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Nature and Fractals in Architecture

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Abstract

The ideal of beauty has always been the perfect form of nature throughout history. Man could only aspire to copy nature but never achieve its perfection and complexity. While the works of art could be beautiful in their own right, nature was the only one capable of achieving the status of the sublime. John Ruskin saw "art's role as the communication by artifice of an essential truth that could only be found in nature".[1]

This theme went on for centuries, so much so that artists felt that copying nature is no longer viable as it has been done over and over again. When asked why doesn't he inspire his art from nature, Jackson Pollock is said to have replied: "but I AM nature". There was a shift in interest from depicting nature to understanding how natural rules of composition, those very rules we are used to like and admire, actually worked.

Peter Smith's widely acclaimed book Dynamics of Delight, Architecture and Aesthetics [2] deals among other themes with the problem of beauty as it can be found in nature. From Pollock's art to the romanesco broccoli, nature's algorithms include newly uncovered rules of fractal geometry and chaos theory.

Rezumat

Idealul frumuseţii a fost întotdeauna inspirat din perfecţiunea formelor naturale de-a lungul istoriei artelor. Omul poate doar aspira să copieye şi să redea frumuseţea naturii dar niciodată nu o va putea egala. Deşi operele de artă pot fi frumoase ele însele, doar natura poate atinge nivelul sublimului. John Ruskin vedea "rolul artei ca o comunicare artificială a unui adevăr esenţial care nu se poate regăsi decât în natură".[1]

Această idee a fost universal acceptată mai multe secole astfel încât, la un moment dat, artiştii au considerat că a atins un nivel de suprasaturaţie şi monotonie şi au încercat să se dezbare de ea. Întrebat de ce nu-şi inspiră operele din natură, Jackson Pollock ar fi răspuns surprins: "eu SUNT natura însăşi". Astfel vedem o schimbare de interes de la descrieri formale ale naturii spre înţelegerea regulilor compoziţionale prezente în natură, acele reguli pe care suntem construiţi de fapt să le apreciem din start ca fiind frumoase.

Dynamics of Delight, Architecture and Aesthetics [2], apreciata carte a lui Peter Smith, se ocupă printre altele de problema frumuseţii aşa cum apare ea în natură. De la arta lui Pollock la brocoli

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romanesco, algoritmii naturii includ pe lângă alte reguli şi nou descoperitele reguli ale geometriei fractalilor şi teoriei haosului.

Keywords: architecture, art, aesthetics, numerology, nature, beauty

1. Introduction

Artists and critics alike have looked for nature as justification for their beliefs regarding the main aesthetic principles of beauty and taste. All beauty present in art and architecture is a mere reflection of the beauty that nature displays and therefore to some extent inferior to natural beauty. Yet a question immediately arises as to how and why do we perceive nature to be so beautiful? Is it because we are accustomed to it or is it something far deeper, genetically imprinted in ourselves. Also, the same question can be asked of how and why do we perceive works of art or architecture as beautiful. As stated as a conclusion in a previous article, it seems that people in both cases (both when perceiving nature and art) actually prefer compositions that exhibit a clash of order and complexity at just the right proportion [3]. Too much order would lead to monotony, too much variety would lead to entropy. There is a difference here between entropy and chaos (as defined by the chaos theory) as the latter actually follows a determined cause that has undetermined results whereas the former follows no rules at all. As such, various researchers from different fields have attempted to postulate several laws regarding the order and variety we find pleasing in a composition. Peter Smith is one of them and for him, as far as the silhouette of historical city centres is concerned, things a pretty clear:

Rules of order in historical cityscapes [4]:

- Characteristics of local materials, like the local stone or clay for bricks and tiles.
- Local building techniques and strength of available materials.
- The state of glass technology in a particular time.
- The optimum span of the available timber laid constraints on plot width which results in variability within tight margins.
- Planning control, especially in Italian cities like Siena. This adds to the list of constraints which reinforce pattern.
- Climate is another determining factor that places limits on design freedom, as does topography.

He focuses on a particularly agreeable city centre, the centre of Amsterdam that draws many tourists each year. As such, he then determines what is orderly about Amsterdam's image in particular. Rules of order in the cityscape of historical Amsterdam, according to P. Smith [5]:

- Narrow frontage, deep plan
- Gables facing the street
- Embellishment of gables to establish individuality
- High ratio of window to wall
- Preference for bright colours for the masonry and white for window frames
- The division of windows into smaller glass panels

It would seem that Amsterdam is particularly well perceived by most as having a great balance between the forces of order and chaos. Smith compares it with Munster, a reconstructed hanseatic city from Germany that was especially affected by WW2 bombings and needed to be rebuilt. Because of the lack of funds and the speed of the restoration works, many intricate details of the original stonework were simply replaced by simpler surfaces, leaving the German city to be perceived as too austere and monotonous as compared to the Dutch capital. These conclusions,

exemplified by Smith were analysed at large in the aforementioned article [6].
The fact that most historical cities appeal to the general public, most often regardless of culture and background, have led many to believe that they might have a certain intrinsic quality. Not by chance it would seem most people share a pleasure in contemplating nature so these two landscapes (old urban and natural habitat) might actually have a few things in common.

For some researchers (Salingaros [7], Joye [8], Bovill [9], Ostwald [10] or Ulrich [11]), this might be a factor measuring the complexity and order of the visual composition. It seems to lie deep within our brain and it seems to have been related with the survival instinct. For example, if you look at three different pictures depicting different natural habitats, a deep forest, a savannah like pasture and a desert or semi desert area, you are likely to chose the savannah. It seems to have a positive mixture of scarce trees for shade, plenty of bushes and grass, a lot of visual information but you can still see far off into the horizon where maybe you could catch a glimpse at the distant mountains. Aesthetically pleasing as it may be, this result is not without logical justification.

The savannah is teeming with life and it is, according to some sources, the ancestral ecosystem where man has actually appeared on earth. If you compare it to the deep forest, it has less visual detail but more balance. The forest, apart from being dark and gloomy for some, could actually hide a series of predators lurking in the shade of the trees to ambush. In the other extreme lies the image of the desert. Lifeless here equates in our brains with little or no visual detail. Most of us understand instinctively the harshness of life in this habitat just by looking at the picture [12]. It is no wonder to anyone then just why people abhor the urban desert where you simply multiply a building *ad infinitum* on the span of an entire street.

So we can see at a closer look that it might actually be a "natural" phenomenon the fact that we enjoy old cityscapes as we do. The amount of information here corresponds to the data hardcoded in our own brains. The brain is hardwired for a certain amount of stimuli and, should that amount be exceeded, it would lead to visual fatigue. Old town centres with their individual buildings developed in the same fashion over hundreds of years seems to correspond greatly because it is the

Fig. 1-3. Different natural landscapes: most people would chose the 3rd (savannah) as most desirable as the deep forest is associated with dangerous predators (too much detail, no larger scale overview) whereas the desert boasts too little life (too little detail up close, barren)

work of a collective intelligence that has abided certain rules of composition for a long period. Compared to some modern urban interventions that come from the brain of a single creator, we can see less information in the latter and that is why some of us might find it lacking. On the contrary, modern interventions where many architects emphasize their different views boast a chaotic appearance where the rules of composition of the entire street or city are lost to too much individuality.

This paper will try to analyze in comparison some of the elements of architecture that we find enjoyable and find parallels in nature. While this is a monumental task, worthy of a doctoral thesis, our job will be made easier by the works of Smith, Joye, Salingaros and Ulrich that have, from different scientific perspectives, analyzed the subject. For example, while Smith and Ulrich are architects, Joye is a psychologist, and Salingaros is a mathematician and polymath.

2. Perceiving Nature

We have seen that most people enjoy seeing pictures of vegetation (trees, flowers) as well as wide plains. The brains, as noted before, can only discern a certain amount of information presented as visual stimuli. In the way we perceive nature we can see the extraordinary capacity of synthesis that the brain has.

For example, when we see an orchard or a forest with similar trees we can obviously note that all of them are different but our brain will interpret the scene in a simpler way, like noting that there are several trees that are *similar*. This is a characteristic of order in composition that our brain uses to simplify and easier digest the visual information presented. It is what, most probably instinctively, the architects of late Gothic cathedrals have done when designing different columns and pillars that bear an overall similarity. This is why we perceive Gothic architecture as complete and we take great delight in observing it up close. We see the various stages unfolded along centuries of labour at the cathedral in Strasbourg, for example, but we can also underline the order that keeps the composition together and makes us easily understand it by dividing it in our brains into simpler shapes at different scales.

The beauty does not stop at this level however. When you get closer to the orchard you can actually see the differences among trees better. You notice the details and what was a hindrance or oversight at a larger scale (when you couldn't filter so much information) is now a delight. Imagine being in an orchard where all trees were exactly the same. It would be boring, no doubt. Whereas no two trees or flowers are ever the same. In fact not even two snowflakes are ever identical. The laws of nature are a juxtaposition of algorithms that help us determine the taxonomy of trees and animals at first level but on top of that comes an extraordinary capacity of adaptation to seemingly chaotic factors. The strict geometry at the general level is thus enriched by the overwhelming diversity at the particular level.

Gothic architecture and most historical cityscapes were developed instinctively on the same principles, across a longer period of time and, most notably, by more than just one person. As compared to classical or Renaissance architecture, Gothic architecture is by far less constricted by Euclidean geometry and rigid proportions. That is not to say it is superior or inferior but more adaptable, like natural forms are.

Yannick Joye develops on this theme and affirms the existence of the NIS (natural information system) deeply imbedded in our brains [13]. Not only do we perceive nature to be beautiful because of the aforementioned arguments, but we like to copy it in our works of architecture. Almost all traditional architecture has vegetal decoration transposed in wood or stone, from native huts in the Pacific to the Corinthian column or to Art Nouveau.

The NIS, Joye postulates is there not primarily as an aesthetic apparatus but is responsible for the very survival of our species. The fact that we derive pleasure when looking at beautiful scenery is in fact a positive response to a stimulus that ensured our wellbeing - we started as foragers and huntsmen even though only a handful of the world cultures still adopt this way of life today.

The NIS is also responsible for negative emotions like fear and phobia. For example, many of us feel great discomfort when looking at pictures of spiders or snakes because we naturally have learned across many centuries and even millennia that these animals are likely to be dangerous and poisonous. The NIS works with emotions like a carrot and stick policy - similar in a way with tastes. We enjoy sweetness because we associate it with edible fruits and we dislike bitterness as we associate it with rotten or poisonous berries.

So if for some people, it would seem common sense that depicting nature in paintings would result in a lesser degree of stress for patients recovering from surgery, for example, it would be less obvious that paintings perceived as "unnatural", abstract or challenging might actually have a negative effect in their recovery [14]. That is to say you are better of hanging a picture depicting a natural landscape than Munch's *Scream* if your activity is particularly stressful.

3. Natural Rules of Composition

It would seem that mimicking nature is bound to yield positive effects in both art and architecture. And so it has for many centuries and across almost all cultures. But while this is obvious, modern artists have found imitating nature as less inspiring than understanding its rules of composition.

What artists do instinctively, researchers try to understand and write down as hardcoded rules. So it has been a topic of research for some to understand why is Jackson Pollock's art so popular when it does not depict anything in particular. Yet when a scientific experiment attempted to see if people would find his seemingly chaotic paintings better or worse than actual random entropic compositions, it was staggering to find out that 113 out of 120 subjects have actually chosen (without knowing) Pollock's paintings as more pleasing [15]. This has drawn everybody to believe that there is no coincidence and Pollock's paintings and natural laws of composition actually have something in common.

Indeed if we think of the technique Pollock used to paint, first developed by Max Ernst in 1942, it is a practical application of chaos theory in painting [16]. By tying an empty can filled with paint by a long string and suspending it to the ceiling, Ernst found that the pendulum motion the painter would instil on the can would leave a distinctive, apparently random trace of dripped paint on the canvas below. Yet what strikes everybody in Pollock's paintings is that these traces, that he only partially controls through this technique, always cover the canvas equally, no more in one part than the other, giving it a homogenous aspect. Furthermore, if you take any of his paintings and compare it with an enlarged section of them you will see the amount of detail is almost the same. That is to say his paintings display what is called *self-similarity* - a property specific to fractals.

Nature, as it turns out, is filled with fractals. From mountains to trees and certain leaves like fern leaves can be easily mimicked by strict mathematical fractal geometry. Naturally, no mountain and no tree is a “perfect” geometrical fractal but they are perfectly adapted to their particular context leading many to believe that nature is closer to perfection than the abstract geometrical forms we approximate it with that are mere copies of it. But that is a different line of thought.

Self similarity across scale is one characteristic present in all aspects of nature though, and it is present in organic city shapes as stated by Michael Batty and Paul Longley. They have clearly defined organic cities as not displaying obvious signs of planned geometry at a larger scale but they may well be a product of detailed and individual decisions in the small [17]. Self similarity across the scale is specific to self organizing algorithms. Organic cities, the works of Pollock and natural forms all display the same self similarity across scale. Thus when Pollock claims that he IS nature he is more likely to be correct than not. Whether he consciously applied these rules found in nature or he simply felt like it, that is another thing and one that holds little interest here. More importantly, he is appreciated because most of us have the tendency to appreciate these same rules of nature that are hardwired in our brain structure.

Nikos Salingaros is known to have worked with Christopher Alexander in his attempts to define a participative architecture and from this research came the need to postulate a mathematical set of rules, derived from the natural laws of physics, that could actually be applied as aesthetic principles for good quality architecture. He came up with a mathematical algorithm for measuring the complexity of the design of a facade that he called box counting. Basically it works by over imposing a grid on the facade of the building and counting the boxes that have relevant detail in them as opposed to blank boxes. Carl Bovill used this very algorithm to demonstrate F. L. Wright's Robbie House shows a lot more detailing at a smaller scale than Le Corbusier's Vila Savoye [18], [19].

Making parallels with physics, Salingaros has come up with three main rules he says are essential for good quality architecture [20]:

1. Order on the smallest scale is established by paired contrasting elements, existing in a balanced visual tension
2. Large scale order occurs when every element relates to every other element at a distance in a way that reduces the entropy
3. The small scale is connected to the large scale through a linked hierarchy of intermediate scales with a scaling factor $e = 2{,}7$. [2]

He went on to postulate that most historical architectural styles, except modernism, of course, instinctively obey these three laws that have as main result that the building is perceived as interesting regardless of the distance it is perceived from.

He goes on to clarify exactly what these rules mean and to prove how he reached this conclusion. For the first rule, regarding the small scale he mentions [21]:

a) basic elements have to be simple (triangles, squares etc)
b) basic units are held together by a short-range force
c) the smallest units occur in contrasting pairs, like fermions
d) the contrast recurs at different scales

For the large scale order he exemplifies the following principles [22]:

a) the smaller scales are determined by a high degree of symmetry which is not required of the higher scales
b) order is also achieved by having units on a common grid
c) visual similarity connects two design elements through common colors, shapes and sizes
d) insisting on “purity” can destroy the connection process

[2] this e factor he defined directly deriving it from the box counting method at different scales. Whereas Robbie house has a healthy $e = 3$, Vila Savoye is closer to $e=1$ at smaller scales.

Finally, for the connection between consecutive scales, his ideas can be summed up as [23]:

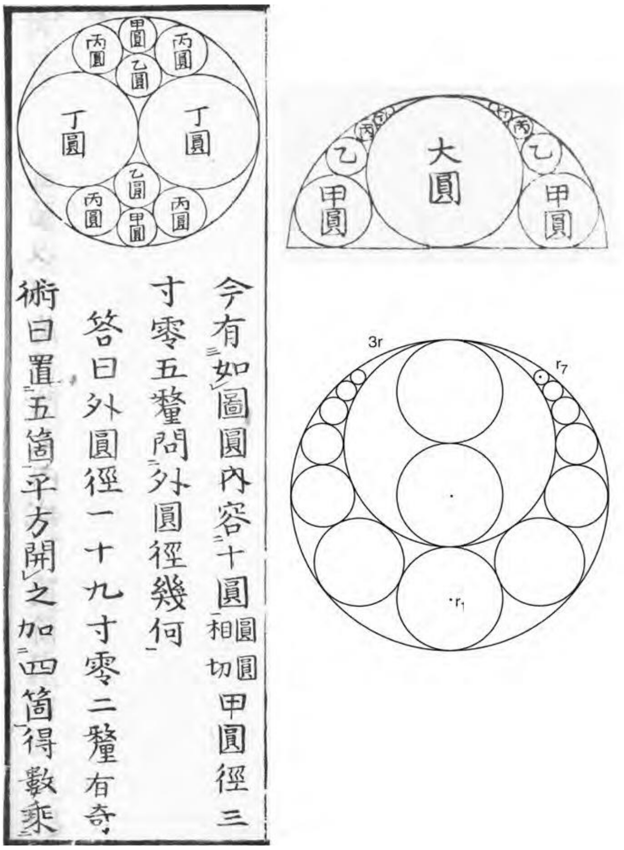
a) every unit will be imbedded into a larger unit of the next scale
b) similarity of shape should link the different scales together
c) different scales can collaborate to define a gradient through similar shapes of decreasing size
d) a building must be placed into the environment in a way that fits the existing hierarchy of scales

While not only fractals answer the rules that Salingaros proposed, it is however true that the self similarity across scale displayed by fractals would meet the abovementioned criteria perfectly. The following chapter will endeavour a very short glimpse of the equally short history that architecture and fractal geometry shared for no more than a decade.

4. Architecture and Fractals

Geometry, which, as its Greek name suggests, originally started out as the measurement of Earth is nothing more than the fascination that man has always felt for the rules and proportions of nature. Some cultures have gone even further in assigning geometry a sacred meaning, the Pythagoreans being particularly renowned for their obsession with numbers, proportions and music.

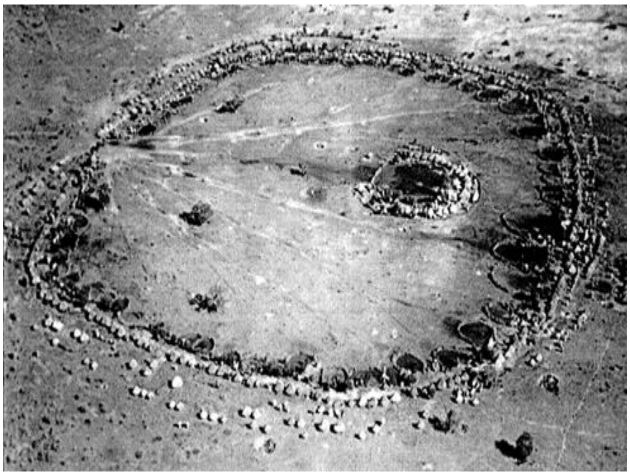
Although far less renowned, the Japanese during the *Genroku* period were probably the only ones to undertake geometry as part of their divine ritual, hanging mathematical wooden tablets known as *sangaku* from their temple walls [24], hence the name sacred geometry came to actually mean literally that mathematics was perceived as divine in itself. Several geometrical problems that the Japanese were confronted with included a series of recurrent tangential circles, smaller by progression, most notable being the one proposed by Kanei Taisuke where in fractal like self-similarity, the circles were related by a ratio among their radiuses, progressively smaller, from r, r/2, r/3 ... until r/7 [25] see also fig. 4.



Fractal geometry itself was not consciously accepted into mathematics until Benoît Mandelbrot introduced the term fractal in 1975. However history abounds with prior preoccupations of men with the recurrent sets present in mathematics and nature. Georg Cantor was, for example, obsessed by the problem of dividing segments that had an infinity of points since you could subdivide them ad infinitum. That would mean that the sum of the segments would be an infinite number of infinities which is a very hard concept to grasp.

Fig. 4. Traditional Japanese geometry problems typically involve multitudes of circles within circles. This problem, which asks you to show that *r*7 = *r*/7, is from a lost tablet hung by Kanei Teisuke in 1828 in the Menuma temple of Kumagaya city, Saitama pefecture and can be

solved by the artifice of inversion, similar in a way and precursor to the Mandelbrot set fractal.
But most important for us here is the presence of several examples of traditional architecture around the world that intuitively uses fractal designs. In his research, Ron Eglash has found out that fractals dominate all aspects of life in Sub-Saharan Africa, from house and village configuration to carpet and fence designs and even to the intricate models of the Ethiopian cross [26]. Not only did Africans use fractals since times immemorial but they seem to be responsible for their discovery in the Western civilization as well, according to Eglash.



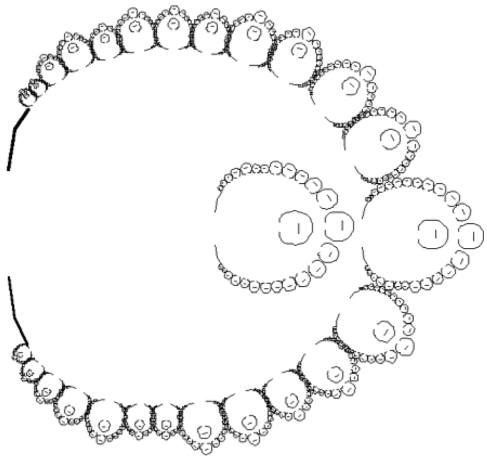


Fig. 5, 6. Ba-ila village remains, South Zambia, and a rigurous fractal reconstruction. In the centre of the village is the chief's hut, surrounded by the huts of his wives, surounded in the same fashion by the huts of the other members of the tribe. In front of the chief's hut is a miniature model of the village of the ancestors build in the same way suggesting the infinity of the cicle [27].

Other examples that clearly though probably intuitively use fractal shapes are most Hindu temples that grow organically from the central spire, surrounded on all sides by smaller but similar spires that, in their turn are surrounded by smaller ones until they reach the human scale. It is interesting to note that this very principle can be found in some Orthodox churches and, later on, cathedrals (the Metropolitan Cathedral in Cluj being one of them) that address the scale of the city with their central spire but decrease with smaller copies of it (four around the central one) until they reach the human scale on all sides and especially around the entrance.

More recent architecture that employed the use of fractals, prior to 1975 and Mandelbrot's manifesto include the works of Kazimir Malevich and even those of late life F. L. Wright like the Palmer house which reiterates the triangle at seven different scales in the floor plan, from the shape of the living room to the small detail of a triangular entrance lamp.

So it is only natural to enquire how come something that was present in history prior to its conscious acknowledgement is unfortunately so rarely seen nowadays in contemporary architecture? The answer could lie in the fact that architects were not yet ready to use fractals to their full extent 40 years ago when mathematicians first understood the concept. Attempts were made during the 80's and 90's when CAD platforms weren't used by many architectural firms as main stray yet. For the unaccustomed architect, the exact work with fractals, however appealing, is very hard to achieve as fractals are self-similar shapes that unfold by themselves and are therefore the final shape is hard to predict. They are self-organizing shapes where you provide the simple shape to begin with and the iteration process to be repeated infinitely resulting in the end in very complicated shapes generated very easily from a mathematical point of view.

Like for example in the case of the Menger Sponge, you take a simple cube and the iteration process is to divide all sides in 9 squares (resulting in 27 smaller cubes) and then to subtract the ones in the middle of each of the 6 sides of the original cube, plus the one in the centre (7 small cubes in all). Reiterating this process for all the 20 remaining solid cubes and then at even smaller scale will give the image of a sponge (hence the name) with many small square holes on the sides. Theoretically this can go on forever but as the holes become insignificantly small, the eye cannot perceive them after the 4th or 5th iteration though the brain can understand very easily that the process is meant to go on *ad infinitum*. (fig. 7)

An application of this geometrical figure was Steven Holl's Simmons Hall (2002), where we can see increasingly smaller square windows on the facade (fig. 8).

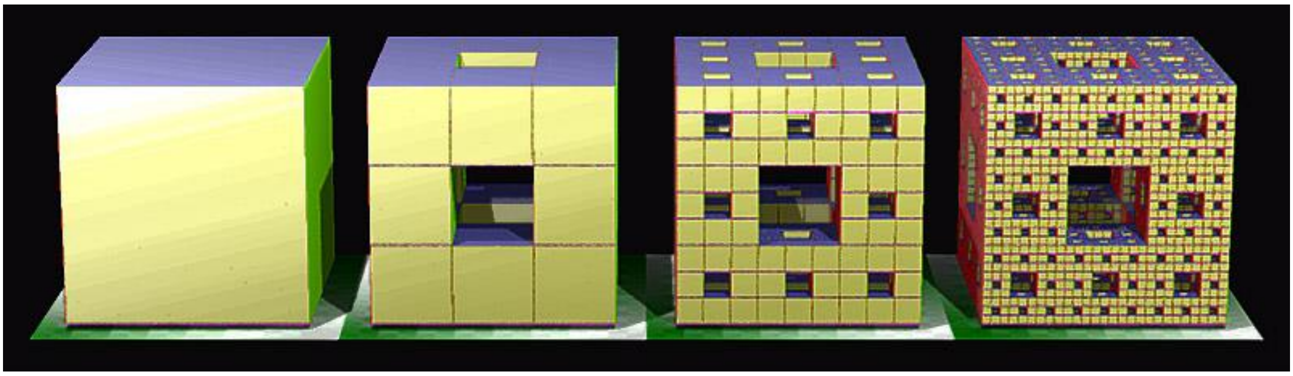


Fig. 7 The Menger sponge exemplifies an infinitely complex figure from a very simple shape (a cube) and a very simple function (removing the centre squares of all six faces of the cube)

Fig. 8 Simmons Hall, MIT, arch. Steven Holl - direct application of the Menger Sponge

Whereas Simmons Hall is derived from a fractal, it isn't a perfect fractal just like no tree is a perfect fractal itself. However our brain clearly understands the process of reiteration whereas the part is treated like the whole and subdivided into smaller parts and so on.

Nor does this paper advocate for precise fractal geometry to be implemented directly from mathematics without any adaptation as that would be too inflexible. Just like many entities in nature start from a fractal rule of thumb and develop from it their own unique shape, so should good quality buildings start from a rigorous algorithm but modify the outcome so that the initial rule remains but does not dwarf the context.

The golden age of fractal architecture was very short-lived. It started out with great enthusiasm at the beginning of the 80's and, by the mid 90's, it was already caricaturized and considered a *bête noire* [28]. Initially many architects were fascinated by fractals and complexity theory, including Asymptote, Charles Correa, Coop Himmelblau, Carlos Ferrater, Arata Isozaki, Charles Jencks, Christoph Langhof, Daniel B. H. Liebermann, Fumihiko Maki, Morphosis, Eric Owen Moss, Jean Nouvell, Philippe Samyn, Kazuo Shinohara, Aldo & Hannie van Eyck, Ben van Berkel & Caroline Bos, Peter Kulka & Ulrich Königs and Eisaku Ushida & Kathryn Findlay [29].

Of these, most famous were the works of Peter Eisenmann, including House 11a and Chora L Works, the latter being developed with Derrida and having a long sidetext dedicated to complexity theory and fractal like shapes [30], [31].

However one of the problems of fractal architecture and the reason it died in its infancy was the incorrect approximation of some of the works of famous architects with fractal geometry. Some have attributed famous objects of architecture to fractals without any apparent logic. In the words of Yannick Joye, *Jencks (2002) had dedicated an entire section of his book The New Paradigm in Architecture to the supposed fractal architecture of such architects as Daniel Libeskind and Frank O Gehry. Yet a critical reading reveals that Jencks's application of concepts from fractal theory is largely misapplied and is only intended to lend authority to the architects and their creations. For example, none of the architectural designs Jencks discusses has any significant self-similarity, which is a critical property of fractal structures. For example, though Gehry's Guggenheim Museum in Bilbao could be claimed to appeal to nature because it consists of curved surfaces, it cannot be considered as a fractal because there are no similar details or structures recurring on different hierarchical scales of the building. Similarly, it is difficult to grasp why Jencks considers Libeskind's Jewish Museum in Berlin as "the most convincing fractal building finished so far"* [32].

Even Chora L Works is only remotely inspired by fractals and the connection with fractal geometry is shallow at best and not very visible. Many critics were so saturated with this trend in architecture that they went on to make very demeaning remarks addressed to all that would even mention fractal and architecture in the same sentence by the late 90's. Even Jencks' attempts to revive complexity theory were met with sarcastic remarks. Most notorious of these seems to have been Sorkin that branded fractal architecture as kitsch even from 1991, calling it a design process that culminates in tracing the "outline of last night's schnitzel" [33].

As such we can see why too much initial enthusiasm that was only partially materialized in good quality architecture seems to have led to a total resentment for this type of architecture later on. Some, like Paul Shepheard, have gone so far as to insult the promoters of complexity theory by saying that for them: *Anything will do – twigs purloined from a pigeon's nest, notes transcribed from the Song of Songs – a scribble he did with his eyes shut, like a shaman in a trance drawing in the dust of the Nevada desert*. [34].

5. Conclusions

However short and open to controversies was the history of fractal architecture at the conclusion of the last century, fractals and chaos theory remain some of the dominant rules of composition in nature, rules that our brains are attuned to like, regardless of our cultural background. Nowadays the need for a complexity at different scales of our architectural designs is evermore present as we have fallen prey to the idea that order and monotony are two sides of the same coin.

Many lessons can be learned by studying natural forms directly and interpreting the rules by which they were generated and others can be derived from what prior cultures have built for ages without consciously referring to fractals or chaos patterns but employing them intuitively to great effects. It is in our interest to learn or re-learn these tested techniques before we see our built environment turn into an amorphous mass of individual yet un-communicating entities that act as an excess source of daily stress to tomorrow's citizens.

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