice age geological events left eskers as a kind of natural earthwork on the land. Eskers are the gravel bottom remnants of the great rivers that flowed in the ice fields hundreds of feet above the ground during ice age times. The snaking forms create natural images of animals, and likewise create raised areas that were often used as sacred places for burial, as well as travel pathways between lakes.

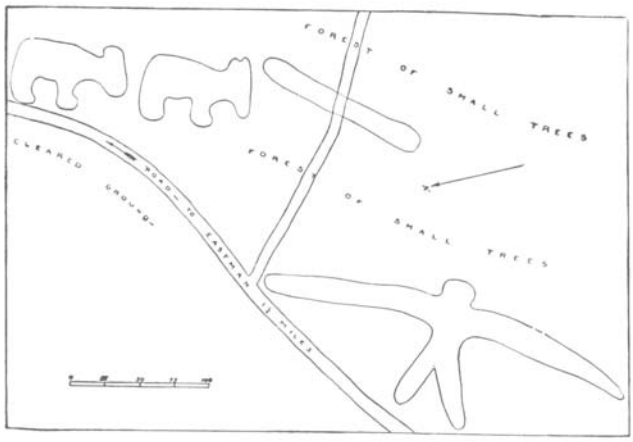


FIG. 16.—Mounds on northeast quarter of Sec. 24, T. 8 N., R. 6 W., Wisconsin.

Figure 24: Bird, Bear, & Linear Mounds[15]

In the modern world of the year 2000, man no longer needs to so strongly distinguish himself from nature. Those Euclidian forms – circles and squares – are not so important to place in the sand. Rather, with so much of the earth disturbed by man's presence, we work rather at trying to become more "one" with nature and to reduce our impact. Thus our developments technologically work

to control storm water runoff and pollution, to avoid destruction of animal-plant communities.

Likewise the geometry of our buildings is becoming more fluid and chaotic, mimicking the fluidity and chaotic geometrical qualities of nature. Thus, Mandelbrot's book *The Geometry of Nature*, first published in 1977, provides a methodology for a whole new method of description of the earth, such as the Greeks (and much of subsequent Western science) never could have expected. It is really a wondrous day for man.

The buzzwords in architecture today are: sustainability, natural, recyclable, green, green urban infrastructure, bioregionalism, restoration, interpretive planning, community values, communal places, collective stewardship, ecotourism, landscape ecology, eco-design, equity ecology, appropriate technology, pedestrian friendly, native, ecological, bioengineering, enviro friendly, environmental, sustainable transition, bamboo, and corn-cob! Many of these terms are actually over thirty years old — almost “hippie” concepts. It has taken a while, but on the face of it, we are "full steam ahead and damn the torpedoes" aimed at trying to turn architecture into something that fits with nature, rather than fights it.

16. Chaos & Non-linear Dynamics in Architectural Engineering: Stone vs. Steel

One normally thinks of engineering as a deterministic field. Architects now days usually turn to structural engineers to ensure that their designs will stand up. Our building codes define specific calculation methods which determine whether a building's structure is acceptable or unacceptable. The engineer makes calculations to determine the yes or no. There is no middle ground.

Contrary to this sense of deterministic structural engineering, recent physics research is discovering that the centuries of engineering success in using such basic materials as rock and concrete, is due in large part to its complex and non-linear qualities -- not just its static strength. A recent article titled "Non-linear Mesoscopic Elasticity: Evidence for a New Class of Materials" in *Physics Today*[16] defines a new class of materials called "non-linear mesoscopic elastic" materials. These are materials made up of grains which act as rigid units, while the contacts between the grains constitute elastic elements. It is found that in sandstone, igneous, and metamorphic rocks the bonding system between the grains consists of a "fabric of defects (cracks) that participates in the elastic response of the rocks."

The article points out that these non-linear materials are quite different from linear strength materials like aluminum, steel, or glass, for which the elasticity arises principally from atomic scale forces between the atoms and molecules. The elasticity, stress, and strain of a material is very predictable when changes are due to such atomic scale forces. However, for non-linear materials the fabric of cracks and grains creates a complicated system that is very hard to mathematically describe due to its complexity.

In fact, when a non-linear structure made of stone or concrete develops cracks, it may well be creating a complex fabric which can increase its ability to absorb energy (such an earthquake or wind load) without significant failure of its strength as a whole. It is possible that the more the material develops a range of cracks, the more resilience the material may have for a range of amplitude of forces.

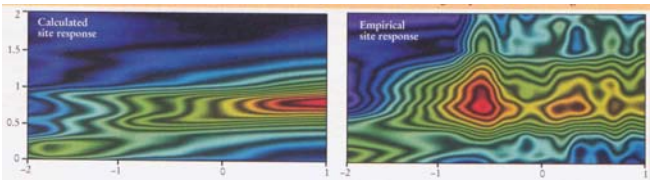


Figure 25: Predicted vs. Real Rock Response

This is quite different from what we mean by "crack" as a structural failure for traditional "modern architecture" materials such as glass and steel. When glass fails it cracks and its strength rapidly disappears. Failure of modern engineering materials during a structural force impact which is greater than an allowable force, often results in the complete failure of the material.

For old-fashioned concrete and stone, however, this study of non-linear material theory suggests that a system of cracks is already existent throughout the material and peak events can often be absorbed without complete failure of the material.

We may learn that the materials of "modern architecture" are more susceptible to failure in short peak events than we had previously thought. This would of course be especially tragic, if we find that our peak events are under-sized. The history of earthquake engineering analysis during the last 50 years indicates that the predicted peak forces are steadily increasing. Here in the northwest, in the Portland area, they appear to be continuing to rise as we learn that there are earthquake faults closer to us than we had thought. Perhaps there are earthquake "cracks" in the earth's non-linear geologic materials closer to everyone than has been previously thought. As our microscopes get better, we can see more of them!

Building code prescribed engineering analysis today does not take non-linear effects specifically into account. As this field progresses, we may find that our understanding of the engineering of materials for building construction is changed through the new understandings of chaos theory and non-linear dynamics. We are probably at the threshold of many new discoveries in the area of construction materials.

In any case, these recent studies show that the method of analysis of a stone or concrete structure versus a steel and glass structure should be fundamentally different. Contrary to this, the building codes of today assume the need to withstand the same force, independent of material type, and not take into account non-linear or chaotic force absorption methods.

It is worth noting that modern codes do recognize the non-linearity of interaction between a building at its site.

The earthquake forces which buildings are required to withstand, are created from movements of rock below the earth. It is the internal fabric of defects and cracks in the earth which result in slippage and motion which in turn travels through the rock, and up through the site substrate into the building.

A common engineering problem is to determine the frequency of the ground motion under the building so that the building itself can be designed with a different frequency to avoid absorption of the earth's vibration energy coming through the base. These kind of studies to calculate the site response of an earthquake often assume a uniformally elastic hard material on which is placed a layer of non-linear earth material which gives amplification to the underlying forces. For example in a model simulation consisting of a 300' thick non-linear layer over an elastically hard base material, theory and empirical studies show there is a resonance in the range of 1/2 to 1 Hz (cycle per second).

Ultimately the whole engineering problem of how to design a building that will stand up in an earthquake, is a non-linear problem. It involves a great deformation of rock deeply within the earth, creating energy which is passed by complex vibrational modes to the earth's surface. Like waves in a pond there are reflections of the vibrational energy between the base rock and overlying materials, so that at the surface some sites have high amplitude vibrations and others have no vibrations, though they may sit nearby each other.

Then there is a non-linear coupling between the site vibration and the base of the building, which depends on types of materials, sizes of structural elements, and the overall building shapes. Finally, there are vibrational modes of the building itself, which harness the ground frequency and force the building to itself begin shaking with various frequency modes.

What an interesting, amazing, and complex problem this is. Our building codes condense this problem down to a static force, as if it is a gravitational steady force acting horizontally. Is this really a reasonable assumption?

My friend Z has an unreinforced three-story brick building in downtown San Francisco, across the street from the TransAmerica Pyramid. The 1989 Loma Prieta earthquake which flattened many buildings in the Marina District, did not do one bit of damage to his little building. Not even the beautiful handcrafted stained glass window installed by an artist friend had the slightest bit of damage. This in spite of the fact that the top eight feet of this same building fell off during the San Francisco quake of 1906. Right now, under San Francisco regulations, a new steel frame is being added to the inside of the building for earthquake protection. Will this modern, linear structural material save the old brick and mortar building? Or will it cause a hardening that ultimately forces the whole building to fail in the next big quake? The chaotic nature of earthquakes and buildings, and our limited knowledge make this an unknown, but a very real possibility!

17. The Significance of Aerial Photography & GIS

-- "The airplane has unveiled for us the true face of the earth." Antoine de Saint-Exupery, *Wind, Sand, and Stars*, 1939.

Aerial photography and satellite imagery have revolutionized site design and building context analysis opportunities for architects. Carl O. Sauer's nitty-gritty, on-site, "look-see" approach is still absolutely necessary to understand the workings of the local environment. The old-fashioned work of the mid-twentieth century geographers and ecologists was vitally important in establishing the importance of "environment" as a necessary ingredient to all design efforts. The impact of such early works as Leopold's *Sand County Almanac* and Sauer's *Man's Role in Changing the Face of the Earth* cannot be underestimated in their influence of where we are today in the availability of site planning information.

The resources are far beyond anything Sauer or Leopold and the others at mid-century could have imagined. We now have satellites with immediate capability of looking anywhere on earth with one meter resolution. And our "old-fashioned" airplane borne camera aerial photography can provide us with anything from broad regional images down to site-specific base maps with a resolution of a hundredth of a meter.

Through a series of aerial overlays, we are able to examine and better understand changes in landscape such as result from season or climate change, or even changing water levels. We are able to see diurnal changes relating to rush hour traffic patterns as well as sun shading angles from topographic influence. With these tools we are better able to comprehend the "wholeness" of a site or region.

Using the human eye as a camera, a personal flight in an airplane allows direct "look-see" of a development's site context as well. Some national retailers know this value well and require that high level company planners and managers examine and approve every new site for a retail store from a helicopter before giving approval for construction work to begin. From the air it is patently obvious whether there are residential areas nearby to serve the store, and whether the highway system provides easy access and visibility — in other words, whether the planned store is going to work or not.

Through the magic of computer chips and data storage devices, all across our nation this information is being gathered, square meter by square meter, and is being turned into a map. Ultimately this map will show virtually every utility pipe, stream, road, and pathway. In commercial forests it may show every tree, and there may be a tag attached to that tree (in the computer) with its date of birth and planned date of harvest. We have entered an information age where all of this data will be available for planning and design of buildings, cities, and regions. And it will be available to the scientists studying watersheds and fisheries and airsheds.

What in the past was called chaos or wilderness, is for today's designer available as knowledge and understanding. It was previously considered chaos because the available information was in a kind of "overload" condition. There was no way to sort it and assemble it in meaningful ways. Using the modern mathematics and physics, designers now have the tools to design with the landscape as a strong backbone of influence in our design efforts. This is true whether we are designing a building, a campus, a piece of suburbia, a park, a piece of a city, or a whole geographic region.

18. Feng Shui

For the oriental culture this sense of fractal interaction between site and building is less a new idea than for us westerners. The ancient science of "*feng shui*" is a form of environmental design that attempts to find harmony and health in relationships between places, buildings, furnishings, and a landscape.

Feng shu" translates as "wind and water." The flow of wind and water over the landscape, is the energy that moves through the landscape. Thus designers create buildings, cities, rooms and gravesites in ways that fit with the energy flows of the surrounding land. If bad energy flows are present, then elements are added to the design to compensate for these problems.

One branch of *feng shui* uses books showing standard geographic forms that can be found in the landscape. A commentary along with a master's training then explains how to site buildings correctly within these specific forms. Another branch of *feng shui* utilizes a compass to identify appropriate directions to orient a building on a site.

Feng shui design utilizes patterns and forms of nature. It is based on an ancient (yet still functioning) integrated art and science that promotes a way of building with nature. The images below are from Needham's famous series of books about science in China. I was fortunate to be able to visit with Needham in the mid-1970's and discuss the subject of *feng shui* with him. He especially directed me to Stephan Feuchtwang's *An Anthropological Analysis of Chinese Geomancy*, 1974, which to this day remains an excellent reference for further beginning study by Westerners.

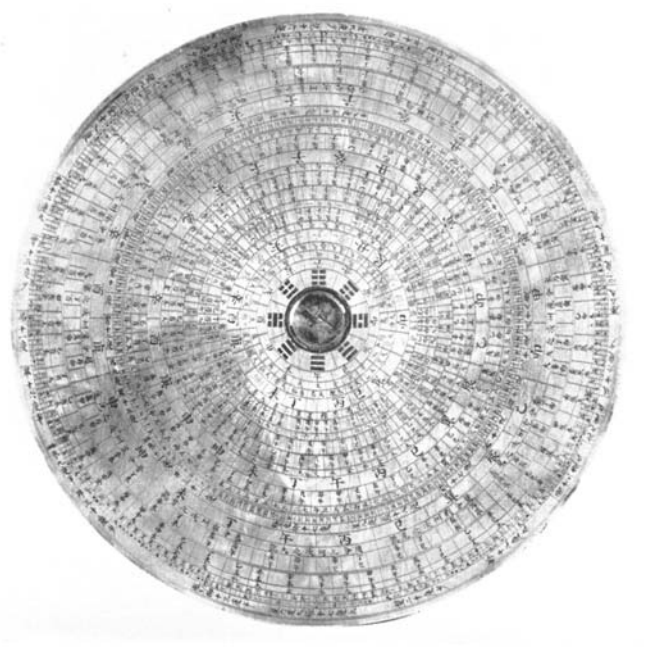
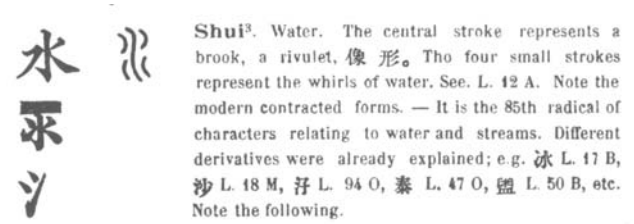


Figure 26: Feng Shui Compass[17]

Figure 27: Feng Shui Diagram showing Hills and Streams[18]

Fêng[1]. The wind; 从 蟲 省。凡 聲。For, says the Glose, when the wind blows, insects are born; 風 動，生 蟲，This composition and interpretation are in the manner of **Li-ssŭ**. —The ancient character was derived from 日 sun, 丿 motion (L. 7 A), 凡 extension, expansion. All this seems to mean that the atmospheric currents are produced by the action of solar rays; which is true for some winds. — It is the 182th radical of a group of characters relating to storms, etc. Phonetic series 439. See 颿 (L. 11 C).

Figure 28: Origin of Character Feng[19]



Shui[3]. Water. The central stroke represents a brook, a rivulet, 像 形。Tho four small strokes represent the whirls of water. See. L. 12 A. Note the modern contracted forms. — It is the 85th radical of characters relating to water and streams. Different derivatives were already explained; e.g. 冰 L. 17 B, 沙 L. 18 M, 汙 L. 94 O, 泰 L. 47 O, 盥 L. 50 B, etc. Note the following.

Figure 29: Origin of Character Shui[20]

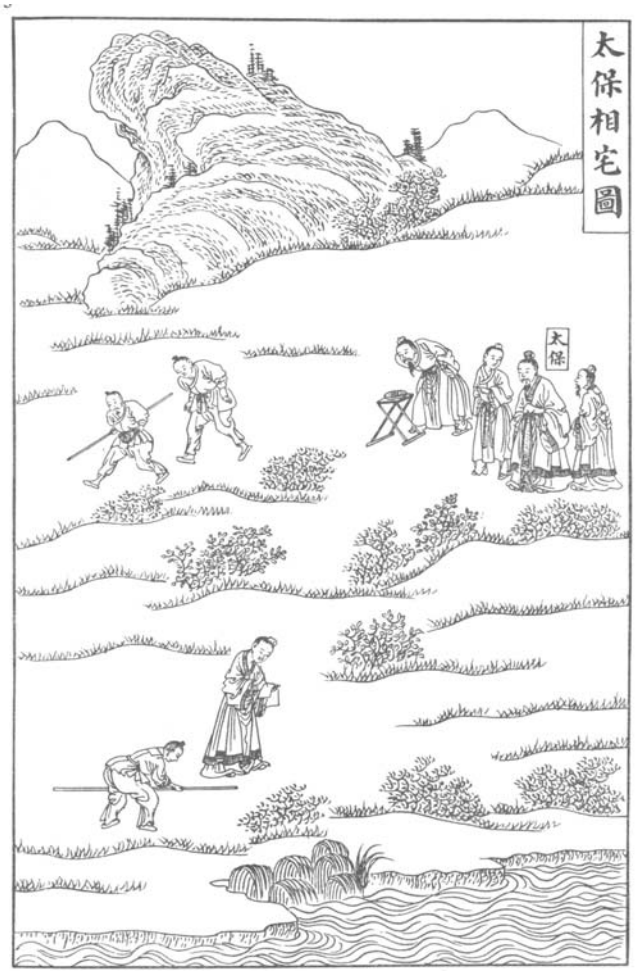


Figure 30: Consulting Compass in Siting of a New City[21]

One can project that the *feng shui* practitioners here are searching for the "geometry of nature" for this specific site, so that they can site the city and its buildings in a way that uses natures forces to reinforce the needs and desires of the human inhabitants. With today's knowledge of geophysics, chaos theory, and fractals, there are tools available to make this a thoroughly modern approach to site planning. Undoubtedly the historic Chinese approach has many hints and methods that would make such an endeavor successful.

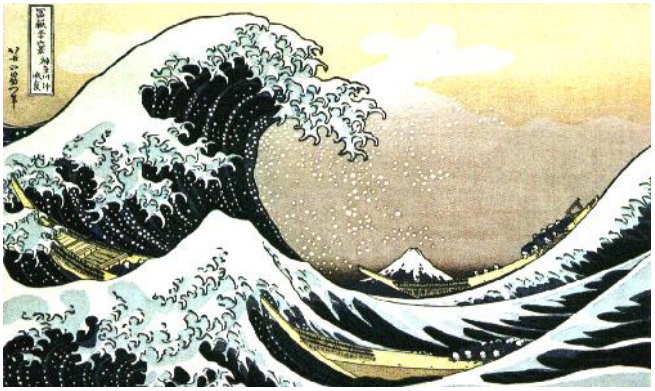
19. Chinese 'li' as Fractal Pattern

The Chinese word for geography is *ti li*, which translates literally as "earth pattern". This word has meant "geography" for over 2,000 years. (Needham, Vol. 3, pg. 500) The character *li* (K 978) in its ancient meaning signified "the pattern in things, the markings in jade or the fibers in muscles; as a verb it meant to cut things according to their natural grain or subdivisions." (Needham, Vol. 2, pg. 558)

Chu Hsi describes the word *li* (in 1713):

> "*Li* is like a piece of thread with its strands, or like this bamboo basket. Pointing to its row of bamboo strips, the philosopher said, One strip goes this way; and pointing to another strip; Another strip goes that way. It is also like the grain in the bamboo -- on the straight it is of one kind, and on the transverse it is of another kind. So also the mind possesses numerous *li*." (Needham, Vol. 2, pg. 558)

Needham says that *li* is "the order and pattern in nature . . . but it is not pattern thought of as something dead, like a mosaic; it is dynamic pattern as embodied in all living things, and in human relationships and in the highest human values. Such dynamic pattern can only be expressed in English by the term "organism."



The *li* of water might be thought of as the living order and pattern of water. The image of water as made up of waves that are in turn made up of smaller waves, has a long tradition in Oriental painting. Chinese, Korean, and Japanese artwork show that artists in those countries used their artwork as a medium to expose the patterns of nature. A painting such as shown above, provides an almost formulaic expose of the "underlying form of water."

Needham in his examination of the concept of *li*, relates it to the organic philosophy of Gottfried Wilhelm Leibniz (1646-1716). Leibniz is probably best know for his mathematical theories – he is credited with inventing differential and integral calculus independently of Newton. Leibniz was also a philosopher, and as a student of Chinese philosophy and literature throughout his whole life, he is believed to have known about the concept of *li*. Needham notes that Leibniz's treatise, *The Monadology*, developed a theory of "monads", of which he considered the world to be composed. For Leibniz each monad mirrored the universe. Leibniz hoped to use the monad concept to overcome the conflict between theological vitalism on the one hand, and mechanical materialism on the other. (Needham, Vol. 2, pg. 499) Here the phrase "mechanical materialism" refers directly to Newton's theories of motion and gravity.

Leibniz explains the theory of "modads" in *Monadology*:

> "Every portion of matter may be conceived of as a garden full of plants or a pond full of fish; but every stem of a plant, every limb of an animal, and every drop of sap or blood is also such a garden or pond." (*Monadology*, Section 67)

We know that Liebniz used the concept of *li* to argue strongly against Newton's whole approach to science. Perhaps our modern concept of fractals has its origins in Liebniz's organic theory of "mondads". If so, then we can likely trace fractals back even a few thousand years earlier to this Chinese concept of "earth patterns" -- *ti li*.

20. Fractal Engineering in China circa 1609

The *San Tshai Thu Hui* encyclopedia of 1609 shows an engineering mechanism designed to distribute the weight of a heavy load so that it may be carried by 16 people. The diagram is shown below.

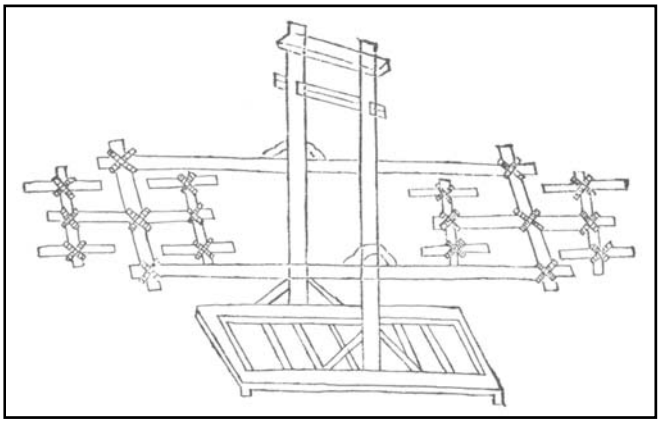


Figure 31: Load Distribution Fractal Machine

The diagram shows how fractal geometry provides a natural way to approach engineering problems that require the ability to add up small forces to create larger forces. In this case an engineering structure is designed so that the load is passed from larger to smaller elements through a self-similar geometrical relationship. Needham says that this method of carrying loads was still common in the mid-1900's, and it is still likely in use today.

Figure 32: Load Distribution Device in Use[22]

21. The Architect as Conjurer

Normally, conjuring is thought of as a mystical activity that only occurred in primitive societies. The book, *The Role of Conjuring in Saulteaux Society* (by A. Irving Hallowall, 1971) contains a fascinating discussion of conjuring activities among the Saulteaux Ojibway of northern Manitoba along the Berens River in the 1930's. In that society the conjurer was a kind of shaman who could tell other members of the band the current health of distant family members, could help to find lost objects, and could accomplish any number of other remarkable tasks, that in our society, are viewed as impossible to provide.

The conjurer's method was to construct a little hut of saplings, that was just barely the size of a single person. The conjurer got into the hut and through various means, including audience participation, was able to conjure up an animal spirit that would then be able to answer questions from the audience.

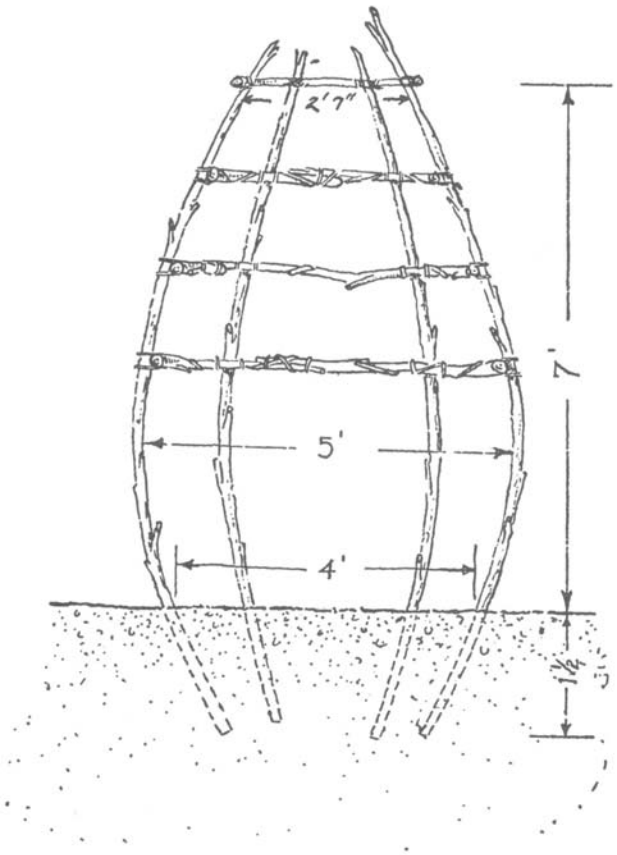


Figure 33: Cross Section of Conjuring Lodge[23]

The construction of the conjurer's hut is described as follows:

"It was constructed of six upright poles driven into the ground to a depth of one and one-half feet. These poles were set in a circle whose diameter was four feet. They were not driven perpendicular into the ground but inclined downwards toward the center at a slight angle. The poles themselves were nine feet long and two to two and one-half inches in diameter. Three were of spruce and three of birch. They were so solidly set that instead of pulling them out after the performance three of them were hacked off at the ground level with an ax. The tops of these poles were attached to a hoop which formed the top of the lodge, the diameter of which was two feet, seven inches. The poles which were diverging at ground level, were thus bent in a curve, and gave the slightly bulging, barrel-like form to the structure, the maximum diameter being near the middle; I estimated the latter to be about five feet."

"The lodge was approximately seven feet in height. Three other hoops equidistant from each other were bound to the poles between the ground and the top of the structure. Like the poles, two of these hoops were of birch and two of spruce. They were bound so firmly to the poles that one could stand on them. The bottom of the lodge was covered with freshly cut spruce bows, such as the summer dwellings of these Indians usually are floored with. To the hoop at the top of the lodge was tied a string of caribou hoof rattlers which sounded at the slightest movement of the structure. The lower part of the lodge was covered with several rolls of birch bark, which are the conventional coverings of summer dwellings. Around the top of it was thrown a piece of canvas, the lower edge of which was pulled down below the birch bark covering. In order to hold the birch bark and canvas in place, a carrying strap was tied about the middle of the lodge." (pages 37-40)

An example of the work of a conjurer is given as follows:

"Thirty or forty people had gathered for this particular seance and they disposed themselves in a circle about the lodge. It was possible to sit as close as one desired, but few sat nearer than four to six feet. Upon the arrival of the conjurer, his assistant, who remains within call during the performance, unloosened the tumpline bound around the structure and by shifting the birch bark to one side the conjurer was able to squeeze in. According to native theory the lodge should begin to shake before the conjurer is fairly inside. . ." (pgs. 40-41)

"Soon several members of the audience began calling for *mikinak*, the Great Turtle. `Mikinak! Mikinak! Where is mikinak?' the Indians shouted and, as soon as he arrived, a gentle ripple of laughter swept over the audience. Mikinak talks in a throaty nasal voice not

unlike that of Donald Duck. It is extremely characteristic and very easily distinguishable from other voices that eminate from the tent. His popularity with the audience was manifested throughout the evening by the almost constant stream of repartee which took place between members of the audience and this *pawagan* when he was present. Anyone may speak directly to mikinak and he always has a witty answer ready. . ." (pgs. 44-45)

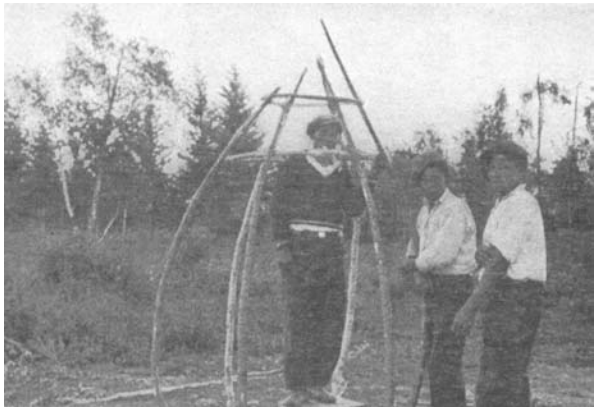


Figure 34: Conjuring Lodge Construction[24]

"On this occasion I said I wanted to know how my father was, as he had been very ill and I had received no mail. After the conjurer had been told my inquiry he repeated it aloud and someone in the audience called out, `Send mikinak!' and in a moment or two mikinak started on his journey to Philadelphia." (pg. 46)

"Suddenly the tent gave a jerk and absolute quiet reigned for a minute or so. Mikinak had arrived at his destination. Then a faint swishing sound could be heard and the tent began to shake with increasing violence. Harder and harder it shook and swayed rapidly from side to side, when, with a deep thud, it stopped abruptly. Mikinak had arrived in our midst again. . . Finally the Great Turtle stated the results of his mission in a sort of recitative style. He said that if he had found the right place, my father was no worse. And he added, as if by way of verification that he had found him living in a stone house, not in a log cabin. He said that I would get further news when I reached the mouth of the river." (pg. 47)

The author notes that when he arrived home at the end of the summer, he found that the mikinak's report concerning his father's health had been quite true.

Is it possible in today's modern world that conjurers exist? In a strange sense, this is exactly what architects do -- no more, no less. They conjure a building into existence.

A person who wants a building constructed commonly finds an architect on the belief that the architect can provide a building. However, really, the architect is only "conning" the person into believing that he can provide a building. It's not as if the architect has a supply of buildings on his site, and that the owner can come out and inspect them, and then buy one to take home. Rather the architect's work is all based on good faith and a belief system under which a building will come to the owner if the right steps are taken. It is not a secret that the architect never buys a board or swings a hammer!

Rather, the architect slaves away for a period of time and creates rolls of paper with lines on them. He tells the owner that these lines represent the building the owner wants. The architect continues the charade and after convincing the owner that the lines on a piece of paper will conjure up the owner's house, shows the lines to the local building department, convincing them ultimately that if the building were to appear it would meet all of the building code requirements for safety and health. Likewise the architect "cons" the bank into believing that if the bank provides money to the owner, that there is a building that will appear. Finally, the pieces of paper with line scratches on them is shown to various contractors, and they are "conned" into believing that if they do what is shown on the paper, a building will appear that the owner will like.

The term "con artist" is a reference to being a "confidence artist". The term is pejorative today. But really, what is wrong with playing the role of providing confidence to an important process. The architect never picks up a board, never drives a nail, and never holds a paint brush. The architect simply "conjures" the building into existence by convincing all of the various parties that if each does his piece, a building of a certain size and type will magically appear.

We read about the Saulteaux Ojibway and with our great "modern knowledge" sneer that such conjuring must be a trick. It does not seem possible that a person could somehow bring another spirit to life in their body, and that the spirit could tell of important actions in the world. Yet if we can accept that architect's scratches on a piece of paper can bring another person's desired building to life, shouldn't this be proof that other forms of conjuring are certainly possible? So, yes, "conjuring of buildings" is an everyday occurrence all over the world; it occurs every day in the creation of architecture.

The Saulteaux believe it is possible to build a tiny hut, get inside, have magical super-human powers to shake it, and be taken over by another being which then telepathically provides important information for human life. In our culture, people work with an architect and relate key pieces of information, and the architect telepathically converts this information into lines on paper, that other people view while in a trace, with the result that a building comes forth. One of these can simply be thought of as the inverse of the other. In one case a person goes into a hut to figure out what is happening in the dream world. In the other case, a person brings people into a dream state, and converts the thoughts into a hut.

22. Architecture & Black Holes

This paper has focussed on the modern science of chaos and fractals. However, these are in one sense just part of the modern general science of geophysics, which is rich with other parallels for study with architecture. One example is with "black holes"! There are many kinds of "black holes" in architecture; we'll discuss only a few here.

First, there are the all important "exceptions" in zoning ordinances and building codes which can make or break the planning and design process. Ultimately, these are local, and every architect needs to know their local applicable zoning ordinance and the applicable building codes to find them. As the *Uniform Building Code* (UBC) used in much of the western states says:

> "The provisions of this code are not intended to prevent the use of any material, alternate design or method of construction not specifically prescribed by this code . . . " UBC 104.2.8

This is an enormous black hole in the code that is very seldom used. It is a recognition that in spite of every effort at making the building design process linear, exact, precise, and democratically equal, the architect or engineer can suggest an alternative to the code if it can be shown to meet the same health and safety requirements. All exceptions processes are a kind of black hole that acknowledges that a set of "normal rules" can't work in all cases. They subtly acknowledge that the building design process is by necessity non-linear and chaotic at times. Otherwise the exceptions would not be in the code.

Currently these kind of general exceptions are very seldom used. The building departments around the country are notorious for resisting use of such exceptions. There is a feeling that by not using normative standards, that risk goes up. Ultimately it comes down to: "Will the building official be sued for allowing an alternative approach or technology?"

The new *International Building Code* (IBC), which will be enacted in the new millennium, is intended to replace the existing three different building codes which cover different parts of the United States. Perhaps this new code will become a standard for the whole world. In its current 1999 draft stage it includes essentially the same language as that of the current UBC.

Sometimes where public agencies attempt to create a level playing field, where one set of rules fits all, they in fact create a sterile environment. The IBC is intended to be a more "performance" oriented code. This is one of the basic tenets that were used as a justification for its creation. Thus at the building code level, there appears to at least be some movement toward the concept that the building industry is healthy when there are alternatives and exceptions for architects and engineers to use during their design. This is a recognition of the indeterminacy of the process. It is an acknowledgement that "less government is better, as long as basic fire and life safety needs are met."

A second kind of black hole in architecture is what some contractors call "the aggravation pit." Architects are notorious for driving contractors crazy during the construction phase, by trying to tell them "how" to build the building and by nitpicking at small issues that the contractor feels in reality borders on being irrelevant.

Here is a story told to me by a contractor. It is a story about how he outwitted an architect while constructing a large seven story hotel project near the waterfront along the east bay near San Francisco, California.

> "We had the building coming along just fine and were up to the second floor. The architect would come on site once a week for his regular inspection and walk-through. On this one site inspection, up at the second floor structure, just looking out over the parking lot area, he saw a big hole. He asked, `What is that big pit out there?' It was actually a pretty big hole, maybe 50' across and 10' deep. Well, we said, we didn't know what that hole was. And that architect got real excited and he wanted us to find out what that hole was and report back to him, because his plans didn't have any hole there.
>
> "So the next week the architect comes out to the job site and we're framed up to the third floor. He does his walk-through, inspecting wall locations, stairs, and all that kind of normal stuff. Once onto the upper floors, he happens to look out the window again and there's that hole still there out in the parking lot. Well, he gets real excited again and says how come we haven't figured out why that hole is out there?
>
> "Well, this goes on week after week. And I can tell you that architect pretty soon was focusing most of his attention on that hole. We called it the `aggravation pit'. And he kept his eye on it and felt really good after a few weeks when finally there was some action going on and we were getting that hole filled in. And he wanted to make sure we had run the correct compaction tests on that soil, which we did, and so he was real happy to see how that hole finally got all filled in.
>
> "Well then the next week, by then we're on up at the sixth or seventh floor, and he looks out and there's a new hole in a different location around the corner. And he gets red in the face and wants to know why the heck there's a hole over there now?
>
> "On all our projects we figure out what the right aggravation pit is for the job, and try to get the

> architects, engineers, building inspectors, we try to get them focused on what they're most concerned about and keep 'em focused there. We'd never get our job done if we let them pick at every thing that they could. By creating an aggravation pit we focus people's attention where we want it, so we can get the rest of the job done.
>
> "In the case of that architect and that hotel, we didn't intentionally dig a pit to get his attention, but once his attention was on it we sure used it as best we could."

A third kind of black hole in architecture is an aesthetic one. Sometimes an architect is so successful in the design of a space that it takes on a magical quality. The space takes on a quality and feeling that far exceeds anything Euclidean geometry can explain.

There is a sense in which all architectural space is non-Euclidean, in that people's perception of space is always warped by their feelings and emotions. A change from low ceiling space to high ceiling space can create in a person a feeling of expansion. Just the use of colored paints can change the human feeling of a space enormously, even though no change to the dimensions or basic structure have occurred in the slightest.

For the architect, this is of course one of the most enjoyable parts of the design process. And if the architect's job is viewed as the choreographing of the warping of space, the black hole is a place where occasionally the architect's effort achieves a kind of transcendence. It is a place where the indweller has the feeling of being in a primordial nest. It is the difference between a "house" and a "home." It is the place where a person has entered another dimension, a timelessness that brings out the strongest of human feelings about place.

23. Music, Architecture, & the Soul

There is no question that music has a special ability to reach the human soul. What is the formula for the magic that can make a piece of music bring tears to one's eyes? Sometimes this can result from the resonances of even the shortest of passages played by a small Baroque ensemble. Or it may happen when a whole church full of worshippers is swaying and singing the gospel. How can simple vibrations through the air carry such emotional content?

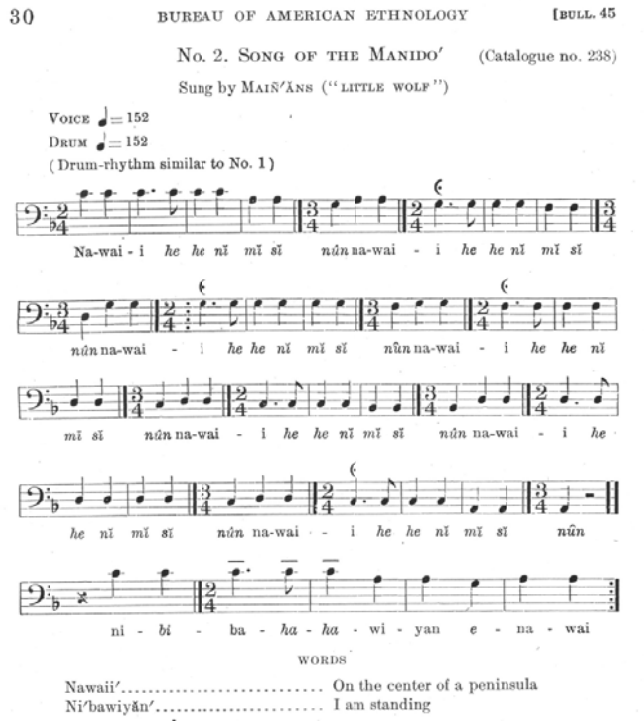


Figure 35: Song named by the Mide' Pole Pictogram

One could theorize that the soul (or whatever we want to call that mystery inside us) is simply vibrating sympathetically. We all know that when you pluck the D string on a cello, all D strings in the orchestra begin to vibrate at least a little bit. One could take an enormous leap of faith (and reason) and note that the latest theories of physics — that attempt to unify everything from atomic quantum theory to the cosmology of the universe — uses a new construct called "string theory."

Under string theory it is believed that the smallest elements of reality should be envisioned as strings that vibrate in various dimensions and modes. These strings have 10 or 11 dimensions, and through a complex process create the four dimensional world humans perceive. We'll go no further with the details of this for now, but clearly there is some movement in many of the physical sciences to work with concepts of harmonics and vibration as supplying a foundation for the fundamental laws of nature.

An unexpected aspect of architecture, is that during periods of war opposing countries devote enormous energy into attempting to bomb and destroy each others' architecture. More important than killing the enemies troops, this demolition of buildings is a measurable, observable quantity that those waging war take great heart in achieving. Buildings are a kind of obstinacy within our culture. They are a kind of permanence that human life can be measured against. Buildings pre-date and post-date a human life, or even an extended family's life. A building becomes the embodiment of the life of a family, of a city, or even of a culture. Apparently the thicker those stone cold walls are, the more vibratory life they contain.

Why are buildings so dear to our hearts? As anthropologists love to show, buildings provide a physical embodiment of a culture. The various buildings on a family farm are projections of the lives that have lived on that farm. A succession of sheds, barns, houses, additions onto houses, wells, fields, wood lots, and fences provide a physical history of the human habitation and dwelling of that place.

All buildings, cities, and rural landscapes have this information stored inherently in their forms. This is a joyous and wonderful side of the complexity and chaos of architecture.

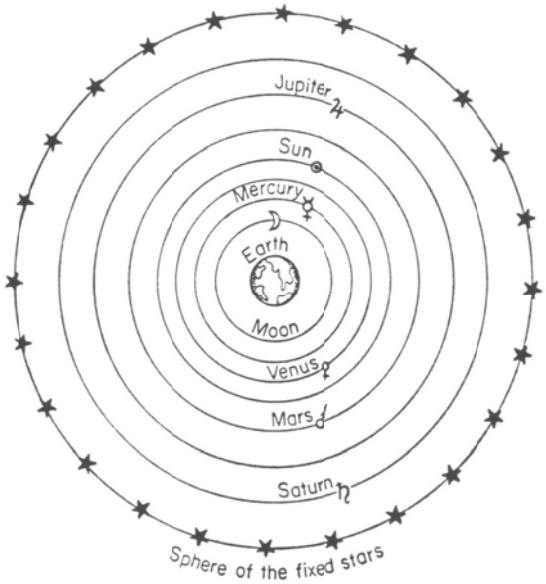


Figure 36: Music of the Spheres[25]

24. Music & Architecture, continued

Suppose musicians only performed music of a composer while he or she were living. Imagine that there was a law requiring that each time a composer died, his or her music would be immediately put into library vaults and musicians around the world notified that it is now illegal to use any of those old riffs or melodies. The law might permit all existing discography to remain. It might be okay to listen to recordings made of the music, but it would no longer be permissible for musicians to play any of the pieces live and/or record them again.

Architects, engineers, and landscape architects' buildings -- with very few exceptions -- are not allowed to be constructed after the designer's death. Construction documents must be "stamped" with the seal of the responsible professional who is licensed by the state in which the building will exist. No use of a deceased professional's stamp is allowed!

I can hear the reader complain already. Music and architecture are just not the same things. A composer's pieces are intended to be played by others after he or she is deceased. The difference is that for architecture there *are* laws that govern these things. An unfortunate result of these laws is that crafts persons are losing many of the skills that existed in former times. It would be a little bit like outlawing oboes and mandolins from any further use in modern music composition. Or it would be like outlawing the use of a Baroque violin with a law saying: "Period music may only be played on modern instruments."

For purposes of health, safety, and welfare, the building code does not allow wattle and daub walls, thatch roofing, or black tents to be constructed in most cities. In earthquake prone areas, unreinforced masonry has been outlawed. For buildings there is the possibility that a person may be killed by the work of art. In the case of rock music there is only the risk of temporary insanity -- most people can recover following appropriate mental health counseling and therapy.

But let's reverse the argument for a minute, and use music as a positive model to see if there are ways to improve our culture of architecture and building. Johann Sebastian Bach's pieces are played live by musicians every day of the year, though Bach has been gone for 250 years. That is an extraordinary fact. Is there any piece of architecture from that same Baroque period that is being reconstructed over and over again by builders every day? No there is not. Our modern historic preservation laws promote the saving of the historic structures themselves, so that there are at least physical pieces of the history to examine and learn from in the future. But these laws do not allow recreating historic buildings in new places. In New England one can find many 250 year old houses to visit. They are available for historians (and carpenters) to at least slightly dissect and explore, in order to learn precisely how designers and builders did things in those days. We are preserving older technologies and design concepts as museum pieces.

There are a few places, however, like Sturbridge Village and Plymouth Plantation in Massachusetts where old ways of building *are* being recreated every day. Thinking from the parallel of music, this is an extremely positive concept for creating a culture of building that is connected to the past. One might even argue that the "shed roof" or "gable roof" or "window" is built again and again every day 5,000 years after their invention.

Architecture schools, perhaps since "modern" Bauhaus times, have tended to ignore history, even to avoid history. Architects in recent times are encouraged to create only new designs. But perhaps this is like throwing one's grandparents out of the house and disowning them. Wouldn't the culture of architecture be all the stronger an institution if all members of the family are acknowledged as related and friendly.

25. Architecture as a Verb

It is this sense that architecture contains a history of human lives, and tells the story of how man interacts with man, and how man interacts with nature, that leads us to the notion that architecture should be viewed as a verb, not as a noun. Unless the architecture has stopped serving its purpose, and has no hope of ever being renewed, altered, adjusted, or changed, only then should it be considered a noun.

Martin Heidegger's famous essay "Building Dwelling Thinking", first delivered as a lecture in 1951 [in *Poetry, Language, Thought*, 1971] spends sixteen elegant pages on this subject, as an essential philosophical and religious issue. Most architecture still 49 years later has still not learned this simple lesson. He begins his discourse:

> "We attain to dwelling, so it seems, only by means of building." -- (page 145)
>
> "If we listen to what language says in the word *bauen* we hear three things:
>
> 1. Building is really dwelling.
>
> 2. Dwelling is the manner in which mortals are on the earth.
>
> 3. Building as dwelling unfolds into the building that cultivates growing things and building that erects buildings." (page 148)

Heidegger concludes by discussing the problem of "homelessness" following the world war:

> "We try to fill the need by providing houses, by promoting the building of houses, planning the whole architectural enterprise. However hard and bitter, however hampering and threatening the lack of houses remains, the real plight of dwelling does not lie merely in the lack of houses. The real plight of dwelling is indeed older than the world wars and their destruction, older also that the industrial workers. The real dwelling plight lies in this, that mortals ever search anew for the nature of dwelling, that they must ever learn to dwell . . . This they accomplish when they build out of dwelling, and to think for the sake of dwelling." (page 161)

It is absolutely amazing that more than one famous architectural historian, has found a need to begin their treatise with a discounting and belittling of "buildings" in order to puff up and inflate that what is important to talk about – "architecture":

> "A building which serves practical functions well and is eminently durable but lacks art, is not architecture at all." -- [this quote from Burchart & Bush-Brown, *The Architecture of America*, 1961]

Is it really necessary to distinguish architecture from building? Given that architects have for centuries happily focussed their studies on indigenous Italian hill towns, Norwegian stave churches and Gothic cathedrals, most of which were designed by "builders", should point us in the direction of answering, "No!" The word "architect" in fact comes from the Greek "arkhi" and "tekton" – whose roots go to "the one who may initiate" "waddle and daub construction." It seems much more reasonable and honest to accept that there is a continuum between "building" and "architecture." Certainly there are differences in meaning between the words. Perhaps the word architecture is best thought of as an honorary title given to buildings that are deemed to be especially meaningful to a culture, a family, a person, or a place.

26. Building with Trees

As I child I lived in a tree house, 30 feet high in the crown of four cedar trees, for three months each year. My father had constructed three runs of split log stairs to the underside of the eight foot square room. A ladder then had to be climbed for the last seven feet, up to a landing with a small door that entered the little room beside the bed. The walls were virtually all open from 30 inches above the floor, to the underside of the shed roof above. These openings into the tree canopy were screened to keep out mosquitoes, but during the worst summer thunder storms, rain would get to the south edge of the bed and the floor would get wet. I constructed canvas shades, which rolled down from the inside of the windows, to use during heavy rains. The outhouse was about twenty-five feet from the bottom of the stairs, but if no one was around in the early morning, I would pee from the top landing into the tree branches, making a shower below.

Recently, a builder of tree houses in Takilma, Oregon ran up against the building codes. He had constructed several

Figure 37: Peacock Treehouse

"bootleg" tree houses that were offered as bed and breakfasts, to the delight of the many people who enjoyed renting them. But were they really safe? The owner-builder intuitively knew they were, but how could be prove it?

The county building department had found out about the tree houses, and wanted them to be torn down, or reconstructed with building permits. After several years of battling between the owner-builder and the county building code agency, an innovative engineer, Charles Greenwood, was found who relished the idea of calculating the supporting forces of trees. He used the building codes in reverse, and calculated the amount of force the tree had been able to withstand due to wind on its leaves and trunks – since clearly the trees were still there after 50 or 100 years of real time testing. Greenwood was able to show through a series of calculations that the tree houses were, in fact, safe. Also, through a review of the scientific literature[26] he was able to show that trees over time grow additional wood where the stress forces in the trunk and branches are greatest.

Thus, after a tree house is in place for three years, the tree can be expected to have grown additional structure to handle the increased load.

Thus, a living tree is a self-organizing structural form that increases its internal structure based on increasing applied forces from its environment. In simple English: the tree grows more wood where more structural support is needed. Surprisingly, even the current building codes recognize the great safety of trees as structural members in a subtle, yet very significant way. The building code requires a doubling of the strength of a building to resist high winds, if the site is not surrounded by trees or other tall objects. Stated in reverse: if living trees of sufficient quantity surround a building, the required strength of the building to resist wind can be cut in half. Thus, our codes are already basing the structural integrity of our buildings on a belief that the strength of living trees is of even greater reliability!

27. Earthquakes, Chaos & Architecture

Chaos theory has opened up a new method for study of earthquakes. There is a group of geophysicists and mathematicians who have developed a theory of "self-organized criticality" that is endeavoring to create a model that can predict earthquakes and their impacts. As with so many things in the science of chaos, it is based on fairly simple physical concepts of sliding blocks of rock. The equations of course are only solvable through the use of computers.

Over the past 50 years the basic engineering model for how to study the impact of earthquakes on buildings, has been to approximate the dynamic energy forces with a static force. This was for the simple reason that the dynamic forces were too complex to compute. Even today, in the year 2000, the best building codes still utilize static force approximations for the dynamic effects of earthquakes.

However this is changing. There are now computer programs available to allow a dynamic earthquake analysis of a building it is likely that these programs can now run on virtually any small personal computer. Thus they are available to all engineers and building departments.

A key issue will be whether these dynamic models actually capture the fundamental structural issues involving earthquakes and buildings. It's one thing to have a computer model that appears to act like a real dynamic building does during an earthquake. It's another thing to verify that the appearance properly models reality.

For example, it may turn out that the extreme forces that can destroy a building during an earthquake have less to do with the detailed dynamic response of the building, than the dynamic response of the geology of the surrounding ten miles of landscape. As the earthquake energy passes through the earth as a wave, it does not just travel uniformly. It is bounced by underlying slopes, tilts, hollows, and hummocks in the bedrock below. Like waves on the surface of a pond this energy can be reflected in ways that reinforce each other in some locations while neutralize each other in other locations. Thus buildings in one part of a city can be flattened, while a short distance away there can be no damage whatsoever.

It will be exciting during the next twenty years to see how this field of study progresses. We can hope, and we should expect, that engineers, scientists, geophysicists, and architects will make new discoveries that make our understandings of how buildings respond in earthquakes much better.

28. A River View of Architecture

Rivers are second only to trees, when it comes to public concern for environmental protection. The flow of water in the landscape provides a kind of reverse image of the topography of the land. Just as the space inside a house is the inverse of the solid walls, the wind and water ways that flow through the landscape represent the inhabitation of the earth architecture. Wind and water represent motions through the landscape on a time scale of minutes or seconds. Even for a river which has existed in place for a millennium, "one can never put their foot in the same water twice." Trees, shrubs, and buildings inhabit the geological landscape on a time scale of a hundred years more or less. People and other animals of course flit through this landscape sometimes like the wind and other times like a river.

In today's cultural and political world, water is gaining respect. Whereas only 25 years ago large cities did not hesitate to dump large quantities of raw sewage into rivers and bays, today this is verboten. Virtually every city has a multi-million dollar work infrastructure program underway to clean up sewer or storm water runoffs.

Architects and landscape architects are participating in this work. In the old days, rain runoff from roof drains, parking lots, even large playfields were collected in storm water pipes and rushed to the closest river as quickly as possible. Initial improvements involved trying to eliminate the flooding problems this rapid collection and dispersion created. Ponding and water storage were designed into projects so that they "leaked" downstream more slowly, to simulate the slower pathway of water through natural or rural landscapes. More recently, vegetated swales are designed which use plants to both slow down the flow of water and cleanse it. In some cases the designs are so creative as to use specific plants which are known to absorb toxic metals flowing as pollution within the water runoff. Through regular mowing and collection, the plants are disposed of literally as toxic material.

Finally, the latest flood plain studies have shown that streams and rivers are most healthy when they flood beyond their banks, rather than being controlled to remain within their banks. When a dam or pond is controlled to maintain only the “bank-full” condition and avoid flooding, the river flows at its maximum speed for the greatest length of time. This increases erosion and thus destroys habitat. So now, the rule of thumb is to try to design watersheds so that they do not typically run at bank-full height, but rather flood well over bank-full, and then recede to under bank-full conditions. This is all completely counter to the majority of the flood control rules of almost every county and city in the United States. But at least we now know the preferred design, and can start redesigning all of the flood control structures put in during the last 50 years!

Figure 38: Willamette River & Falls

Figure 39: Clyde Rice Artist's Retreat on Clackamas River

29. The Tree as Archetypal Architecture

Many cultures have a simplified ideograph image of a tree. For example, the modern Chinese character for tree is:

which comes from the more ancient character for tree which is:

The concept of weariness or exhaustion, that requires one to rest and take dwelling, is the image of stopping and camping under a tree[27] as shown below – perhaps the first form of architecture of all nomadic peoples of forest lands.

These are clear simplified, cartoon-like images of an upright trunk with horizontal branches and with roots. The hand motion of drawing the characters, is an important part of the information passed along. The drawing of the lines is a growth process in itself – the adding of line upon line, to express a concept through a form.

In the Objibway Mide-win-win society there also is a similar ideogram of a tree on a rock (the place being an important ceremonial lodge or encampment).

The Arts and Crafts movement of the late 1800's picked up on the image as a common motif:

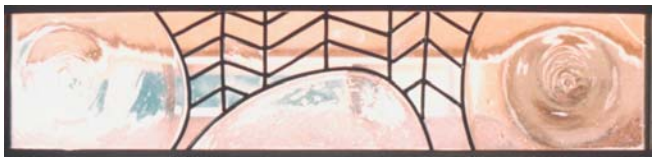


Figure 40: Kim-Reimann House Glass

And American's most famous architect, Frank Lloyd Wright, often used a variation of this Tree of Life image in his stained glass windows and trim work.

Even among the diverse cultures and epics that are represented above, it is easy to see a "tree" in all of these images. In fact, if this simple form is considered as the seed of a fractal generator, one can apply the iterative nature of fractals to this seed form and generate in rapid succession something that looks more and more like a naturalistic tree:

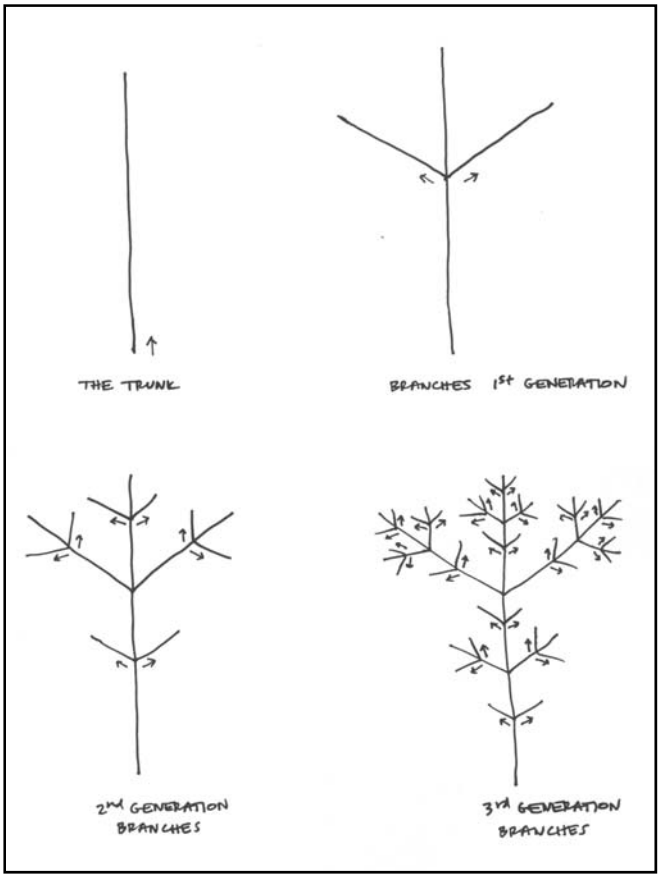


Figure 41: Fractal Oak Tree[28]

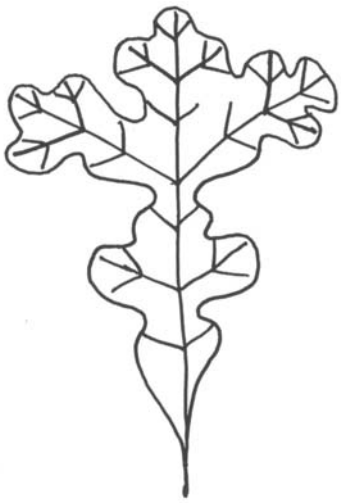


Figure 42: Outline is Oak Leaf

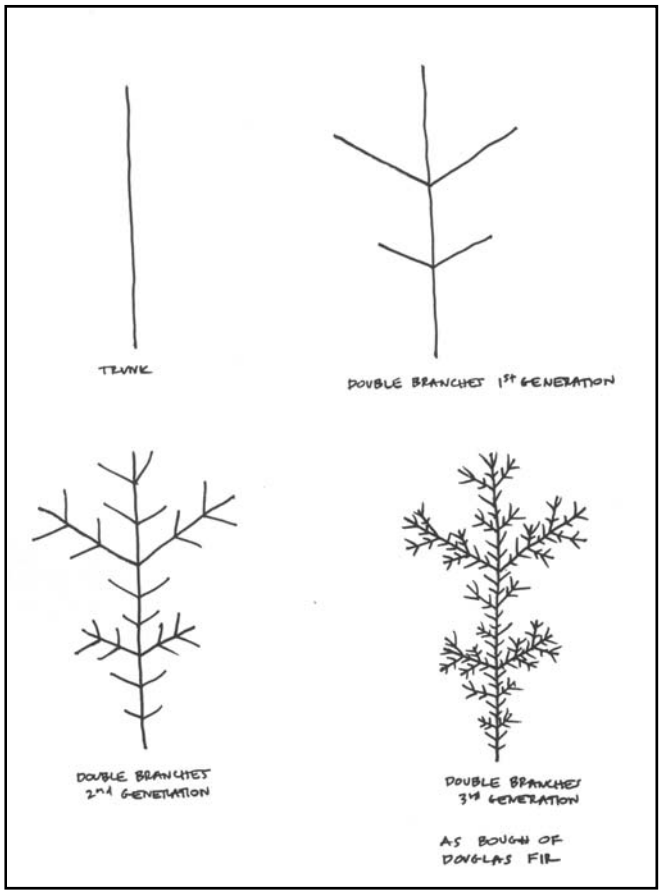


Figure 43: Fractal Douglas Fir

30. What Does the Tree of Life Have to do with Architecture?

Perhaps nothing. But one senses that there may be a clue here for how architecture in the new millennium can participate in a complexity of construction which is so far not greatly present.

We have already considered how architectural drawings are in some ways a fractal of the larger building. Within this context, it is clear that the graphic methods and shorthand's available are key to the success in transmitting complex information on how to build a building. The little "tree of life" image though static and simple, has probably always somehow portrayed the root sense of complexity of trees.

Trees are incredibly beautiful objects. We love to photograph them and study them. They provide a metaphor for life, where generations build upon generations, where families branch out from the root stock, generation after generation. This sense of continuous growth and expansiveness is why we call this image the "tree of life."

Figure 44: Live Oak in Santa Rosa

In fact, a single tree is perhaps as complex as all of nature. Yet this simple diagram provides us a root understanding for how it is formed and grown.

In our structural engineering there are ways that we can utilize graphics such as the tree ideogram, or the image of the enclosing roof or hut, as discussed in another section of this paper, to indicate a sense of structure or space while not necessarily limiting it to the elements shown. Either through a prescribed iterative methodology, or an implied one, there are new graphics which can help us design buildings which are more like trees than pyramids, more like forests than telephone poles.

31. Fractal Dimension as a Tool for Architecture & Landscape

A useful tool from this new science is called "fractal dimension." Imagine that there is a continuum between one-dimensional objects and two-dimensional objects, and then between two-dimensional objects and three-dimensional objects. A straight line between two points is one-dimensional. But how about a very squiggly line between two points? If the squiggles repeat often enough, then they start to fill in a plane and create a two-dimensional object. Fractals bring forth a method for measuring the "squiggliness" of lines, and assigns a number between 1 and 2 to the object depending on whether it is closer to a straight line or a plane filling meandering line. The figure below could be of a coastline, or it could be the outline of a quite interesting building or garden path.

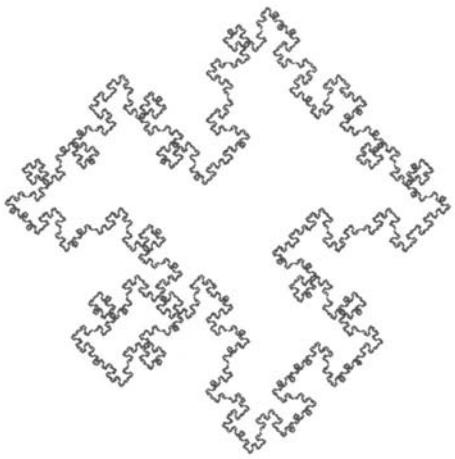


Figure 45: A Building with Perimeter Dimension 1.5[29]

A building constructed like a box, with flat hard surface walls, is bounded on the inside by a two-dimensional surface. Now imagine a building, which is more or less a cube in overall shape, but is filled with shelves, mezzanines, stairs, alcoves, and rope ladders. Imagine it starts to have the complexity of a Pacific Northwest dense rain forest filled with trees, shrubs, and vines. The inside surfaces of this building approach three-dimensionality.

There can be calculated fractal dimensions of a building's wall surfaces which will always be values between 2.0 and 3.0. In the real world no wall or ceiling is perfectly smooth so there is a practical minimum of, say, fractal dimension 2.1. On the other hand, a building could be so full of shelves and alcoves that there is no room left for a human to actually navigate through the space. Thus there may be an upper bound of, say, 2.5 to the fractal dimension of a building interior wall that a human can inhabit.

An interesting theoretical question would be whether there is a method of defining the fractal quality of the "space" of a building, which would range from 3.0 to 4.0. 3.0 would represent the simple static volume of space in a cube, while a higher dimension would represent the space inside the highly complex rainforest kind of building described previously.

The point is that "fractal dimension" gives us a measuring stick for this kind of complexity in architecture. Some people will always prefer less complexity, while others will prefer more complexity. Just as natural landscapes vary in complexity from desert to rain forest, so human buildings should be expected to have variability depending on personal or cultural needs. The “savannah” openness of suburban lawns with shade trees need not be a requirement for all!

It should be recognized that the fractal number can be very different at different measurement scales. Thus for example, even though at many scales a desert is much more sterile than a rain forest, when the first spring rain comes to a desert, Joseph Wood Krutch describes the marvelous burst of life, energy, and complexity that blooms in that landscape if measured as a small size.

32. Using Fractal Dimension as a Measure in the History of Architecture

The science of fractals provides a method of measuring the complexity of an edge between things. Initially, the concept of fractal dimension was developed to quantify the amount of twists and turns in a river, or the complexity of bays, inlets, peninsulas, and islands along a coastline. Fractal dimension is based on the concept that as one examines an edge closer and closer, one finds that there are more and more twists and turns in it. The fractal dimension of a river is 1.0 when it is a concrete channel with flat sides. Likewise, a river of fractal dimension 2.0 is a swamp in which the river flows in all directions at once, and is barely identifiable. A river of fractal dimension 1.5 is a river with twists that are somewhere in between.

Thus the fractal dimension of a building might be defined as the distance around the perimeter of all the walls in the house. The first measurement would be made with a 25' long pole. One starts at one corner and has to go out the door of one room, into the door of another room, before reaching the end, and then starting the next 50 feet from there, and going around in a circle. Then one could measure it with a yard stick and would conclude it is a certain length. Then one would measure it with an inch stick and the length would grow, since as one came to window trim, fireplace, or appliance, the measurement would go in and out around the boards and detail elements. At the extreme, one could finally measure the interior perimeter of the house with a 1/100th inch measuring stick, which would then follow the in's and out's of textured plaster and other materials, again lengthening the perimeter distance.

By studying the change in total length, relative to the dimension of the measuring stick, we can create a graph which shows the changing length of the perimeter, based on the measurement dimension. Where the graph is flat, there is no change in total length based on a changed measuring stick length. That identifies the characteristic length range where the interior spaces do not effectively utilize those dimensions. Where the graph has a sharp rise, it is an indication that the space has many objects of that characteristic dimension.

This concept could be developed into detailed examples for different historic eras of American architecture. Examples could show how a calculation works for different buildings: one a Dutch colonial house dating to 1750, another a Greek revival house dating from 1810, another a Queen Anne style Victorian dating from 1890, one a house from the Modern movement dating from the 1950's (Phillip Johnson house), and one a Frank Lloyd Wright Usonian house dating from the 1960's.

The fractal dimension graph for each house would tell us about the spatial quality of the floor plan. One could do the same analysis for "sections" through the buildings. This analysis would find the variation in length around a room as one took into account the baseboard, picture mold, and plaster textures, if they existed. In architectural school, I recall one classmate telling of the importance of the baseboard in her childhood house. She would line up little animals and people on the top 3/4" of the board and play for hours in that setting. Sometimes a small dimension in a house is vitally important!

33. Does Chaotic-designed Architecture Have to Look Chaotic?

There seems to be a trend in current architecture to create buildings that have some "chaos" to them. Fashionable designs for housing have canted shed roofs of varying bright colors with a rich mix of materials ranging from corrugated metal siding to plastic. Does this represent a direction in architecture which relates to chaos theory?

Some might bring up the Bilbao Museum by Frank Gehry. It is being heralded as being the greatest architecture at the end of the century and it is said to have only been possible to design and build with the advent of computers. It has enormous fluidity to its design, a kind of organic skin of metal, and the building process was integrated with the design, again through shared use of computer modeling. Is this also an example of architecture beginning to move in the direction of "chaos"?

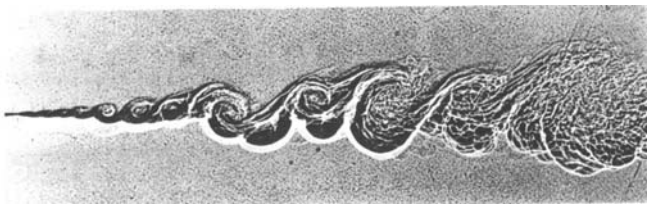


Figure 46: Nitrogen & Helium Mixing Chaotically[30]

First, it is important to recognize that the union of chaos theory and architecture is surely not about building things that look "chaotic." Chaos theory is a modern science which allows us to understand what previously appeared to be "chaotic", but which with further analysis is found to be quite understandable. In fact, more properly, one would imagine that the integration of chaos theory with architecture would allow for the creation of a more "stable" and "calm" architecture. Chaos theory allows us to study phenomenon which are filled with "chaotic changes" and find within them the stable solution states. Chaos theory provides us with scientific methods to solve problems within a "chaotic environment." The end goal, still, is to find predictable and stable solutions.

Where chaos theory usually surprises the practitioner, is in the finding that there is not one stable solution, but that there are several or many stable solutions. What appears to be chaos may be a system which is allowed to flutter between stable solutions in a kind of madness that does not appear to have order in a linear sense. When a practitioner assumes that a linear set of actions will result in the "best solution," as if there is only one best solution, then this is where madness creeps in. Under chaos theory, we should expect to find that there are many, good, stable solutions – not just one good solution. Chaos theory, at heart, is about the healthiness of diversity.

In architecture, we may find that chaos theory allows us to more clearly work with a client to evolve a "calm, stable solution" that meets their specific needs. This may be far superior than ending up with a building which is half-way between two stable, design solutions.

Thus, the Bilbou Museum may well be a good example of the use of computers in architecture and construction, and it may be an excellent example of how to construct a complex building, but under chaos theory what we really want to evaluate is whether the building provides a "calm, stable, design solution" that meets the community needs. That will only prove true or false through time and history. As to sprouting shed roofs on the tops of buildings, we can safely assume that they don't have much to do with chaos theory and architecture.

34. Architecture Designed for Living with Chaos

There is a chaos to modern life that is caused by the constant flow of information from telephones, televisions, computer screens, Internet, and a bombardment of urban related environmental impacts that create enormous stress to an average person's life. There are techniques and methods for designing architecture that provides a calming environment for the occupant.

Just as a river system can have a deep cool pool of water that fish happy dwell in, between roaring rapids, the architect can create a calm place in the midst of the chaos of everyday urban life.

Figure 47: Cottage on the Willamette River

35. Bridge Design: A Hopeful Sign for the Future of Architecture

Since the advent of chaos theory, a clear and substantial change in bridge design has occurred. Of all the areas of engineering and architecture, bridge design probably represents the one where complexity, fancy, imagination, and a healthy mixing of different building systems occurs, to create in many cases a structure filled with surprise and life.

The Miho Museum Footbridge[31] in Japan is a good example. This bridge takes visitors emerging from a hard rock tunnel through a mountain, and then flies them along a 400' open walkway over a 100' deep canyon. The structural system supporting the bridge is an amalgam of perhaps three different systems, with the result that one is in the end unsure whether anything is really holding up the bridge. Emerging from the dark tunnel and literally flying across the air and space of the canyon, high over a lush forest, this has created what will be a remarkable experience for each pedestrian. Stay cables from above visually hold up only one half of the bridge, while a hidden tension king post underneath holds up the other half. A third structural system, a space frame along the bridge deck, provides the continuity between the discontinuous systems.

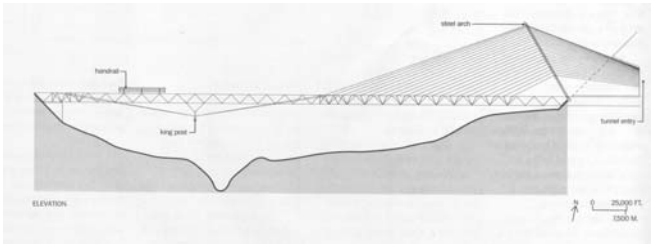


Figure 48: Miho Museum Bridge

Figure 49: Reed College Bridge

Other bridges have developed the notion of compound curves (the cable stayed Lockmeadow Millennium Bridge in England and the reinforced concrete Reed College canyon bridge being good examples). While rising up over the water and back down to the other bank, the bridge has both horizontal and vertical curves so that one can never fully see the path before them. In the old days of engineering, this would have been unthinkable. There would have been no way to confidently calculate the forces. The computer has once again rescued engineering from linear Newtonian physics, and launched it into a complexity that truly has hope and promise.

Then there is the crazy Duisburg Pedestrian Bridge in Germany. It at first appear to be simply a 250' suspension bridge connecting two sides of the harbor on the Ruhr River. With the push of a button, the tension is increased in the cables and the whole bridge changes its shape, with the center arch rising an additional 25' to allow boat passage underneath. This is "Galloping Girty" in slow-motion being used as an engineering device. In the early days of suspension bridge design, the fundamental design problem was one of stiffening the bridge so that it didn't oscillate during a wind storm. The famous amateur film "Galloping Girty" – the Tacoma Narrows Bridge – self-destructing, as the bridge deck began to rise and fall as if floating on large ocean waves, was the terror every engineer wished to avoid. This Duisburg bridge harnesses

the same concept in slow motion for a dynamic useful purpose.

The engineers of this unusual moving bridge are Schlaich Bergermann & Partner. Their web-site at www.sbp.de starts with the simple picture of a spoked bicycle wheel with no tire. In the case of the Duisburg Pedestrian Bridge they have taken this simple concept of a stressed, efficient structure to a new level.

Our human buildings have not yet harnessed this new chaotic kind of engineering excitement that is found in bridges. We all long for vacations in grass huts, but deny them in our building codes for safety and fire reasons. That is our old Newtonian linear thought process still at work. There is no reason that our buildings cannot include the wildness of tents, grass huts, underground caves, tree houses, boat docks, and all other old world technologies. In part we abandoned the old technologies because we could not understand them -- we could not "compute their strength"! With the new science of chaos and complexity we should no longer be afraid. We should be openhearted to these old ways, and embrace them as the old friends they are. In doing so we will find that there was more meaning in a grass hut than we might guess. There is some inherent human, earth, and spiritual value – indefinable for the moment – yet the proof that it exists is in the yearning our culture has for visits to remote places where this old-world complexity still exists.

36. The Engineering of Bridges and Baskets

The *NOVA* TV series "Secrets of the Lost Empires" recently broadcast an hour-long show about a Chinese type of bridge that had not been built for 900 years. An article about this same bridge can be found in a recent issue of *Civil Engineering* magazine[32].

The bridge was best known from a 12th century silk scroll painting that depicted the unusual structure. The bridge has the classic Chinese "camelback" configuration, but surprisingly appears in the painting to have an underneath structure of "woven" straight wooden logs. It is believed that this was a very common type of bridge but that its technology disappeared about the time of the painting. There were no known extant bridges of this type to be found or documented after that date.

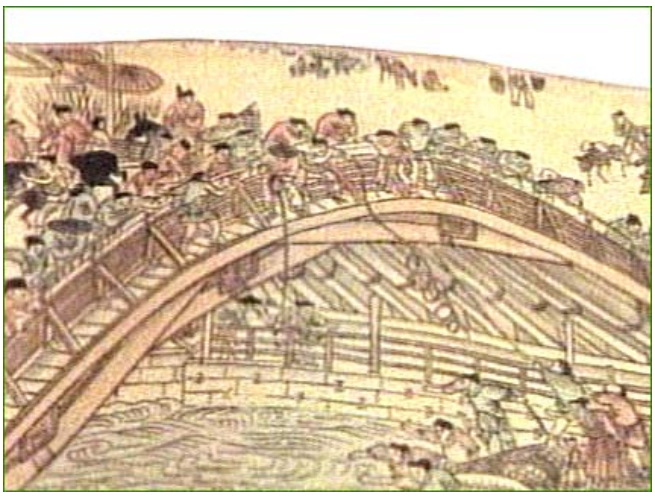


Figure 50: 12th Century Basket Weave Bridge[33]

Figure 51: 21st Century Replica Bridge

The TV show presents several bridge engineers debating the structural issue of "how it works" and how one would try to assemble one today. They argue hotly with each other, accusing each other of not understanding the laws of physics, as each describes a different theoretical mechanism for why the bridge stands up.

The actual construction of a full-size replica of the historic bridge in China is shown in the show. The structure is so complex that prior to construction, the engineers never could come up with a way to model it with computers. Rather, they ended up making a scale physical model to figure out how to construct the full size version. On completion, the bridge is load tested with several heavily loaded oxen, and proves to function perfectly well and carry the heavy loads necessary.

It's significant that modern bridge engineers, in the year 2000, are trying to understand a complex structure such as this. And it is equally interesting that they were unable to reach unanimous agreement as to how the structure works. Of course, none of them were hesitant to walk on the bridge when it was done. They were all proud of what they had helped to accomplish, even if there wasn't agreement as to how it worked.

The beauty of the bridge is that it uses a basket weave type of technology for its construction. This is a technology that man has used for millennia. As knowledgeable as we are today about nuclear physics, brain surgery, and many other specialized scientific fields, apparently engineers are still unable to calculate how a woven basket supports its contents. With future increases in computer memory sizes and speed, we may find that there are unique and superior structural concepts to be found in the simple technology of woven baskets, and bridges.

37. The Nature of Architecture

This whole analysis of fractals, chaos, and architecture assumes that there should be a positive mutual relationship — a symbiotic relationship — between nature and architecture. This is an assumption that some architects, philosophers, and cultural analysts would not agree with.

The human geometry of squares, circles, and triangles can certainly be seen as providing the basis of a human architecture, which is in contradistinction to nature. In America we have for centuries admired the beauty of the New England fall leaf colors viewed against the walls of a white colonial New England house. It is undeniable that there is a beauty in architecture being a kind of picture frame that can set off and highlight nature. We have all admired the beauty of a white picket fence marking off the territory of a farm, or a Christo sculpture demarking the force of man's impact on the land. There can be no question that this approach can be very effective in landscape and architecture design.

Figure 52: Morgan Rock Pillar

However, this paper focuses on the value of a sympathetic approach between nature and architecture. It works from the idea that man is part of nature, and like a bull in a china shop, must be careful in how he inhabits the world. In American life this tradition perhaps began with Emerson, Thoreau, and the Transcendentalists, working its way through the Arts & Crafts Movement, modern developments in geography and ecology studies, hit the regional planning industry with Ian McCarg's *Design with Nature*, and is becoming even more forceful in today's movement toward "green" architecture.

Figure 53: Morgan Grain Elevator

Surely there is enough room in our world for both senses of design. There is something wonderful about mankind's ability to know life — to be conscious of the world. But it is presumptuous to assume that we reside at the peak of some pyramid of life, or that mankind should reasonably dominate or control the rest of life from that pinnacle position. In America today, it seems that most architecture is still speaking in a loud, imperialistic, power-hungry language.

This paper attempts to nudge us as architects and designers toward a gentler approach, one that works more with the geometries and complexities of nature. Man's place on earth is now united with an incredible knowledge of geophysical phenomena and forms. As architects we can enter this never before imagined era — one in which buildings have the potential to be as friendly, beautiful, exciting, and breathtaking as that which we find in wilderness and Nature.

38. The Integration of Art & Science

This paper began with a discussion of architecture as a union of the art and science of building. Today we think of "art" and "science" as being different disciplines. A student in art school is expected to have a completely different path in life than a student in engineering or science. However with the use of computers as a tool in our everyday life, our culture is more and more reintegrating art and science.

The modern movie industry exemplifies the extent of this union. Many of the blockbuster films released in 1999 and 2000 are filled with animated or digital images created only through integration of art and science. The "Star Wars" and "dinosaur" movies are obvious examples. Less well known is that even the Victorian movie *Titanic*, is filled with "virtual people" created by computer. When the ship departs the dock and throngs of people wave from the ship -- these are all virtual people created in the computer.

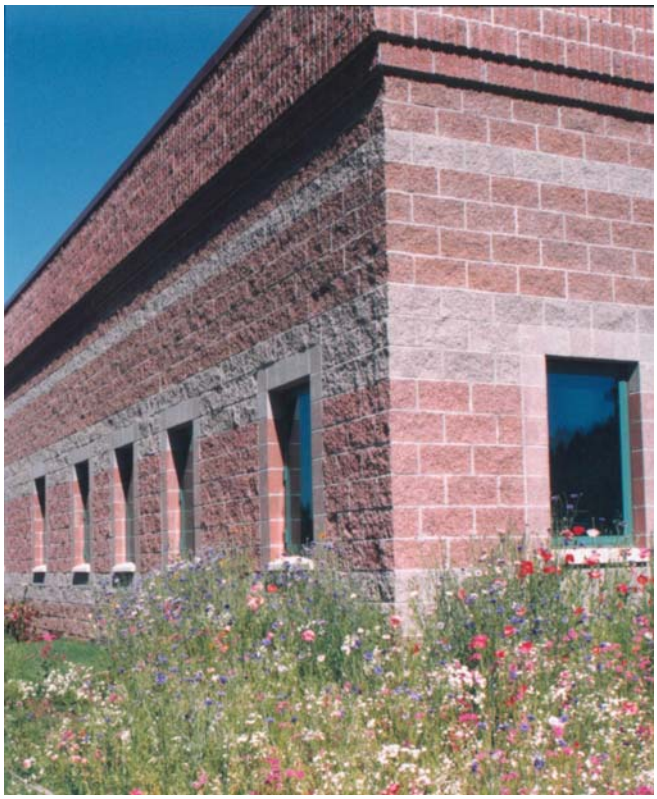
We used to talk about the "art" of something as implying that a person had special "intuition" or used abilities that were "beyond reason." One could talk about the "art" of driving a car ["she drives with grace and skill"]. And one could talk about the "science" of driving a car ["she uses just the right turn angle of the steering wheel"]. But in day to day life, a human lives "art" and "science" as one thing. We just "drive a car."

In fact, the human brain is a far superior computer to an abacus, to a slide rule, to a calculator, to a PC, and yet even to a main frame. Only today has the computational technology gained the capacity for really complex problems to be solvable -- like the everyday problem of driving a car. It may have been the invention of early computing techniques the started the split of art and science; and it is the invention of high power computers, that will help us remember that art and science can be re-integrated.

The interest in the "greening" of architecture represents the integration of the art and science of building.

39. Landform Geomorphology & Architecture

In many places the landscape exhibits an underlying geometry which is fundamental within the rocks beneath the surface. This underlying order, or geometry, is a piece of site information that should be useful when designing a building or landscape within that setting.



In some places, such as the Adirondack Mountains of New York and the old Laurentian Mountains of Ontario, Canada, the underlying geometry is so strong, that one can almost look at the land as a form of building in itself. Every lake and stream is coordinated on that geometry. And as with fractals, when one looks at the shore or smaller pieces of landscape the same geometry continues at smaller scale.

While in architecture school I became aware of the incredible power of this geologic geometry for some settings. In an area of Ontario that I knew well, I could look out and see the angle of the low mountains rise and then look at my feet and see the same angle and pattern repeated. I could go to the Blind River Waterfall that flows into our lake and sit on bench-sized rock outcroppings that mimic the mountains in the distance. *O* the feeling of magic and geomancy. It was as if there is a creator with a capital "C", and He/She was well trained in constructing a consistent order in architecture.

Today I pass more commonly through the great Columbia River Gorge and view the exposed layerings of basalt, which are exposed and stacked along the sides of the canyon creating designs vividly alive. They look like the work of a while first year architecture student whose been given a billion tons of cut-face CMU and told to begin laying the foundations for some great building.

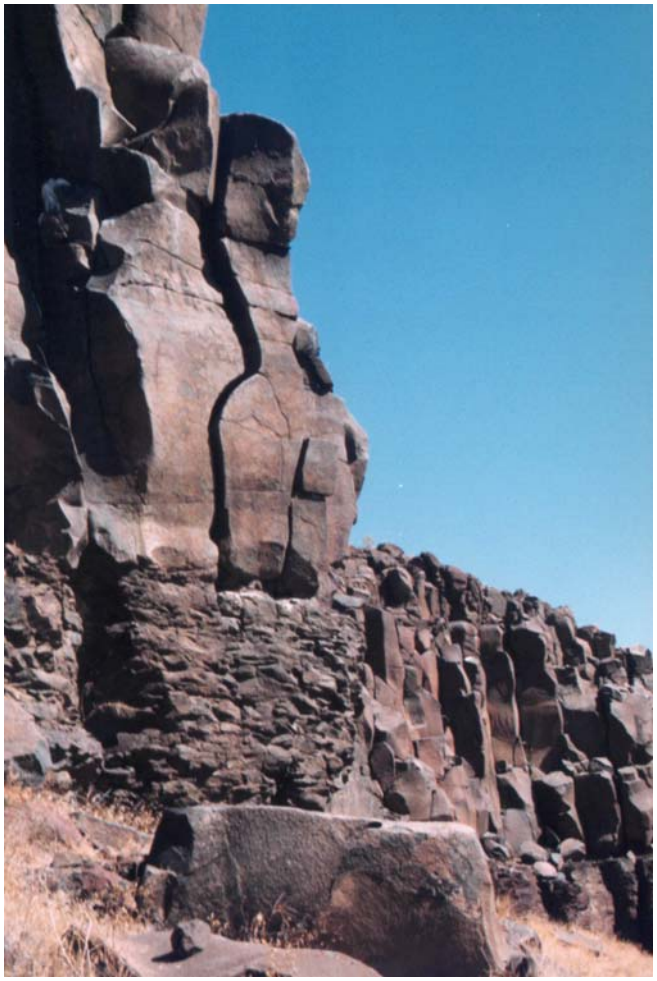


Figure 54: Basalt Layers

These natural geometries in the land have an order to them which our human habitations tend to follow and work within. But there is also an educational or information side to the order. The exposed Columbia River Gorge rocks speak directly about the massive Bretz floods that poured through the Gorge on 100 year intervals when a great ice dam would break in Montana and flood billions of gallons of water, ice and rock through the Gorge as a wave 500 feet tall. Our city of Portland, Oregon is but a 300 foot deep gravel bed backwash of those great floods. This kind of thing gives one perspective for erecting a building.

Figure 55: Columbia River Gorge

Scientists for decades scorned J. Harlen Bretz' 1923 flood theory, and ostracized him terribly. But the land proved more convincing and powerful than man's imagination. In the 1950's the geological profession finally acknowledged that it was indeed enormous floods that created the Columbia River Gorge and its beautiful striated rockwork[34].

And of course it was about the same time that plate tectonics, and the mountain building process of continental plates ramming into each other, was also proved true. Geology, one of the oldest and most staid of the sciences, today provides us a living organic model for architecture. As with fractals, it is all a matter of scale. In this case it is a scale of time that is millennia rather than months. It is the movement of the earth's crust like a river, rather than the moon's monthly series of tidal forces of birth and death.

40. Forces in Architecture

There is a sense in which one can view the process of architectural design as involving a variety of forces acting on an object. For sake of argument and discussion, it is useful to think of these forces just as one would think of forces in physics.

Fundamental to the creation of architecture is that "someone wants a building." This "wanting" is a force of attraction. A family might have a child and want to build an addition with a new bedroom for that child. This is a very directed need. A city grows over time and it is found that fire trucks do not get to the newly developed areas quickly enough. So there is a need for a new fire station in the area of the new urban development.

These kind of forces might be considered as first order, or fundamental, forces of building. There is a fundamental need, someone perceives it, it is brought to wider recognition in the family or community, and a building is brought into being to respond to that force or need.

It is useful to think of this as an "attractive" force. It is not unlike the force of gravity. A fundamental need comes into being and it attracts an architect, it attracts a contractor, and a building results.

This sense of an attractive force or need is one that we all know about. We generally try to live our lives in this kind of directed, logical way, where we see a need or a goal and we direct ourselves toward it. One can imagine it simply: a person is standing and looking forward through their eyes at a distant place that they wish to get to.

But there is another force of which we are usually less conscious. It is a pushing or repulsive force in contrast to attraction. It is the force of what is behind us driving us along, rather than what is in front of us in our field of view pulling us. It is the force of an inward moving ocean tide, that can be pointless to swim against.

The force of repulsion doesn't need to be thought of as "negative." It is more like the story of the "push-me pull-you." There is a larger complementarity. Just because it is hard to see in the local view, or is hard to be aware of due to lack of experience, it should not be thought of as a bad force. A way to view this force is to think of an architectural problem as being like a small piece of bar magnet sitting in the middle of a table, with many other pieces of magnet around it.

We all know that two north ends of a magnet repel and two south ends of a magnet repel, whereas north and south ends of two magnets attract. In this analogy our building project which is a magnet of some type in the middle of the table is being pushed and pulled by the other magnets around it. As these forces push and pull, a form is drawn forth. The other magnets on the table are just the environment that the building is being designed within.

What are some examples of design forces which are "pushing us from behind" rather than being within our "positive field of view"? In the case of building a home, this might be the force of whether to build the home large or to build it small. If we build a large house, we may take on a larger debt to the bank, which means we have to spend more hours of the day earning the payments on the house. Perhaps this results in so much tension and pressure that a husband and wife give up on each other and divorce, ending the family that the house was intended for.

The pushing forces are often ones that are much harder to see or define. But they are often the ones that have the strongest force of impact on the process. Building economics can be a repulsive force as was discussed above. We all must more or less live within our means, yet each of us has no way of knowing for certain what next year's income and expense will be. So there is a kind of hedging or guessing. When an organization builds a building that ultimately costs more than could be afforded, and this puts the organization in bankruptcy, which was the proof that there was a repulsive force that was not sufficiently recognized.

But are there any positive or happy outcomes from this "force from behind us"? Goethe, unlike Newton, focused on examining the forces that create living things. Newton showed how to calculate the gravity force that made the apple fall. Goethe described the forces that got the apple up into the tree in the first place. But Goethe's formulas and science books are to this day still not taught in the science classrooms of America. They're not easy to comprehend. Maybe their formulation is more sensitive and personal?

One way we all use this "force behind us" in architectural design is to pick and choose when we design a building, and when we construct it. By picking the right time, we may greatly impact how our project proceeds. If we wish to excavate the earth and pour our concrete footings in the middle of the rainy season, we can be sure that work will be slow, expensive, and ultimately of less quality. Conversely, if we design our construction project so that work begins in the early summer when the soil is dry and temperatures are warm, we'll get a lot more for our money, the project will proceed much more smoothly, and the construction quality will more likely be excellent.

This same sensibility can be applied to the design process itself. If people's lives are in flux, it is likely the design will suffer. In the example of designing the big house to have a big family, the positive way to look at it is that if one had worked at designing the strong healthy family first, then this would have resulted in the large home first. The strongest force behind the large home was a healthy family. If a person creates a strong healthy family, this becomes an immensely powerful force that will create a wonderful large home as a building.

Another way of looking at this issue of forces in architectural design, is to consider a building to be like a tree. The tree grows toward the sun to gain the light needed for photosynthesis. But in doing so it grows away from the earth which is its foundation, and away from the water which percolates through the earth. The hidden force is in the earth and water, the attractive visual force is the sunlight.

Of course things are never as simple as they are made out to be. In fact there are roots in the soil, which are growing downward, and outward, to find nutrients and moisture. And our buildings similarly have hidden sewer systems, water lines, and telephone lines, which are part of their hidden structure. In rural areas, these may be the most difficult part of the design.

A positive example of the use of a hidden force in urban planning would be the location of transportation systems, such as the siting of light rail lines, subway stops, or the location of a bridge. This exercise is often delegated to planners or engineers, but ultimately has more effect on block after block of architectural design than the work of any one architect "designing" a building nearby. The planner already set the uses, the infrastructure, and probably wrote the design standards of what the buiding is supposed to look like. The light rail line as infrastructure becomes the dirt and soil on which a forest of buildings can come into being.

The purpose of this discussion is not to get the reader feeling mystical and teary-eyed. Rather, it is just a reminder that when we look at architectural design and buildings, we should be aware of the obvious direct forces, but equally or more importantly, we must gently feel for the hidden forces which are the driving forces behind the whole project. It is often the hidden forces which will determine success or failure. With some openness, receptivity, and gentleness, the architect can learn to see these forces. An architect may find that they do have eyes in the back of their head!

A seasoned practitioner – whether architect, engineer, or landscape architect – knows these things. During apprenticeship and the initial years of practice, a designer learns these things in the process of learning the trade. The seasoned practitioner often knows these things in their gut, but can't always explain them. The young architect longs to "design" and shuns interest in what is often called the "grunt work," where these lessons are learned.

Our purpose in talking about the "hidden forces" is to point out that in the work of sewer pipes and financing and family health often lie the fundamental “design” problems. The more savvy architect, engineer or landscape architect perceives these other forces and carefully designs using these forces as well.

41. Fractal Zoning

Land use planning as it is practiced in the United States today, is fundamentally based on the use of Euclidian geometry. By this is meant, that specific areas of land are zoned with certain properties such as "residential", "industrial", "commercial" or "agricultural." Each of these areas is bounded by lines, with the interior then intended to function principally for the purpose of which the name reflects.

This system is based on the historic cultural problem that occurred in the early-1900's when industry was king, and its influence became a major detriment to the quality of life for other land uses. This Euclidian land use zoning approach assumes that a fundamental type of use should be established throughout a reasonably large land use area, and that each of these areas should to some extent be isolated from another different use. It is assumed that each use is to some degree incompatible with the other.

It is somewhat standardized in today's typical zoning ordinances that within each zone there are certain outright permitted uses which are considered fundamentally consistent with the intent of the zone. But, recognizing that these general use categories are hard to define, and that some diversity of uses is healthy, some variety of other uses are often allowed through a "conditional use" process. For example, in an agricultural zone some non-agricultural commerical uses may be allowed, if only in the form of a home occupation. However, a home occupation could only be established through a public hearing and review process. Uses that differ from that of the basis zone intent require the applicant to "prove" why it would be acceptable. One must gain the concurrence of neighbors, local transportation engineers, police and fire departments, and so forth.

With the new science of fractals and chaos, there is a new method available to organize, map, and establish uses within zones. By the use of fractal geometry a much richer interpenetration of uses can easily be described and established. Rather than thinking of all industrial uses as being incompatible with all residential uses, a pattern can be established which considers both the size and category of uses within the same framework. Thus for example a small industrial use (like a home occupation) might be viewed as an outright allowable use within a larger residential zone. Likewise a small residential use (like a caretaker) might be viewed as an outright allowable use in an industrial zone. Current zoning ordinances in some cases allow for this much diversity. However, that kind of minor interpenetration is usually considered a threat to the whole zoning system. There is always an underlying fear that if even one real "industrial use" is allowed into a "residential" neighborhood, then the agency will have to allow all the others to come as well.

The problem is that the normal approach to land use zoning approach has a tendency to create sterile environments. It creates suburban tract house areas that stretch for miles on end, while also creating expansive industrial areas with their own integrity and isolation. Every morning thousands of cars take the local population from the residential areas and move them to the industrial areas. Like waves of migration the life and spirit of a culture migrates between home and work. Once away from home, the residential areas are dead and the industrial areas come to life. Once nightfall comes the commercial areas are devoid of life, with everyone back at home in their beds in the residential areas. This difficulty of resolving how to interpenetrate different uses or forms into a workable whole, is a common problem for all scientific planning methods that rely on a Euclidian framework of geometry.

Planners have long recognized this as a problem and nowadays work to create more diversity through creating special exceptions to the rules, or special conditions that are permitted contingent on other conditions. For example, certain rules might be added to the zoning laws that specifically allow some forms of housing to be placed in a downtown that is otherwise intended to be only a "commercial" use zone. In that case, housing might be added to promoted "bringing life back to the city." Likewise some "home-based" businesses might be promoted in residential zones to reduce highway traffic problems and respond to family needs for working at home due to family needs. In Oregon, these kind of exceptions to the zoning ordinances are being promoted.

Fractal geometry provides a system of math and science that can establish these kind of mixes of uses through a positive process that encourages and innately allows the diversity, rather than through a negative "exceptions" process that does not allow the use unless it can be proven acceptable. It is the difference between being "innocent until proven guilty", rather than being "guilty until proven innocent". The use of fractal geometry would turn the zoning process into an affirming process rather than a denying process.

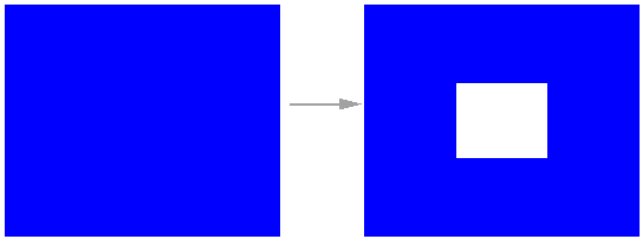


Figure 56: A Park is Placed in the City

There is a sense in which we already require the interpenetration of "agricultural" with the other zones -- we just don't recognize it as such. Every urban center has a system of parks within it. The diagram shows how in concept we can take an urban commercial zoned area and place within it a major central park.

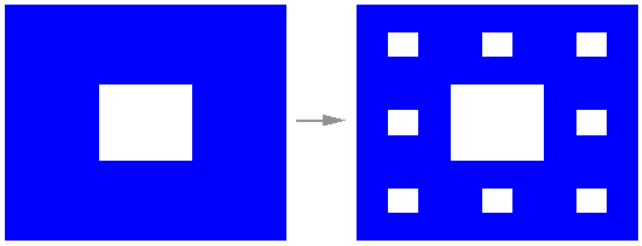


Figure 57: Landscaping is Placed in each Building

Within this context of a park within an urban area, we then historically find that each large commercial building surrounding the park has within it a courtyard garden of its own. In current practice this interpenetration of gardens with commerce is created through zoning ordinances that require "landscaping" or “courtyards” or “plazas” as a kind of agricultural zoning into the base zone. Landscape requirements in zoning ordinances have gotten quite extensive. It has gotten down to requirements for specific numbers of trees and square feet of shrubs per square foot of parking lots.

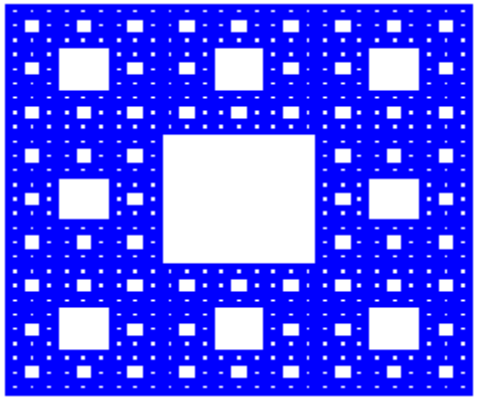


Figure 58: Down to a Potted Plant in Each Room!

In fact, every park and every tree in an urban area can be considered a small piece of agricultural zone within the city limits. The size of these "agricultural zones" varies from hundreds of feet on a side for a large public park, down to a 3 foot by 3 foot tree planting well in a sidewalk. We're all familiar with these kinds of requirements and we support them because we know they improve our "quality of life." No one questions the need for this interpenetration of agriculture into our urban areas. The reason we like the interpenetration of "green" into our urban, commercial, industrial, and residential high density areas, is that we know it improves our life. The diagrams shown above are called “Sierpinski’s Carpet.”

However, isn't the inverse just as needed? Shouldn't every agricultural zone include pockets of commercial, pockets of industrial, and pockets of high-density residential? Shouldn't a farm owner be encouraged to have a small home business that serves his community with special skills he or she can share with others?

I recently worked for 10 months with a 24 year-old young man who owned land in Oregon in an "exclusive farm use" zone. One of his special skills is that he is a world amateur champion skateboarder. He applied for a conditional use permit to teach skateboarding to young kids living in his rural community. He had set up skateboard ramps in two of his barns and wanted to be able to teach skateboarding to neighboring kids.

He was turned down out of fear that this would set a precedent that ultimately could destroy the entire exclusive farm use zone. Since the skateboarding was not related to an agricultural use, it was considered a threat to the whole system.

Suppose instead, his skateboarding were thought of in the same way we think of a tree being planted within an urban center. His skateboarding proposal was simply a little spark of life being offered to the kids in the community. Is there some reason that rural kids should have to drive 15 miles to a city in order to learn this popular new sport?

Under the science and math of fractals, a level of diversity can be established which allows for a certain amount of interpenetration of uses but no more. In other words, a home occupation skateboard park in a barn might be established as a size that is outright allowed in the zone and creates no threat to the zone. Rather it enlivens the zone and gives it spirit. A significantly larger size use (like the size of an urban park) might be allowed in an agricultural zone on intervals of say two miles -- so that it is predefined as something that cannot take over the whole zone. Even a blueberry pancake restaurant -- which

under current zoning would be a threat to the whole zone -- might be found to be desireable by adding life to the agricultural zone, if a use of that intensity were only allowed say every five miles in the agricultural zone.

The point is that there are ways of allowing diversity and life into our agricultural zones without initiating their destruction. But it requires a new way of looking at zoning that attaches the size and intensity of the use as a factor which is just as important as the use itself. Thus, just as every urban household cannot be denied its little vegetable or flower garden, so every agricultural property should be allowed its small home occupation that adds life and spirit to our rural lands.

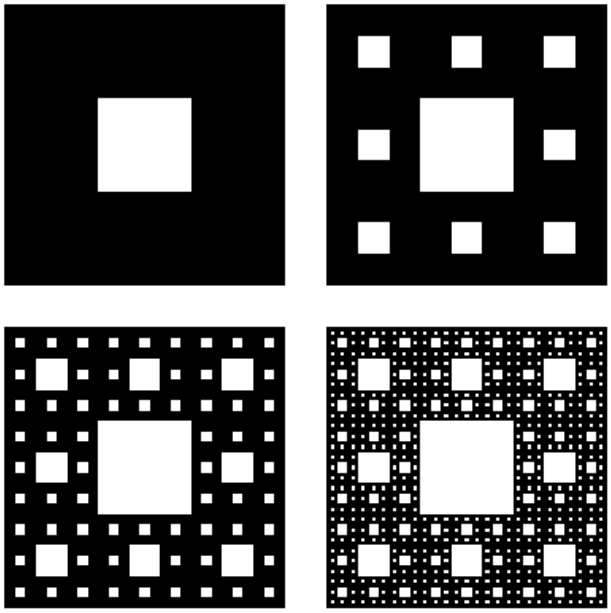
The use of fractal geometry to lay out zoning maps would allow for a framework that acknowledges that all places of human environment should include a mixture of agricultural, industrial, commercial, and residential uses. Rather than starting from a negative position, that each type of use should be isolated from the other, a positive starting point would establish that all use types should be incorporated into all zones -- but in varying extents. Thus, for example, in a residential zone, some form of home occupation (as a commercial or industrial use) would always be an outright allowable use. There could be varying limitations on amount of deliveries, amount of client visits, and size of space devoted to the use, but it would start from a position that home occupations are desirable and positive uses. Home occupations would be allowed unless proven to be objectionable. Innocent until proven guilty.

Our zoning ordinances are getting thicker and thicker every month and year. We are adding more and more exceptions, special requirements, overlay zones, public review, and debate. We are trying to create built environments that are dynamic and healthy places to live in. But we are using a zoning language and and zoning tools from a bygone era. We are using tools from an era when industrialism and capitalism had run rampant through the country and were destroying our natural environment and expanding out of control.

Now we live in a world which has shrunk through the availability of rapid commercial airplane service between cities and countries. We are living in a world with an Internet communications system that links all parts of the world at the speed of light, and new knowledge in science about how the universe was formed, where we fit in it, and what the elementary particles are that it is constructed of.

Using fractals we can better understand how patterns of land use create livability. For example, consider the following fractal analysis of interpenetrability between urban and agricultural/resource land.

- From the Space Shuttle take out a telescope and look down at the city of Portland, Oregon;
- Focus on the city as a whole with its defined Urban Growth Boundary surrounding it;
- Notice that there is a dense downtown core of urban development, yet there are large tracts like Forest Park that are all green;
- Thus at this scale it is a mixture of urban and natural at the largest scale;
- Now zoom in with a higher power telescope to the downtown core that is mostly gridded and built up;
- But inside of that we find a waterfront park of green grass, trees, and flowing water, wild nature inside the city;
- And then we zoom in yet closer and find within that park a commercial food vendor selling tacos, a propane burner charring the meat and onions to be joined with beans and wrapped for lunches;
- And when we zoom in yet closer we find a flowerpot hanging from the fabric-covered metal roof structure, the nasturtiums in full bloom;
- And the flower is bringing about a smile, on the face of a person, waiting in line for lunch, in the beautiful city of Portland, Oregon.



42. Urban Design Standards in the 21st Century

The science of chaos and fractals opens the door to a new set of tools that planners can use in creating architectural design standards. It is common for planning agencies to create historic districts, downtown development zones, and other special districts for which urban planners desire only a certain style, type, feel or sense of architecture.

Such standards might list specific colors that can be used on an exterior of a building. Or they might require glass over a certain percentage of the distance along a streetfront. There might be a requirement for bay windows, brick, balconies, hip roofs, and so forth.

Design standards in the 21st century could have more unusual requirements like:

- All facades below the first story shall have fractal surfaces of dimension between 2.1 and 2.2, while all stories above shall have fractals dimension 2.5 to 2.7.

Those who have studied fractals and know what the numbers mean might see sugar plums dancing in their heads with this idea. Here there is at street level a relatively flat façade that is fractal dimension 2.1 – almost a flat 2 dimensional surface. Above there are required balconies, bay windows, and flower pots, in order to get the texture of fractal dimension 2.5. Suddenly this fractal measure provides is a much more alive, vibrant, and multi-dimensional tool available for design standard codes than has been yet available.

Likewise the mathematics of topology can be used to describe the connectivity of spaces and buildings. If a district's rules require a connectivity of 2.2, they may be calling for a set of sky bridges between buildings which challenges those of the old 19th century historic town of Chester, England – which unfortunately are still more exciting than anything done in the 20th century.

43. Fractal Programming

A building is often thought of as a self-contained, single object. To create it, architects have developed a straightforward, linear approach. First, a 'program' is made for the building. Then the 'program' is turned into a 'schematic design', and this is then eventually turned into a 'construction drawing' which can be used to contract with a builder.

During the 'programming' stage an attempt is made to name all the specific uses and required places needed within the building. A verbal description is made of each use or place, with a list of its square footage, spacial relationship to other uses or places, and equipment or utilities needed for the item. This is a method of creating a whole by inventing pieces which are then assembled and massaged together.

It is believed that the building can be created through a study of the essential elements needed for the building. As with physics, the ingredient atomic particles are identified, and then assembled into molecules. This is a directed process where one stage of design is intended to morph into the next. Each is intended to follow logically from the former. Often, this results in an actual building of spaces that are little more than a diagram of the original program. One can look at the program document, and the final building, and find a one-to-one correspondence between them. This system has worked well for much of the past 75 years.

Using the concept of fractals, there are alternatives to this linear programming process of the past. Fractals are self similar constructions. When any piece or part of a fractal is examined in detail, it is found to also contain the image of all of its parts. This is quite different from the concept that each program element is unique and different from any other.

A fractal program for a building could attempt to find the "kernel" concept that is trying to be achieved. The program would then show how, by taking this kernel idea and elaborating on it or expanding on it, a building comes into being, meets the needs of the owner, is healthy for its occupants and visitors, and creates "life" for all. In this sense, the program might be thought of as a "seed" that the building design is developed from.

Another approach to using fractals in programming is to expand the building design to include more than a determination of the physical spaces and their configuration. Let's make a hypothetical example. Suppose we wish to design a museum building in a remote site. Let's say the museum is to contain exhibits about the local area, which is a nature wonderland – one the last pristine saltwater estuaries remaining on the west coast. But there are only limited funds for the building, and the estuary also functions as a research resource. We could start by trying to define what the exhibits will be. We could believe that if we don't know what the exhibits will be, that we are therefore unable to fully define the program – and thus are unable to design the building form. However, the uniqueness of the place also being a research facility means that new science is constantly being created – so the subject for the exhibits keeps changing.

However, using a broader, fractal view of the program, we can say that the program should include anything that will help the building project come to life and be the success that is desired. Thus, for this rural museum, we may decide to build two bunk houses and a dining hall on a nearby property, to house university student volunteers who will be solicited to come live in this beautiful natural setting, to study the unique marsh, and then design and build the exhibits. We may find that in this rural location, where only limited funds are available, the best hope for success of the museum lies in creating some rustic housing for these volunteers.

By using fractal principles, we might conclude that the single most important element in this program for the exhibit hall, is to build a bunkhouse two miles down the road! We'll still need an exhibit hall of some size to put the exhibits into. But in this hypothetical fractal program for the exhibit hall space, the first and most important piece is to build the piece that attracts the people who will create, build, and man the exhibits. By this means we truly create a dynamism that results in an exhibit hall filled with excitement about the saltwater estuary that was the subject in the first place.

44. Fractal Problems

Modern geophysical science shows us that what appears to be one large hurricane at a macro scale, is actually constructed of smaller chain of storms in a more or less spiral form. As with so many geophysical phenomenon, the large hurricane spiral is found to be constructed of smaller storm cells, each mimicking the other in form.

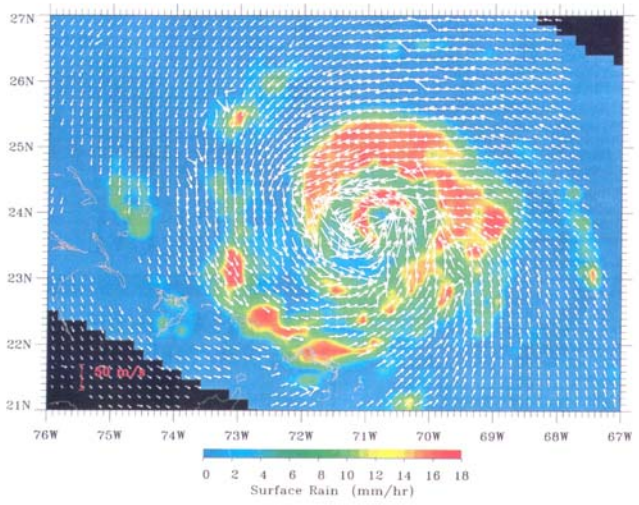


Fig. 1. Hurricane Floyd is revealed by wind vectors (white arrows) from SeaWinds and surface precipitation (color image) from the microwave imager on September 13, 1999, along the ground-tracks of QuikSCAT and TRMM, which are approximately 78 minutes apart.

Figure 59: Hurricane Floyd, 1999

That image from *Eos*, Volume 81, Number 23, of hurricane brings to mind the geophysicist's doggerel which goes:

Big whorls have little whorls,
Which feed on their Velocity:
Little whorls have smaller whorls
And so unto viscosity.

When performing environmental impact assessments for constructed projects in sensitive settings, this concept seems to apply as well. One begins an environmental assessment with an alternatives analysis, which explores different design options. These design options are each examined to determine what their environmental impacts are. In theory, a matrix or table can be created which allows a comparison of the alternatives. The alternative with the least environmental impacts can then be selected. In some cases this process works quite well, and it is possible to come to reasonably good conclusions which prove themselves over time. In other cases, where the design alternatives are in sensitive settings, the selected alternative can turn out to be more like a hurricane made up of little hurricanes.

As an alternative is examined, it may break apart into smaller but equally intensive problems. The further one digs into the problem, the more problems that are discovered. In these kinds of cases, the full impacts are not known until the project is designed in detail, and all permits are in place. Even then, more problems may pop up during construction.

What are the flags that signal architecture or engineering projects which have this kind of design complexity? Three common indicators are: wetlands, archeological findings, threatened and endangered species, and intense community involvement. Wetlands are a common environmental site condition taken into account in many projects today. By their nature, wetlands are extremely indeterminate structures. It is difficult to determine the edge between water and land, when it varies enormously by season, by soil characteristic, by changing upstream development, and by decadal oscillations between El Niño and La Niña, and now even expected centennial changes in polar ice caps.

How do we make choices between alternatives, for projects such as these? When the examination of a wetland must lead to an examination of whether the wetland will remain significant with changing global climate, the issues become far more difficult than simply "choosing between alternatives."

For projects that are more like hurricanes there will need to be developed a different kind of framework analysis. Rather than a simple analysis of alternatives that looks at direct impacts, there will need to be an analysis of the likelihood of additional problems arising as the project proceeds. In other words, there will need to be an analysis of the likelihood that when one problem is solved, two new problems will appear. A hurricane could not be stopped by the stopping by one of its cells.

Fractal problems are things that when you look into a piece of the problem, inside are found more and more complex problems. Rather than finding answers, one finds problems inside the problem.

This sounds like a kind of negative view of things. The word "problem" implies that something is problematic, uncertain of being accomplished, difficult. But maybe there's a positive side to it. Problems that are themselves still filled with more problems are certainly things that are filled and brimming with life. It makes them hard to define and categorize. It makes them hard to solve.

45. Bruce Goff on Order in Architecture

In 1953 Bruce Goff, the Dean of the School of Architecture at University of Oklahoma for 15 years, tape-recorded his thoughts on architecture. These have been recently released in the book, *Goff on Goff*, edited by Philip Welch.

In the chapter titled "Order in Architecture", he encourages his students, and architects everywhere, to find a "basic order" or "idea" to be used as an organizing principle for the design of each building. He says:

> "The Japanese have words for this, too: *edaburi*, which means, as nearly as you can say it in English, the formative arrangement of the branches of a tree. In other words. the sense of order in the design of a particular kind of tree that you would find in the arrangement of its branches. If you were speaking of the *edaburi* of a willow tree, it would be quite different from that of an oak tree or a pine. This sense of order isn't just in the differences of the kinds of leaves; it carries through the textures, all the way through. . . .
>
> "I think there are very few things done by man that have this sense of order. A sense of order does not necessarily mean you have to design with a straitjacket or a frugal restricted design diet. It can be very rich and can be very complex at times and still be ordered. You can have an ordering chaos, if you can hear the order in chaos, or see it, or feel it. It is possible." ([35])

Here is an architect 47 years ago recognizing what is now called the fractal quality of plants, and asking his students and the architectural profession to see it and work with a similarity of purpose. Thus, we recognize that the "organic" architecture promoted first by Sullivan, then by Wright, and closely followed by Goff, is an attempt to look at growth form, and find principles or ways of working that can help the architect create buildings that are as rich and exciting as nature itself.

Even the old pre-revolutionary war English colonial house used in early America is in some ways purely organic. The big masonry fireplace in the middle provides the heat and the food for the family. The house is organically grown out from that chimney and fireplace.

There is a sense in which history makes everything organic! Every generation in some way grows out of, or in opposition to, the previous generation. Architecture as a whole is no different. Thus, "organic" does not mean amoebas or curves so much as something which has an order of growth to it.

46. Building vs. Architecture, continued

It is apparently easy for architects to put down builders. Architectural historians may be the worst, but even the "organic architect" Bruce Goff felt the need to distinguish architecture from building. In his essay "Order in Architecture" he says:

> "It is the thing that will make architecture, rather than "just a building." We do not have to have any kind of order in "just a building." It could be a good building, do everything a good building should do, but still it wouldn't need to have one bit of order, would it? It might, accidentally; maybe the fact that the columns are twenty feet on center will give some kind of order, but that would be about all, maybe. It wouldn't necessarily have the kind of order we are talking about. But a work of art, or architecture, should." ([36])

As we noted earlier, Goff is ready, willing, and able to look to nature as a model for "order" in architecture. In fact, that claim is made in the same essay that the above quote comes from.

Of course, we must recognize that Goff was the dean of a major school of architecture for more than a dozen years. He was in the business of training architects with a capital "A." Yet, a grain elevator or a barn in a rural landscape can be as beautiful as any piece of architecture with a capital "A." That grain elevator or barn, with its simple human rectilinear geometries, set against a rounded mature landscape, speaks of "order" to the highest degree. Perhaps we just have to admit that underlying bias, and acknowledge that it wasn't until Bernard Rudofsky's *Architecture Without Architects A Short Introduction to Non-Pedigreed Architecture* was published in 1964 that the beginning of the end of the need to distinguish between architecture and building began.

This underlying need to distinguish architecture with a capital "A" from building with a little "b" speaks to the lack of self-confidence in architects.

47. Fractal Government: From Family to Nation

For more than a century, the concept of "government" has been considered as relatively easily definable, by categories. The common categories have been democracy, Communism, dictatorship, anarchy, socialism, tribalism, and so forth. People have debated, and threatened, and on occasion fought with each other as to which is better. The categories "democracy" and "Communism" have faced off with each other for most of the last century. With the fall of the USSR, it is claimed that "democracy" won out over "Communism", though of course China, the largest populated country of the world still uses communism.

There is a strange sense in which these categories of government are reminiscent of the simplistic figures of Euclid's geometry. Their form is known by their large-scale shape. These governmental categories are like giant circles, triangles, and squares. And like the debate about how many angels can sit on the head of a pin, perhaps we will discover that the terms themselves are relatively meaningless when it comes to studying how governments "really" work.

It is well known that Marx and Engels used Louis Henry Morgan's studies of governmental organization among the American Indians as a foundation for their creation of modern "communism." Morgan's *Houses and Houselife of the American Aborigines* is a must read book for those interested in either communal architecture or the meaning of architecture in a native society. In fact, analysis of native cultures has long been a basis for creating a "science" of government. Two recently published books attempt to consider social organization from the standpoint of a "native" or "first nation" perspective -- rather than from that of the anthropologist or conquering culture. These works provide impetus for upsetting the traditional "science" of classifying governments.

Indians in the Making: Ethnic Relations & Indian Identities around Puget Sound, by Alexandra Harmon (University of California Press, 1998) discusses the notion that in the Pacific Northwest, prior to the advent of "white man", there was no such thing as a "tribe." She discusses how the governmental structure was in fact founded primarily in a family unit, and then through life necessities spread to larger overlapping groupings. It was the invading whites that invented the concept of "tribe" and then established tribal reservations as convenient places to force groups of natives to stay living within. The concept of "tribe" or "nation", was not known among the natives themselves.

We are forced to realize that even the names we have given to Indian "tribes" is thus itself even completely flawed. Englishman Broughton sails his ship across the Columbia River bar and into the estuary in 1792, and points to a village on the shore and asked a native in a canoe – "What are these people called?" He records the name "Chinook", and it becomes the name of a tribe or nation living on the lower Columbia River. Two hundred years later linguists and anthropologists finally figure out that it probably is the name only of that village, and even then, as spoken in a completely different language by other peoples living much further north along the coast – i.e. their name is not "Chinook!"

The anthropologist Jacobs[37] tells us that the "Clackamas Indians" on the Willamette River and the "Chinook Indians" on Wapato (Sauvie) Island, both speak "Chinookan" languages. They trade with each other and inter-marry since they are only a couple of hours of easy paddling from each other. However, their languages are enough different that only some of the words overlap -- they can trade with each other, but the language of customs, myths and histories are to some extent unique. When inter-marrying, one party would have to learn the new language of the other. It is said that natives often knew several languages.

Now mix in the American juggernaut "democracy" as it rolls through the Pacific Northwest as a westward migration of non-native settlers, and we find in hindsight that this so-called "democracy" failed at the most fundamental level. Consider the fate of the Modoc Indians living in their original lands in the mid-1800's, near the border between what we now call Oregon and California. White settlers had created an immigrant route through the middle of the Modoc lands, both disturbing the native culture and subsequently forcibly taking portions of it for private settler ownership. A sequence of battles ensued, with whites brutally massacring Indians and scalping them, and with Indians brutally massacring whites and scalping them.

When Oregon Indian Superintendent A. B. Meacham -- representing the US government -- met with Captain Jack (Ki-en-te-poos), chief of the Modocs, to ask for the surrender of himself and his people, Captain Jack asked Meacham[38], "Who will be the jury that tries us for having killed settlers?" Meacham answered, "It will be a white person jury." Captain Jack then asked if the US military will then turn over those whites who massacred Indians so that the Modocs can try them with a Modoc jury. Meacham, as an Indian sympathizer, knows that Captain Jack is right, but must answer "no" and recognize that the "democracy" is as false here as it was during the promotion of slavery of blacks.

Another book which looks to the roots of our understanding of government is *Decolonizing Methodologies: Research & Indigenous Peoples* by Linda Tuhiwai Smith (University of Otago Press, 1999). She begins the book:

> "From the vantage point of the colonized, a position from which I write, and choose to privilege, the term `research' is inextricably linked to European imperialism and colonialism. The word itself, `research', is probably one of the dirtiest words in the indigenous world's vocabulary. When mentioned in many indigenous contexts, it stirs up silence, it conjures up bad memories, it raises a smile that is knowing and distrustful. It is so powerful that indigenous people even write poetry about research. The ways in which scientific research is implicated in the worst excesses of colonialism remains a powerful remembered history for many of the world's colonized peoples." (pg. 1)

Smith points out that what is today called a "democracy" or a "free" government, is founded on the imperialism and colonialism of the past. Her work points us to the possibility that the very concepts of "government" and "social organization" that are in use today, are poisoned by their own tortuous history.

Let's look back at Euclid's geometry. It was invented as a way to simplify the description of the world, and to make the world more capable of scientific examination and prediction. With the last thirty years of computers in science, we have developed new ways of studying the world of chaos and complexity. Can we imagine a use of this science in the study of governments?

The concept of fractal geometry might be a door to a much richer view of government. Using the concept of fractals, it seems easy to imagine that a native government in the Pacific Northwest was one whose fundamental organization was based on a "kernel" concept of family unit. This unit then repeated itself and organized itself in a fractal manner in which the larger size organization and the smaller size organizations became self-similar. There was a self-similarity between the family unit and an extended-family unit, an extended-family and a village, a village and several villages, and even at times several villages and a regional alliance. Thus the governmental system was not one of "governance", rather it was one of "being."

Is it that our Euclidian "Western scientific methodologies" are in fact flawed and useless in studying something as complex as government? Using the model of fractal geometry, we can say that we are poised to understand government with all its complexity included, rather than simplified and put into boxes, triangles, and circles. It is a system of interlocking governments, operating at all different sizes of social organization.

Using fractal analysis, it will be possible to determine the "health" of a government by seeing whether there is a consistency of form or structure starting at the family unit and going larger to neighborhood, village, and region. The roles of men and women would provide a good measuring tool. In the United States there still has never been a woman president or vice-president, yet there are many, many women who are heads of the family unit. This kind of analysis of government at its different scales, might be considered a fractal analysis methodology. It provides a test of the similarity of the governmental or social organization at different scales.

In today's Western world we believe that the layout and form of family relationships is a very straightforward and logical process. On the basis that an egg from a woman and a sperm from a man create a child, we have a lineage process which goes from child to parent to grandparent with cousins to the sides and so forth. This is a linear, rather sterile, model that is severely lacking in richness, life, and health – when compared to other more traditional examples of family.

48. Fractal Government, Part 2: The Complexity of Healthy Families

Other cultures have much more complex forms and systems of family relationship. In the early 1920's Jaime de Angulo spent several years doing linguistic field research with the Achumawi Indians -- commonly known as the Pit River Indians -- in Modoc County, California. He describes his experience living, traveling, and exploring with those Indians in his book, *Indians in Overalls* (City Lights Books, 1990). In several places he provides detailed descriptions that illustrate the complexity of family relationships in that culture. In the following example de Angulo tries to explain where his friend, Robert, got his name:

> "At this place of Astaghiwa (meaning `hot being,' because there is a hot spring) there also lived Robert Spring (he took the name from the spring -- but his brother was Jim Bailey, and why?? but Jim Bailey was the son of Blind Hall's Woman, but Blind Hall was not his father . . . . Indian relationships are very complex and the adoption of white men's names does not simplify things)." Page 23

It is fascinating to have a last name come from a local piece of geography. Is the "landscape" somehow his "father" with the use of this as surname? Further along in the book, de Angulo brings up the concept of "cousin":

> "He is a Pit River by birth, but he was brought up by the Klamath Indians (who are first cousins to the Pit Rivers)." Pages 38-39

What the white culture calls "tribes" may to native culture be considered as "first cousins," where "tribes" are located near each other. As this is Modoc County, perhaps Captain Jack though hung by a US military court lives on in these Achumawi that de Angulo in spending time with. And below, another friend is found to have quite a variety of names. De Angulo describes a trip with friends Sukmit and "old Mary":

> "So I took them down to Berkeley in my auto, Sukmit and old Mary (she once told me her Indian name; it had something to do with tule reeds at dawn; but I never heard anyone call her by it; Sukmit called her *miini*, baby-talk for *nen* `mother'; and I also called her that after a while; other Indians called her `aunt', or `sister-in-law on the brother's side,' which is *wattulaawi*, or whatever the relationship term." Page 54

De Angulo also touches on a rather different concept of "tribe" than whites would normally use, that he found being used by the Pit River natives:

> "We were all inside the cabin; still old Kate was waiting for something; finally she said: `Dat white man going to stay?' `He is no white man!' said Jack. `He is Indian just like us.' `What tribe?' she asked me. `Spanish,' I answered. `Oh, dat's all right. Spanish good people.' To her, too, Spanish meant Mexican." Page 61

De Angulo in the following long dialogue provides a wonderful example of the complexity of relationships among the Achumawi's. It is a complexity that at first may seem confusing, but which upon further thought can be seen as providing a far greater richness of culture over what we have in our modern world:

> "I was surprised to see him. He had tied his horse to a post in the corral and came over to me. He said he had come for the funeral, and that the woman-who-had-died was his cousin. He said `sister'.
>
> "How can she be your sister, Bill?"
>
> "Well, she is, Indian way."
>
> "I don't see how."
>
> "Oh, yes. Look: her *apun* her grandfather on the mother side was the elder brother, what we call *apau*, to my sister, the younger than me, my *enun*."
>
> "But, Bill, that doesn't make her your sister!"
>
> "Sure it does, Doc. . . See, if a man is my wife's brother I call him *malis*, and my own brother, if he is older I call him *apau*, but if he is younger I call him *atun*. Just like my sister, *apis* or *enun*. But if he is my uncle, if he is my father's sister then I call him . . . oh, hell, Doc; you can't get it straight in English. . . But I tell you, this woman who died she is related to me, I know, because she always called this here Tom-Chief, *aqun*, and he also called me *aqun*, and that proves it." Pages 66-67

A reader interested in this subject really should read de Angulo's entire *Indians in Overalls* book, as the context for these quotes is of a very interesting life and culture. Ten pages further into the book, de Angulo describes how a man's relationship to his wife is shown to extend beyond her death:

> "She was very good, that woman, Doc. She never quarreled. I have had four, no, five, [wives] before her. We have been together a long time now. You know

my daughter Jessie, well she raised her. Jessie has got grandchildren now."

"But, Jack, I thought Jessie was this woman's daughter . . ."

"No, another woman's. I have had three women already, no, four. No, two only, according to Indian way. This woman I paid for her and she paid for me. That's according to Indian law. I gave Jack Wilson, you know, . . . the old fellow who was singing that night, I gave him a white mare, she was awful fast, she had won several races for me, and her people gave me the right to fish on Hat Creek . . . but you noticed that woman that's come in with them? She is ordering everything around, she is bossing everybody . . ."

"Yes, I noticed her. Who is she?"

"She is younger sister of the woman who died, what we call *enun*, same as what you call "cousin." So, she has come to claim me."

"What do you mean, claim you?"

"It's this way, Doc: according to Indian law, *the dead people have got the say*; the relations of the dead person have got the right. If I had died, then my people, my relations, they are the ones who have the right to bring another man in my place. It don't matter he is an old man good for nothing. They say we bought that woman, she belongs to us now; here's a man for her; she take him, or give us back our present; we gave you a horse for her; where is that horse? now, this woman who died I married her according to Indian law. So, her people, her relations, they come here with this other woman, and they say to me: you lost one, here's another, you got no claim against us."

"Well, then, it's all right, isn't it?"

"No, it ain't all right, Doc. I don't want that woman. She is all right. She is young, I know. She is clean; she is a good worker . . . but she is bossy as hell! She'll boss me . . . I am too old to be bossed!" Pages 76-77

In spite of the fear of being bossed around extensively, Jack does become the husband of this younger sister, and he is excessively bossed around just as he had feared. However, through the complexity of the native traditions, there is a way out, so that the story has a happy ending for Jack. De Angulo says:

"I saw him again the next summer. He was radiant. `I got rid of her, Doc. I was camped at Davis Creek, and her brother he come and see me, and he says: Jack, I wouldn't stay with that woman, if I were you. She is too damn bossy! . . . Well, Doc, that's all I wanted to here. He was her elder brother, so he had the say. So I called my own boy, Millard, you know him, and I said: I am going -- when that woman comes back to the camp, don't tell her where I am gone -- you don't know nothing about it, *sabe*?" Pages 79-80.

In our modern American culture we look at a complex set of relationships such as these described by de Angulo – as being odd, mysterious, irrational, and appalling. We don't have a framework to understand family relationships that have this many nuances. One guesses that our great great ancestors may have had relationships this complex, but like mythology and witchcraft, we are modern now. We attribute the complexity to the times being "old fashioned." However, perhaps it is more that in our "modern times" we have simplified the "equations" of social order to make them easier to describe. We have attempted to put our social and familial relationships into a "scientific" form like Newton's law "F equals M A." Maybe with the accepting of complexity in science, we can as a culture become more accepting of complexity in social and family organization!

49. Fractal Government, Part 3: Architecture for the Family

My friend J has a daughter (American) who married a young man from Cameroon. His daughter was a little upset the other day that her husband's cousin's aunt had called from the old country. She was a person who J's daughter didn't even know. The Aunt was enthusiastic to hear about how the baby was doing and quickly asked "how is my son?" In American culture of course, this comes across as much too familiar and could be a very risky thing to say to a new mother – especially given that there is a high probability that the mother is already sleep deprived and ready to make mincemeat of anyone who crosses her.

In Cameroon, it seems that the father's cousin's aunt is another "mother" to the child. Perhaps in Cameroon the "birth mother" actually gets to sleep through the night, while other of the "mothers" take over. To add to our confusion as logical Americans, J was watching a videotape of his son-in-law's recent arrival in the old country for a visit to his relatives. On seeing her son his mother exclaims: "My husband's home! My husband's home!" In Cameroon apparently the word for son and for husband are interconnected in some fundamental way. It was a joyous reunion, and clearly we Americans have much to learn when it comes to a healthy and close-knit family! We have simplified millennia old traditions of interlocking, complex familial relationships, presumably to make them fit better with our "scientifically logical", Newtonian sense of culture. And with this we are missing a lot in the way of family support, family continuity, and joy.

Whether it is a product of our European history, or our extraordinarily Puritanical founding fathers, America today has a strong bias towards the simple, singular, nuclear family. And sadly, the extended family has been eroded to the point where grandparents, aunts and uncles rarely live in the same house or community as the family. And then inevitably, this idealistic family structure of father, mother, son and daughter (and Holy Ghost?) results in a very high divorce rate. In fact single female heads of households form a major form of family structure in all income levels of our society.

Also in America today, the single-family house has become an architectural icon, a kind of benchmark for architectural analysis. One thinks of the single-family houses of Frank Lloyd Wright, Walter Gropius, Mies Van Der Rohe, Philip Johnson, Michael Graves, Peter Eisenman, and so forth. The innovative design of a single-family house has been used over and over again as the basis for a new theory and approach to architecture.

This should then give us cause to fear a great failing of American architecture. To have the basis and meaning for the architecture -- a single family unit -- which is culturally crumbling and idealistic rather than functional, should cause us to question the health or success of our architecture. If the basic tenet of a design is false, the architectural response to it should certainly be suspect.

Add to this the extremely high incidence of divorce which follows an architect's work in helping to perform a major remodel or new house project for a family. We all know that many house projects are undertaken as a subliminal attempt to remodel or renew the marriage itself. Hope is somehow transferred to a new building, and that by repair of the home, somehow the repair of the marriage will follow. Many, many architects have been heartbroken from providing years of work for a married couple to create their dream home, only to have them divorce the year after it's done.

Surprisingly, the current state of the American family is itself leading us back to a more complex family structure. The high incidence of divorces is resulting in "blended families." There is one boy in our neighborhood who now has four fathers and no mother. He was originally raised by a gay couple, but they broke up, each subsequently finding a new partner. This boy is now being actively parented by all four fathers. Under normal American social analysis this would appear to be a tragedy. However, who is really to say if this boy will not in fact have a much stronger, stable, and healthy family structure as a result of this rather unusual circumstance?

It may be vitally important to our culture and governmental system that we recognize that our American concept of family is too simple, too dead, and ultimately unworkable. As we allow familial complexity to enter American culture, we may see that having multiple "fathers" and "mothers", and each of those having multiple "sons" and "daughters" outside of the traditional description, is a far healthier reality to work toward. And in our homes and dwellings, this means designs that have enough complexity of space to house additional fathers, mothers, sons, daughters, aunts, and uncles. This is an exciting future to imagine and take part in.

50. First Nations

As we reach the end of this paper, we should acknowledge that the First Nations had a more traditional, symbiotic relationship between man and nature. Probably there was no separation of "art" and "science." Western culture has almost completely overwhelmed these native American cultures. It is only several hundred years later that we recognize the great strengths of those cultures, and we envy them. During the next 100 years, the "conquered" may turn out to be the conquerors, as concerns the need for an understanding of wholeness and interdependency between man and nature.

51. Finishing Building

If we accept that "building" is a verb, then how can we ever "finish" a building? If – as former essays have considered – a "building" is simply the physical, outer manifestation of a human life, then must we conclude that the only way to finish the building is to finish the life within? Is a building really just a big coffin – drive the last nail, climb in, and shut the door?

Personally, I love a construction site. Like most architects I feel a sense of exhilaration at the sound of nail guns, boom trucks, and an occasional jackhammer on concrete. The sharp sawdust smell of cedar and Douglas fir, mixed with carpet glue, fresh vinyl, and hot tar jolts one to life – better than any cup of strong coffee. Yet not everyone enjoys living in a construction site. During the renovation of our family kitchen, my wife was driven so crazy she almost decided to leave our house forever – to find a small house of her own where she could find peace and quiet. Even though the kitchen work was being done at her insistence, and was designed to her very specific wants and wishes (by an architect friend, not me), the process was unsettling in the extreme for her.

Our two teenage kids and I, on the other hand, enjoyed the smear of dust on everything. Taking the dishes upstairs to the bathtub and washing them there, was a bit like carrying them to the nearby stream and scrubbing them with moss, mixed with sand and gravel. There is something very elemental about living in a construction site. You have to invent ways of getting by, even for the most simple of daily activities.

These essays have elsewhere boldly proclaimed, "Building is a verb." My wife would say that living in a house while the kitchen, bathroom, and entry area are being remodeled is like living in chaos – where chaos is some form of hell. She needs a life in which it is not necessary to invent a solution for even the simplest of daily activities. And to be fair, I have to admit that she is absolutely right. The kids and I enjoyed the madness, but there would be a limit for us as well. Just because "building is a verb", doesn't mean that our lives must be in constant mayhem, in a constant state of verb. “Building” is not just a verb it is also a noun. And if you think about it, that makes it a truly remarkable thing, to be capable of being both a verb and noun!

The root of the word "building" is, of course, "being". Some who regularly meditate, sitting Zen, believe that if you sit quietly, you can perceive every intake of breath as a coming to life, while every outbreath as a kind of dying. The metabolism in the brain becomes energized and euphoric on the inbreath, while is experienced as mortality and death on the outbreath.

Certainly the renewal of a building -- the replacement of rotted roof shakes, the repainting of walls, the refinishing of floors -- these are life-affirming actions. Conversely, when a roof is clearly past its life expectancy, porch posts are missing, and quadrants of a building are sinking into the earth, a building is truly proved mortal as well. An inbreath of air into the lungs takes perhaps two seconds -- three or four beats of the heart. Building renewals occur perhaps every 20 years – once per generation. Both are fundamental activities of human life, they just have fundamentally different time periods.

There are some cultures where the building renewal process has been codified and made into a cultural ritual which allows the building life to far exceed the lifetime of an individual. The most famous example may be the Ise shrine in Japan. In that case the shrine is reconstructed every 20 years. The first shrine was built 2000 years ago, and yet the same shrine exists one hundred generations later, through starting and stopping of building the same building, every 20 years. The process is so thoughtful a form of building, that the trees to build later shrines are groomed in the forest for more than a hundred years in advance of their planned use.

The point of all this, is that to "finish a building", does not necessarily have to mark the end of the life of the building, or of the people inside. Rather, the sense of building as a verb may occur as a kind of rhythm, in balance with the sense of building as a noun. First one, then the other.

There is a sense in which all verbs require a starting and stopping over and over again. When someone says they are farming, it doesn't mean that they get on their tractor and plow the field for 24 hours a day, 7 days a week, 365 days a year. Rather, like most human activities, a farmer gets up in the morning, has a cup of coffee, goes out and does a day's work -- hoping to finish some piece of it -- and then comes in at least for the evening. Then there are the times between the growing season, when the fields grow unattended, or are fallow, when some farmers are indeed "finished farming" for the season, and head to southern warm climates.

There is something exhilarating about "finishing something". So with a building, though it is a verb, finishing some portion of it becomes a point of time for celebration. For a building, perhaps the periods of construction inactivity are considerably longer than the periods of actual "doing building."

What are the lessons for architecture out of all of this? First, that to "finish building" we must have an extended period of building. If we live in a "building" then the "finishing of building" becomes a periodic point of celebration. The finishing of a building is a marker in time that identifies the end of one period of change. It is accomplished knowing that there have been many prior cycles of building, and that there will be many future cycles of building as well.

Thus, when we think of building as a verb, we don't have to imagine living constantly in a state of flux. We don't have to expect our spouse to enjoy chaos in a continuous way. Rather, we might think of the finishing of building as the point when the chaos of building reaches a stable or calm state for an extended period of time. It is the period of exhaling, of outbreath, when a calmness takes over. But in the larger picture, we know if building is alive, and like a verb, that through change our building will take us through chaos again, so that we can finish building again, another day.

How a person views living with construction and building in their life is to some extent a personal value largely based on experience. In my own case, I grew up in a house that was constantly in construction. The house started fairly small -- approximately 700 sf. We moved into the house about six months after construction was started, as soon as there was a dry and warm place to live. After a few years a wing with four bedrooms was added on to the east side of the house. After ten years of ongoing work on the house, my mother noticed that the property tax bill on our house had suddenly risen. She went to the tax assessor's office to try to understand why. The tax assessor said that he assumed that the house was finally finished, so he had appraised it at just the value of a completed house of our size. My mother said, "No! My kitchen cabinets are still just a stack of orange crates. Our house is nowhere near done." The tax assessor sympathized but said, "Okay, I'll lower the tax bill to the same it was last year. But you tell your husband that he better finish those kitchen cabinets this year because I'm going to charge you the full tax on the house next year no matter if it's finished or not."

Not only was the house always in a phase of construction, but there were sailboats, iceboats, canoes, a duckboat, motorboats, a sternwheel steamboat, go-carts, and a hundred other things being built and experimented with in the house throughout the year. My father was always trying to create the lightest canoe possible for use in portaging, and got one down to an amazing 25 pounds. Then, later he built an amusement park-style airplane ride that ran on a cable running from a 25-foot high post attached to the side of our house, down to the ground. No wonder our friend Ethel Untermeier could tell my mother, "Dorothy, you live in a ten-room workshop!"

Our family has many stories about living in that house that we built and "finished" year after year. One of the most exciting days I remember, was coming home from junior high to find my father slowly working his way around the house with paint brushes and three cans of paint in his hands, hanging from strings with paint dripping from them, all over the floor. For the first eleven years our flooring had been a slate-gray 30" x 60" linoleum desktops that were glued to the concrete slab. They were very attractive, waxed and polished up very nicely, and worked superbly. But my father, with my mother's permission, had decided it was time to give the house a little more cheery life. So he was speckling the floor with different colors of dribbled paint. Thus, in our day-to-day life – until he changed it to wood parquet a few years later – we were walking around on something very much like a Jackson Pollock painting.

Children growing up today, experience very little of this kind of dynamic sense of letting a building become a part of one's day-to-day life. Nowadays people expect, and the building code demands, that a home should not be occupied until it is "substantially complete." So it seems we have developed a culture that resists this sense of a building as being alive and breathing. From my personal experience, I would suggest that this is a great cultural loss. We must take measures to recapture this vital way of life, where building is never finished.

52. Poetry & Architecture

One of America's foremost poets once said: "Form is never more than an extending of contents." I have always found this to be the most useful phrase as to defining "form" in architecture. What would the "extending" of "contents" mean in the context of architecture?

The phrase "form follows function" has almost become a household phrase. It was an attempt by the Modernists of the 1950's to get away from styles that only had meaning in relation to the history of architecture. The idea was that architecture should be more like a machine that functions as a dwelling or place for mankind to live and work within. In searching for an architectural form, one need only define the functions for the building, and the form would follow.

In hindsight, this is a bit rational and linear in its approach, as if we can define the function of our own lives and activities. It is also severely limiting, as our lives and activities usually have multiple purposes and functions, all present at once. Is there a piece of paper large enough to list them all? Yet when we live in the world, we physically can open the door to only one room at a time!

"Form is never more than an extending of contents." One of the beauties of this poet's sense of form is that there is an inherent circularity to the statement. It is almost a tautology. If we look at the root of the word "extend", we find that it means "from tension" – "ex" "tende." The intent of "tende" is that there is a tension holding something together. By adding the "ex", we are being told that there is a releasing of that tension.

Likewise "content" is a containment of "tende." It is as if a pair of cupped hand are holding something within, containing them.

Thus an "extending of contents", is a releasing outward of something which is held within, and which by its nature has a natural force of tension within it. By releasing the natural hold of things, there is a movement outward, like from a pebble dropping into a pond. There is a wave which sits at the outer edge of the dropped pebble and it is expanding outward into space and time.

Another aspect of this sense of "extending" is that it must occur into something. Does the extending occur into a void? Is there already a space in nature that the extending occurs into? And here we have tied our building to the question of how the universe was formed. A building is formed around a life. A building is constructed from trees and rocks that exist in the surrounding landscape. So the expansion outward results in a form made by re-organizing what is nearby.

However, our poet did not say that form "is" this extending of contents. Rather, he said it is "never more than" the extending of contents. If a form is present, how can it be less than some quantity? In the case of architecture, let's say that a building is designed with reference to a specific style -- in a sense, copying some forms from the Egyptians, or even a post-modernist American who in turn has copied some other historic style for decoration of a rooftop. In this case there is a "extending of contents" but it's pretty much disconnected from a specific building site, a specific people who will be inhabiting the place, the natural surroundings of the place, or any other specificity for that building. Rather, it is a reference to someone else and some other place.

This does seem to be "somewhat less than" what can be imagined as optimal. It's a release of what might be called "cerebral tension." But it's sure missing the connection to the "body politic" -- the corpus, the earth, the surrounding nature.

This issue of "tende" as being at the origin of form, is a reminder that the "tents" of the nomads are the real origin of architecture. The thin fabric of a pup tent like a cocoon around a Boy Scout, is in some way the most fundamental of architectures. Of course the tipi, yurt, black tent, and other advanced technological forms carry this sense of the building actually being in tension, to more glamorous and extravagant forms. Frei Otto and the other 20th century tension architecture specialists carried this forward to a modern set of forms.

When a log house begins its drying out process, there are loud pops and bangs as the tension in the logs releases itself and forms long cracks. This is especially true for spruce logs, which even have a slight spiral to the grain down the length of the log. The spiral form showing how the vigorous growth bound back on itself – holding its years of growth energy tightly within its narrow trunk.

What would architecture look like that is "not less than" its extending of content? It would be a building whose shell is kind of a concretization of the life and activities that take place inside. It is a building where the materials might still pop and crack, showing the internal tension in a piece of wood that grew for a hundred years, ring by ring. It would be a building that extends and weaves itself back into the larger site. It would be a building that changes shape and size depending on what is happening inside, and on the pull of the moon.

It is the "tect" in architect that refers to this unusual knowledge of how to intertwine things. And it is this weaving of materials – waddle and daube, logs, steel I-beams – that creates the fabric, that can be tensioned between things, to form a tent – a building, an architecture.

53. A Language for Building

In this paper we are trying to talk about buildings. In some ways this is a fruitless exercise. Buildings are things in themselves -- and thus speak their own language. What we are trying to do here is perceive them for what they are -- hear what they have to say directly to us.

Part of the problem is that those of us living in the modern western European tradition view buildings as objects which are lifeless. As lifeless things, how could they talk to us? A rock is a rock, a log is a log, a pretty facade is an object of art and nothing more.

That is not to say that historians don't study buildings and architecture to find cultural meanings. Through study of architecture university professors commonly will teach that this tells us something about the life of the people that lived at those times.

But suppose we started from a different initial assumption. Suppose that we understand all things to have a fundamental life to them, with an ability to speak for themselves. Suppose they speak their own language and not English, Chinese, Ojibwe, or any other human language.

What word in English would we use to describe that ability for a thing to speak its own language? Perhaps it is enough to just say that anything which is living, expresses itself in its acts of being alive, whatever that means for that thing.

At heart, language is a shorthand for explaining how things work. Words or language provide a mechanism for condensing down the reality of actions or things into a string of utterances, hand signals, or written texts.

Or perhaps language can even be thought of as simply "one thing representing another." In the language of architecture a set of architect's drawings represents the building. Alternatively, a small model of the building can represent how the whole building is to be constructed. Thus we can say that an architect's set of drawings are "words, sentences, and paragraphs" that are written in a language that the building itself understands and will allow it to be brought to life.

In this vein, would the seed of a tree be considered as the tree's "words" for itself? In the science and art of "fractals", a small mathematical equation or a simple computer program provides a kind of "seed" that can on the computer screen construct a tree of infinite complexity. There is a sense in which the fractal code is the underlying utterance for the growing and living image that the fractal becomes. The fractal code may be the fractal image's word for itself.

What word can we use to describe this fact that a seed somehow contains the whole of the tree within it? What word can we use to describe the fact that all buildings are living and that their whole is somehow contained in their pieces as well? What word can we use to describe the fact that even a small piece of DNA from a living being, may be used to recreate the whole animal. In English this is a difficult task.

It seems that the concept of "fractal geometry" has provided the first word to examine this notion that the whole form is contained within the parts of the form. But the word "fractal", as invented by the mathematician Mandelbrot, is still unknown in the common language of American English. Some architects have used words like "living architecture", "sustainable architecture", "design with nature" . . . but these all seem weak and lacking.

Perhaps it is best to simply revert to the verb "building." If we can develop a "reverence for buildings", that may be all that is needed for us to hear the building speak to us.

Figure 60: Morgan Rocks

54. The Fractal Geometry of Estuaries

An example of the kind of new landscape studies which can be undertaken are provided by a look at the South Slough National Estuarine Reserve for which fractals provide a measuring tool. Benoit Mandelbrot has gained worldwide attention with his development of this new science. Mr. Mandelbrot developed this field in part to provide a method for studying the geometry of natural objects. Thus, in the introduction to his classic book *The Fractal Geometry of Nature*, Mandelbrot asks:

> "Why is geometry often described as 'cold' and 'dry'? One reason lies in its inability to describe the shape of a cloud, a mountain, a coastline, or a tree."

In examining this contradiction, Mandelbrot identified a family of shapes called fractals which do prove useful in describing the geometry of nature, and are leading science into a mode of being able to better understand what heretofore could only be described as "chaos".

A fundamental problem within the study of fractals is to determine the length of a shoreline. In the case of South Slough we can phrase the problem as:

> "How long is the shoreline at South Slough?"

Figure 61: South Slough Estuary at Very Low Tide

Although it sounds like a simple problem, if a portion of shoreline is first measured on a USGS topographic map and then measured on a more detailed air photo, it will be found that the shoreline length increases.

The distance increases because the more detailed in's and out's of the shoreline can be measured in greater detail on an air photo than on the USGS map. Common sense tells us that as we increase the fine detail of our measurements, the distance of the shoreline will forever continue to increase. What sense can we make of a continuously increasing shoreline length?

Figure 62: Estuary Edge at Differing Scales

Mandelbrot developed a method whereby a "fractal dimension" of a shoreline can be determined. Unlike the ever changing distance of the shoreline, the fractal dimension for a specific type of shoreline may be found to be constant, and more importantly--highly descriptive of the shoreline's geometry.

Using Mandelbrot's methodology we find that a sample estuary shoreline length determined alternately from a USGS map and then an air photo, suggests a fractal dimension of $D=1.2$ for the South Slough estuary high tide shoreline.

When one adds to this analysis the extreme changes in estuary shoreline length that occur as the tide comes in and out we recognize that estuary shorelines are unusually complex. For example, performing similar measurements to those described above, but for low tide conditions, suggests a fractal dimension of $D=1.5$, somewhat greater than that of the high tide.

Application of the science of fractals to the study of South Slough may provide a descriptive methodology for classifying estuary types and for relating estuaries to the

continuum of other shoreline types, which could provide a basic organization and methodology to the science of estuaries as a whole.

Fractals represent a distinctly new way of scientifically describing natural systems. The watershed walkway and trail system can function as an armature for introducing these concepts to students and the public, as well as for the undertaking of original research.

Figure 63: The Estuary Trail

The value of the estuary as an integrated, ecologically beautiful system, should be considered as an important educational subject. Estuaries, at their least, represent a form of "wilderness" in our understanding. More importantly the estuary study program will bring to the student such important questions such as: "What does a wild estuary look like?" "Can a diked, human-impacted estuary be returned to a wild state?" "Can man control nature in this way?"

In some ways, it is this issue of wilderness and man's ability (or inability) to control nature, that is beneath the "ancient forest" debate currently before the public. The estuary provides another forum for education and learning on this important subject.

In designing a walkway through this estuary and its freshwater feeder streams, we can use this concept of fractals to create a walkway that braids, and weaves its way through the landscape – following the crooked branches of streams, the ridges between high and low water, while circling the skunk cabbage.

55. Chaos, Fractals, and the Landscape Approach to Design

Some might say that this paper is severely deficient, in that it does not really address the problem of finding ways to connect the science of chaos to the day-to-day issues of architectural design. To some extent we have resisted any attempt to come up with rules to govern how buildings should be designed using chaos and fractals.

However, the connection of chaos and fractals to landscape architecture design is more straightforward. The connection between design and nature is a little bit easier to make when the construction materials are living pieces of nature.

We won't try to make specific rules here, but we can imagine that they would not be so difficult to make. They might be things like:

- In designing a road or pathway, the shortest distance between two points is never a straight line.
- In developing plans, design a habitat, not a collection of pretty plants.
- Design a landscape that looks so-so when it's built, a little better when it's 20 years old, and extraordinary when it's 100 years old.
- Start with the geologic forms of the site, and plant metamorphic forms which have a fractal similarity.
- Initiate a design, that is never ending.
- Listen to the wisdom of our elders, as if it is the sound of wind in the trees and water in the creek.

And with the end of these essays, it may be appropriate to conclude with the remembrance that we are but short-lived beings on a planet spinning through space, warmed by a sun that will one day burn out.

The sun is but a morning star. – Thoreau

Through science and art we study our immediate world of summer thunderstorms and wildflowers, while recognizing that this life is punctuated by winter ice ages that can last 10,000 years, and that repeat at 40,000 or 100,000 year intervals. Under a microscope, a grain of sand is found to be a universe in itself – perhaps made up of the smallest of small vibrating strings. Through orbiting telescopes we look into a distant part of our universe where spiral galaxies just like our own Milky Way exist by the thousands, in swarms. Architecture is poised to enter this broader worldview. It is poised to develop a way of building that shares the adventure and wildness of this newfound universe.

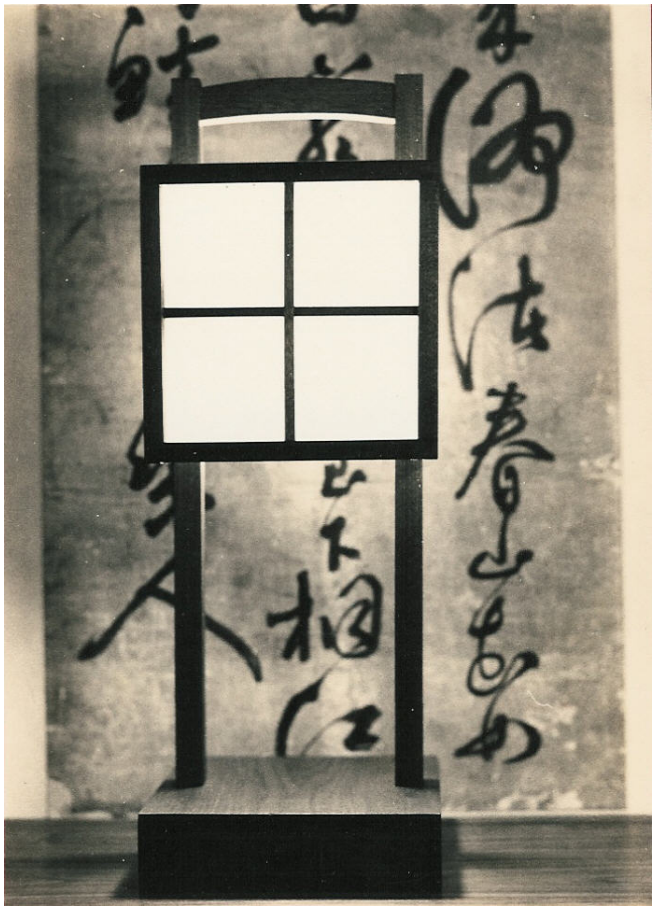


Figure 64: Lamp for Namhi Kim Wagner

Sections Under Development: Unanswered Questions!

What word can we use for this formative issue of these essays, instead of fractal? Fractal is not a word that means much in the common culture. But how do we describe the quality of a tree that it starts as a seed, grows into a tree and produces more seeds which can grow into trees? We can cut off any branch of a willow tree, and put it in moist soil along the riverbank that is its natural habitat, and it will grow into a new willow tree. Every piece of the willow tree embodies the seed of the tree, while hidden in the seed of the willow tree is the embodiment of the whole of the tree itself.

"Earth patterns"

"Nature patterns"

Essays:

Sound in Nature

Why everyone should fly a floatplane: or How to experience life as a Duck

Airplane Use in Pre-contact Native Cultures

Bifurcation of Space: Inside and Outside

Natural and Unnatural.

Natural and Supernatural.

A Medieval Truss as a Fractal Engineered Design

Pictures to consider adding by text:

Flightcraft truss at tree of life article.

Scappoose Library with Watts House in background at History of Architecture section.

The wave of the Columbia Center roof at River section.

Picture of waterfalls by geology section

Log spiral at Poetry and Architecture]

Matinenda rocks distant and close

Elementary Books and Articles on Fractals and Chaos Theory:

[to be inserted]

Aron Faegre is an architect with strong interest in art, science, landscape, and non-linear dynamics. In the 1970's he performed research in what has become called the science of chaos. His Reed College study, "An Intransitive Model of the Earth-Atmosphere-Ocean System", was published in the *Journal of Applied Meteorology*, as one of the first models to show that the earth's climate system has multiple solutions and thus is chaotic. He was awarded a three year National Science Foundation fellowship to attend the Massachusetts Institute of Technology in the Department of Architecture. After apprenticeship at Canessa Park in San Francisco, along with much practical training and experience, he gained licenses as an architect, professional engineer, and landscape architect. For the past 19 years he has practiced as the principal of a small multi-disciplinary design firm in Portland, Oregon. The firm works in a diversity of areas, including: public governmental buildings, housing, community centers, educational facilities, wetland mitigation, airport master planning, park planning, acoustics, environmental impact analysis, and basic research. He lives with his family along a large back-eddy of the Willamette River, in a home filled with chaos.

End Notes:

[1] U.S.-Russia Venture Probes Siberian Peatlands' Sensitivity to Climate, *Eos, Transactions, American Geophysical Union*, Volume 81, Number 43, October 24, 2000, page 1.

[2] Ackerman, James S., "Ars Sine Scientia Nihil Est," Gothic Theory of Architecture at the Cathedral of Milan, *Art Bulletin* 31 (1949), page 97.

[3] The word "objects" is in some ways quite crude. They could be called "beings" as their complexity gives rise to the thought that they may somehow have life. For architecture there is convenience in using the word "buildings" since it is etymologically related to the word "being" and acknowledges that there is life and change to the "thing."

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[5] Mandelbrot, *The Fractal Geometry of Nature*, 1983 (first published 1977), Plate 53, page 52.

[6] Heisenberg, Werner, *Philosophic Problems of Nuclear Science*, in "The Teachings of Goethe and Newton on Colour in the Light of Modern Physics," page 71.

[7] Peitgen, Heinz-Otto et. Al., *Chaos and Fractals: New Frontiers of* Science, 1992, Plate 8.

[8] Young, Phillip T., *The Look of Music: Rare Instruments 1500-1900*, Vancouver Museum, 1980, page 31.

[9] Needham, Joseph, *Science & Civilization in China, Vol. IV No. 3*, 1971, page 119.

[10] Conway, Thor and Julie, *Spirits on Stone: The Agawa Pictographs*, 1990, page 63.

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[12] Ghil, Michael, "Cryothermodynamics: the chaotic dynamics of paleoclimate," *Physica D 77*, 1994.

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[14] Strong, Emory, *Stone Age on the Columbia River*, page 16.

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[17] Needham, Joseph, *Science & Civilization in China, Volume IV No. 1*, 1962, Plate CXX

[18] Needham, Joseph, *Science & Civilization in China, Volume II*, 1956, Plate XVIII

[19] Wieger, Dr. L., *Chinese Characters: Their Origin, Etymology, History, Classification, and Signification*, 1965 (first published 1915), page 64

[20] Wieger, Dr. L., *Chinese Characters: Their Origin, Etymology, History, Classification, and Signification*, 1965 (first published 1915), page 287

[21] Needham, Joseph, *Science & Civilization in China, Volume II*, 1956, Figure 46, page 362.

[22] Needham, Joseph, *Science & Civilization in China, Volume IV No. 1*, 1962, Plate XCVI, page 20

[23] Hallowell, A. Irving, *The Role of Conjuring in Saulteaux Society*, 1971, Figure 1.

[24] Hallowell, A. Irving, *The Role of Conjuring in Saulteaux Society*, 1971, Plate 1.

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[27] These images and comments are taken from *Chinese Characters: Their Origin, Etymology, History, Classification, and Signification*, 1965 (first published 1915), by Dr.L. Wieger, page 276.

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