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INSIGHT INTO FUNDAMENTAL PRINCIPLES OF DESIGN USED BY NATURE AND APPLICATION OF SAME TO ACHIEVE A SUSTAINABLE BUILT ENVIRONMENT

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Abstract: Architecture, for a long time, has been all about thinking of volumes and spaces in geometry of basic forms such as rectangles, triangles and circles. They are rigid, none adaptive and none sensitive. The roots of issues of built environment we face today including urban heat island, inefficient space arrangements, waste of materials and resources are rooted in this system of imagining forms and spaces with Cartesian geometry. Classical Mathematics, on which our thinking systems are grown on, has a profound impact on ultimately what we generate as built environment.

Recent studies show that mathematics used by Nature to create forms and volumes are not classical but they are based on Complex Numbers and Complex Vector Spaces. If we follow the mathematics of nature, we would reach an altogether different kind of Architecture which is adaptive, responsive, sensitive and humane.

With the modern day computer simulation powers, generation of such works of architecture and urban design is becoming popular. A new style of architecture is immerging under the name of Parametricism.

This study points at understanding mathematics of nature such as fractal geometry and application of them through parametric design systems in order to generate more sustainable built environments.

Keywords: Sustainable architecture; parametricsm; nature; design;

1. Mathematics behind conventional architecture

Civilized architecture has always been based upon simple geometry. Forms and spaces created based on combinations of rectangles, triangles, Circles, cylinders, Cubes, pyramids and corns.

From pyramids of Egypt (2500 BC)

Greek and Roman Architecture (500 BC)

Buddhist Architecture

Classical Architecture (8th C)

Most profoundly in Modern Movement Architecture (19-20th C)

Elements, Components, Materials and tools in building construction industry are shaped to support the construction of such simple geometric forms and not otherwise.

But if you look at any natural organism or organ, you see, they are not rooted in any of those basic geometries. Form of your ear, form of your arm, form of clouds, waterfalls and rocks cannot be described in this geometry.

Why have we limited our Built environment to this smooth geometry? Is it essential? Can't we do otherwise?

There is no fundamental need to restrict our built environment to a smooth simple frame of geometry. Spaces and forms can take extra-ordinary forms. Like seashells, mushrooms, caves of rocks. They have received their forms that cannot be described in any simple smooth geometry. Similarly, spaces, Places and forms of built environment may also take extraordinary shapes.

The restriction is in our minds. True that the restriction is in our habit of copying previous works, learning from past, carrying heritage traditions forward, Following Conventions etc. but it goes far deep than that.

True that the restriction is in our tools used to design buildings, such as 2D plans on paper, tools to draw straight lines and curves but not organic forms. But it goes far deeper than that.

True that the restriction is in our habit of thinking and imagining in terms of rooted geometric components such as walls, floors, windows and doors, but it goes far deeper than that.

True that the restriction is in our habit of designing to construct with geometrically smooth materials such as bricks, plate glass, iron bars, extrusions, plate tiles etc., but it goes far deeper than that.

The restriction is in the mathematics upon which we built up our imagination. The Cartesian geometry and Euclidian mathematics in our minds are the tools upon which we build up, imagine, analyse and quantify our dreams of forms and spaces consciously or unconsciously.

Today, in the verge of environmental crisis and need of maximum sustainability in everything we do, we need to relook at this system of architecture that has come to our door step across entire human civilization. The system of architecture came in the disguise of many styles, epochs and traditions yet bearing the same fundamental set of axioms.

How sustainable it is for us to continue designing within this frame of axioms? Can we do better, if we re-think architecture in a different platform? Can we do otherwise, even if we want to do so? Is there a practical way out?

Main drawbacks of rigid geometric forms in sustainability are three-fold. The forms, spaces and places they create are,

1.1 None adaptive

Rigid geometric forms are none adaptive. They have no adaptive capacity to the context and environment they inherent and take form out of the context.

1.2 Not sensitive

Being rigid, they are not sensitive enough to obtain influence from its economic, cultural and environmental context and take form.

1.3 Cannot merge

Rigid geometric forms have no capacity to merge itself with the context. Merge with the existing buildings, urban fabric, roads, trees or mountains and become one with them. Instead they only can stand alone as separate entities. Individuals.

If you look at any ting designed by nature, mountain sitting on a terrain or your Norse sitting on your face, they cannot be described with any simple geometric form or combination of geometric forms. They are sensibly formed to suit the functions they perform and to be with the context they immerge. There are no defined edges that show the boundary between them and the context. Instead of standing as separate individual elements, they are merged with the context they inherent and have become one with it.

How does nature design such things? What are the concepts behind these designs? What are the mathematics behind natures complexity?

2. How to Understand Nature

Benoit Mandelbrot was the pioneer of understanding the complexity of nature with mathematics. In his book FRACTALS Form, Chance and Dimensions (1977) he described that many forms of nature can be described mathematically as Fractals. Fractal is a term championed by him.

A fractal is a curve or geometrical figure, each part of which has the same statistical character as the whole. They are useful in modelling structures (such as snowflakes) in which similar patterns recur at progressively smaller scales, and in describing partly random or chaotic phenomena such as crystal growth and galaxy formation.

In fractals, self-similarity of a pattern keeps on going in all scales. Fractal Geometry can be seen almost everywhere in Nature. In trees, leafs, flowers, corals, mountains, rivers, roots, snowflakes, water crystals, lightning, and clouds. Fractals are the one and only strategy to understand complexity of nature. Fractals can describe mathematics behind all of them.

Fractal geometry is the generator of the form of your lungs, kidneys, vascular system, and neuronal systems. To understand the complexity of nature is to understand what it takes to produce complexity.

Fractal geometry explains the formation of galaxies to the formation molecular crystals. It is present at all scales.

There is order in chaos you see in Nature. There is geometry in clouds, waterfalls and flowers you see.

Fractals can also be seen in Arts and Crafts and Music from times immemorial, although they have not been so understood.

2.1 Complex plane

A complex number is a number that can be expressed in the form **a** + **bi**, where **a** and **b** are real numbers and i is the imaginary unit, that satisfies the equation i2 = −1. In this expression, **a** is the real part and b is the imaginary part of the complex number.

Complex numbers extend the concept of the one-dimensional number line to the two-dimensional complex plane by using the horizontal axis for the real part and the vertical axis for the imaginary part. The complex number a + bi can be identified with the point (a, b) in the complex plane. A complex number whose real part is zero is said to be purely imaginary, whereas a complex number whose imaginary part is zero is a real number. In this way, the complex numbers contain the ordinary real numbers while extending them in order to solve problems that cannot be solved with real numbers alone.

In mathematics, the complex plane or z-plane is a geometric representation of the complex numbers established by the real axis and the perpendicular imaginary axis.

2.2 Julia set

Gaston Maurice Julia was a French mathematician who devised the formula for the Julia set. (1893 – 1978)

a set of complex numbers which do not converge to any limit when a given mapping is repeatedly applied to them. In some cases, the result is a connected fractal set.

A very popular complex dynamical system is given by the family of complex quadratic polynomials, a special case of rational maps. Such quadratic polynomials can be expressed as

$$f_c(z) = x2 + c \qquad \text{Eq. 1}$$

where c is a complex parameter.

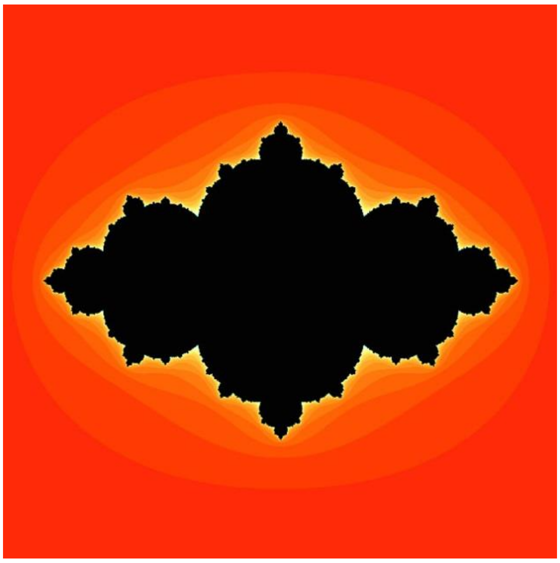

Fig. 01. Filled Julia set for *fc*, c=1−φ where φ is the golden ratio

2.3 Mandelbrot set

A particular set of complex numbers which has a

The **Mandelbrot set** is the set of complex numbers c for which the function $f_c(z) = z^2+c$ does not diverge when iterated from $z=0$, i.e., for which the sequence $f_c(0)$, $f_c(f_c(0))$, etc., remains bounded in absolute value.

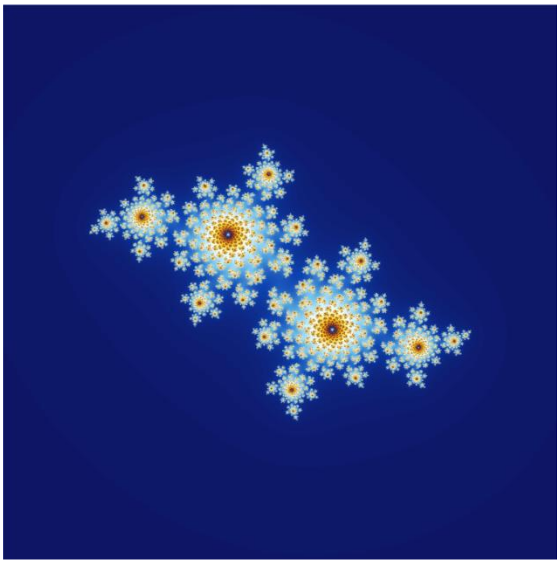

Fig. 02. Julia set for fc, c=(φ−2)+(φ−1)i =-0.4+0.6i

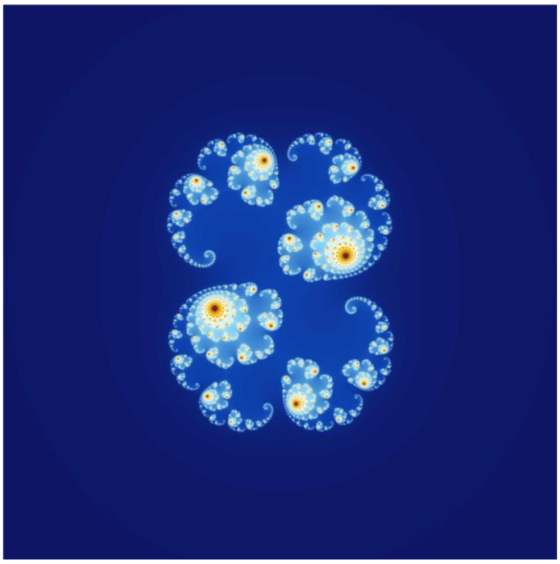

Fig. 03. Julia set for fc, c=0.285+0.01i

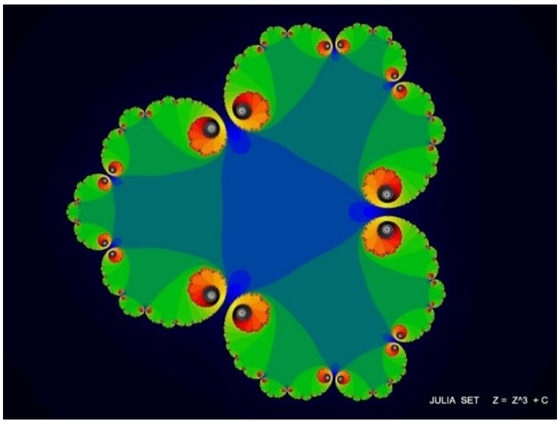

Fig. 04. f(z) = [(z2+z)/Ln(z)] +(0.268,0.060i)

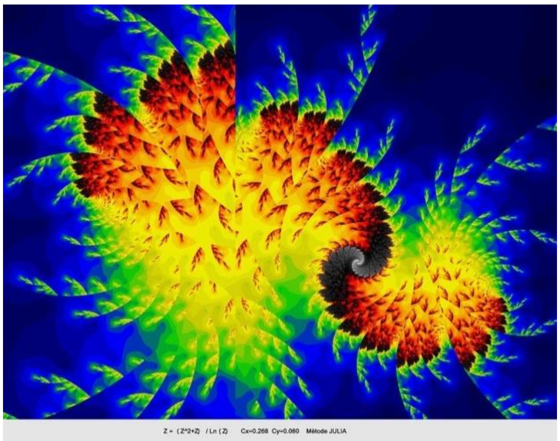

Fig. 05. f(z) = [(z2+z)/Ln(z)] +(0.268,0.060i)

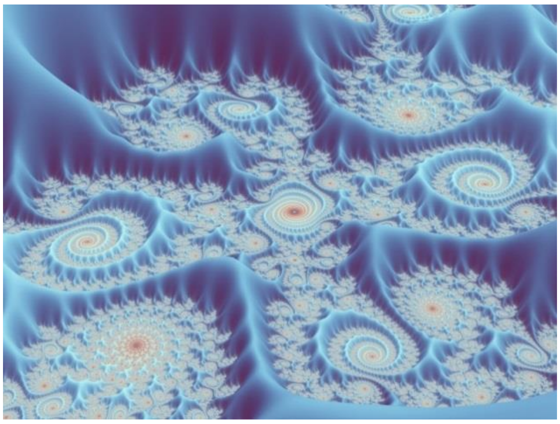

Fig. 06. Three-dimensional rendering of Julia set using distance estimation

Mandelbrot set images are made by sampling complex numbers and determining for each whether the result tends towards infinity when a particular mathematical operation is iterated on it. Treating the real and imaginary parts of each number as image coordinates, pixels are colored according to how rapidly the sequence diverges, if at all.

More precisely, the Mandelbrot set is the set of values of c in the complex plane for which the orbit of 0 under iteration of the quadratic map

Images of the Mandelbrot set display an elaborate boundary that reveals progressively ever-finer recursive detail at increasing magnifications.

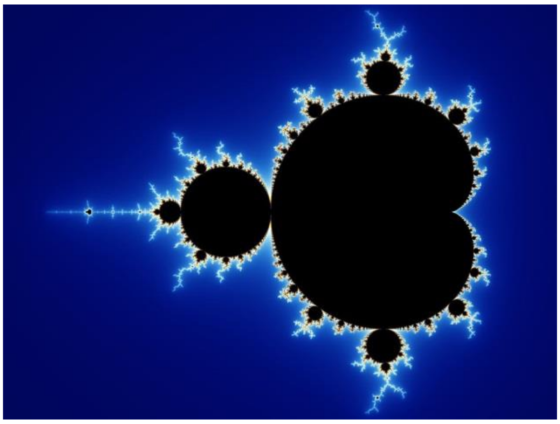

Fig. 07. Mandelbrot set close-up

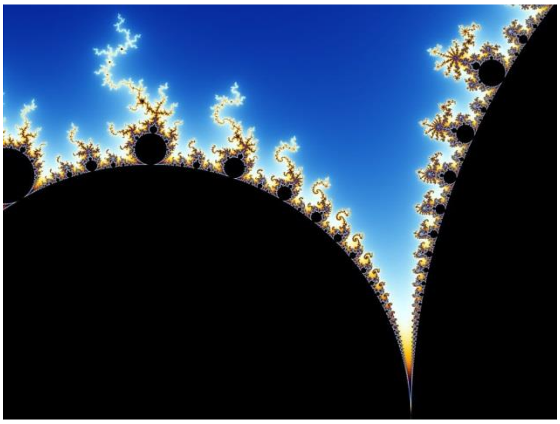

Fig. 08. Mandelbrot set close-up

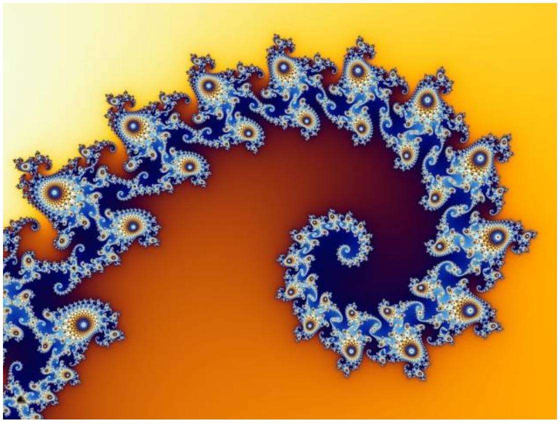

Fig. 09. Mandelbrot set close-up

The "style" of this repeating detail depends on the region of the set being examined. The set's boundary also incorporates smaller versions of the main shape, so the fractal property of similarity applies to the entire set, and not just to its parts.

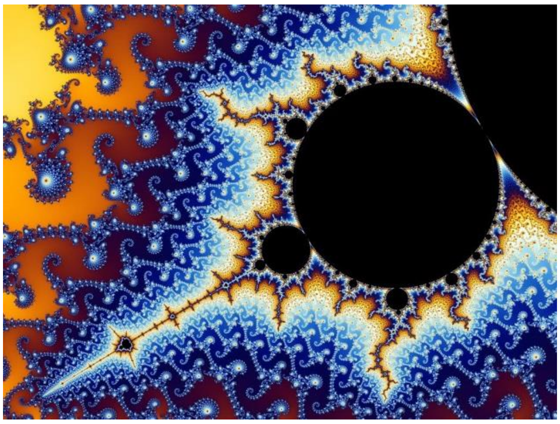

Fig. 10. Mandelbrot set close-up

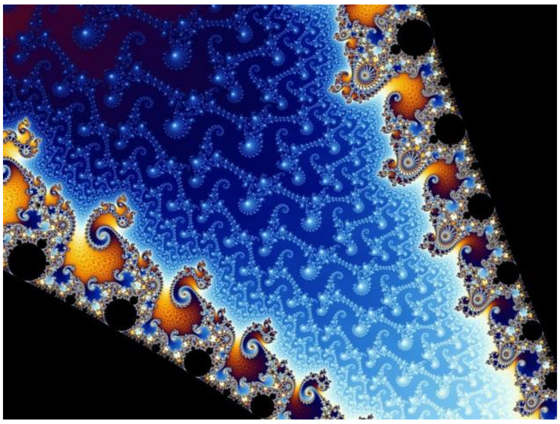

Fig. 11. Mandelbrot set close-up

The Mandelbrot set has become popular outside mathematics both for its aesthetic appeal and as an example of a complex structure arising from the application of simple rules. It is one of the best-known examples of mathematical visualization.

2.4 Fractal Art

Fractal art is a form of algorithmic art created by calculating fractal objects and representing the calculation results as still images, animations, and media. Fractal art developed from the mid-1980s onwards. It is a genre of computer art and digital art which are part of new media art. The Julia set and Mandelbrot sets can be considered as icons of fractal art

It is usually created indirectly with the assistance of fractal-generating software, iterating through three phases: setting parameters of appropriate fractal software;

executing the possibly lengthy calculation; and evaluating the product.

It was assumed that fractal art could not have developed without computers because of the calculative capabilities they provide. Fractals are generated by applying iterative methods to solving non-linear equations or polynomial equations. Fractals are any of various extremely irregular curves or shapes for which any suitably chosen part is similar in shape to a given larger or smaller part when magnified or reduced to the same size

Scientific forms of art, including fractal art, have developed separately from mainstream culture. Starting with 2-dimensional details of fractals, such as the Mandelbrot Set, fractals have found artistic application in fields as varied as texture generation, plant growth simulation and landscape generation.

The fractal forms generated by fractal equations most of the time appeals to be like natural forms. They resemble a sense of organisms. Living things or animal forms.

2.5 Mathematics of Nature that produced life – quantum mechanics

What creates this synergy? Is Nature a product of running fractal equations? Well, this is far beyond the scope of this paper. However: If you fathom deep into the nature of reality at quantum level, if you fathom through living organism to genetic cords to molecules that operate genetic codes, to quantum realm, you will see that at that fundamental level nature could only be described with complex numbers. Complex vector spaces and complex equations.

At plank scale and quantum level nature is a parametric operation working with complex numbers.

When we take fractal explanation of Nature into one hand and the computer generated fractal art into the other hand and look deep into the act of creation of both: There are two Key insights we can reach at.

1. Fractal Geometry shows the way to understand complexity of Nature.
2. Fractal Geometry shows the way to design like Nature has done.

Fractal geometry has shown the way to design with complex numbers and equations. Design not only 2D graphics but 3D forms and spaces.

3. **Parameticism**

Parametricism is a style within contemporary avant-garde architecture, promoted as a successor to post-modern architecture and modern architecture. The term was coined in 2008 by Patrik Schumacher, an architectural partner of Zaha Hadid (1950-2016)

Parametricism has its origin in parametric design, which is based on the constraints in parametric equations. Parametricism relies on programs, algorithms, and computers to manipulate equations for design purposes.

3.1 What is parametricism?

Parametricism implies that all architectural elements and complexes are parametrically malleable. This implies a fundamental ontological shift within the basic, constituent elements of architecture. Instead of classical and modern reliance on rigid geometrical figures – rectangles, cubes, cylinders, pyramids and spheres – the new primitives of parametricism are animate geometrical entities – splines, nurbs and subdivs. These are fundamental geometrical building blocks for dynamical systems like 'hair', 'cloth', 'blobs' and 'metaballs' that react to 'attractors' and can be made to resonate with each other via scripts.

Parametricism aims to organise and articulate the increasing diversity and complexity of social institutions and life processes within the most advanced centre of post-Fordist network society. It aims to establish a complex variegated spatial order, using scripting to differentiate and correlate all elements and subsystems of a design. The goal is to intensify the internal interdependencies within an architectural design, as well as the external affiliations and continuities within complex, urban contexts.

Aspects of parametricism have been used in urban design, architectural design, interior design and furniture design. Proponents of parametricism have declared that one of the defining features is that "Parametricism implies that all elements of the design become parametrically variable and mutually adaptive." According to Schumacher, parametricism is an autopoiesis, or a self-referential system, in which all the elements are interlinked and an outside influence that changes one alters all the others.

Parametricism is a global architectural style that has converged rather than being invented. Parametricism is architecture's answer to our computationally powered network society, representing a paradigmatic shift in architecture after the collapse of the hegemonic style of Modernism, in response to the global shift from the Modernist era of Fordism (mass production) to the Post-Fordist era (mass customization). The style continues to evolve in an increasingly complex and fluid network of global communications. Parametricism evolves with the advancing computational design and fabrication technologies. e.g. multi-agent computational systems, genetic algorithms and robotic fabrication.

Aim of those working within the style of Parametricism to conquer the mainstream arena and see Parametricism evolve into a global best practice standard for architecture and the design disciplines.

4. Conclusion

With the developments of parametricism, we are equipped with tools and software to design buildings, spaces, urban places and cities with equations and mathematics.

If we look deep into nature and understand the way nature create things, not literally to copy Nature, but to get the very essence of mathematics of Nature, and apply them in the process of designing, we would reach at a totally different style of Architecture.

An architecture that is much more creative, Humane, Efficient and Sustainable. A style that could generate fluid forms from the socio- economic, cultural and environmental context. A style that has capacity of adapting to Climate and context. A style that have capacity to merge with its context and be one with Nature, urban fabric and human life.

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