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Fractals, architecture and sustainability

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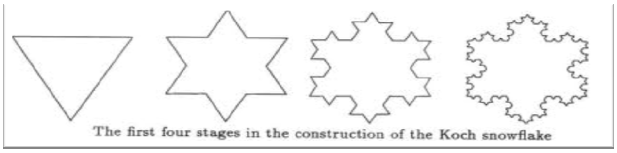
Abstract
The concept of fractals has brought about exhilarating and innovative changes deepening and broadening our understanding about the nature, culture and science. Sustainability as understood is an attempt looking at three dimensions- social ,economic and environmental. Architecture accomplishes some of the basic human needs namely aesthetics, functionality and sustainability. Fractal architecture with its unique feature of organic assemblage of units is better endowed to answer questions of sustainability than many other form of architecture. The fractal theme serves as a framework or reference for organizing an intellectual and aesthetic presentation in order to explain the reality that 'everything in the universe (nature) is connected to everything else.' The concept of fractal explains nature, where sustainability is a current concern. The topic of Fractal is a realization of the natural world expressed mathematically where the structure of every piece holds the key to the whole structure. The application of fractal theory in architecture is a new concept. The following research paper will discuss about fractals, their existence in architecture and how further they can be related to sustainability

Keywords: Fractals, sustainability, architecture

INTRODUCTION

The term, 'fractal,' comes from the latin word 'fractus' which means 'broken' or 'irregular' or 'unsmooth' as introduced by Mandelbrot. A fractal is a mathematical set that typically displays self similar patterns, which means they are "the same from near as from far". Fractals may be exactly the same at every scale, or as illustrated they may be nearly the same at different scales.They include the idea of a detailed pattern repeating itself. A fractal has a fractal dimension that usually falls between the integers. The term "fractal" was first used by mathematician Benoit Mandelbrot in 1975. According to Lorenze a self similar structure is changed by modifying the structure by the same factor of scale "the new form can be smaller, larger, rotated or reversed but the shape remains the same. If you look at one of the "leaves" coming off of the main stem, then it looks approximately the same as the whole fern, just smaller. If you again look at one of the "leaves" coming off the stem of this leaf, it once again looks approximately the same as the whole fern, just smaller. Famous examples of fractals in nature include: Ferns, Mountains, Coastlines. Fractal created by longitudinal compression, by tension and breaking, curvature occurs from longitudinal compression. The basic procedure to create a Fractal is by iteration. Fractals provide a description of much around us that is rough and fragmented objects. Architects have used Fractal Geometry as a shape design instrument. Fractal geometry can be explained by computer-generated programs and computational techniques.



The first four stages in the construction of the Koch snowflake

Fractals in Architecture

We can find some fractals components in architecture also. Fractal architecture arose naturally in different cultures, African architecture, European Architecture, Indian Architecture

A settlement in Kotoko in African architecture showing new enclosures being built around older, often sharing walls with the older rooms. This arrangement reflects existence of Fractals in the design.

In European Architecture the structure of Eiffel Tower shows the existence of Fractals in the construction materials

In Gothic Architecture the existence of Fractals is seen in the Cathedrals in ornamentation

The application of Fractals in architecture can be usually done in following different methods:

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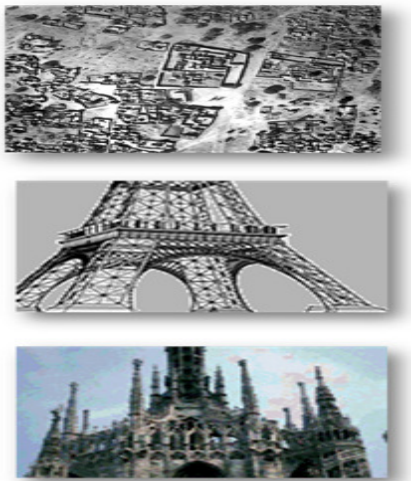


1. **Conceptual method**: This uses fractal geometry and its concept as a guiding element to its theories. This method provides a theoretical solution that ultimately influences the final form.
2. **Geometric-mathematical methods:** which uses scheme of counting squares to calculate the Fractal dimension. This method is used to analyze the existing building also.
3. **Geometric – intuitive method**: This uses the geometry as inspiration for creative expression

Fractal analysis in Architecture can be done in two stages:

1. **Analysis at a small scale** (e.g.analysis of a single building) the building's self similarity (components of building that repeats itself at different scales)
2. **Analysis at a large scale** (e.g.analysis at urban scale) the box counting dimension (to determine the fractal dimension of the building)

Formula for fractal dimension

For self similar dimension the calculations can be done based on the formula

$$D = \frac{\log(a)}{\log\left(\frac{1}{s}\right)}$$

a= No of pieces,
s= reduction factor
D= Fractal dimension

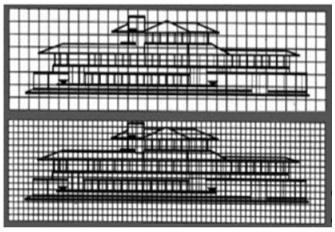
Another is the **Box Counting Dimension** where iterative procedure is used

- A grid of square boxes is superimposed over an image (the grid size is taken as S1)
- Count the number of boxes that contain some of the image [N(S1)]
- Repeat this procedure, changing (S1), to smaller grid size (S2)
- Count the resulting number of boxes that contain the image [N(S2)]
- Again repeat this procedure changing s to smaller grid sizes

$$D_b = \frac{[\log(N(s_2)) - \log(N(s_1))]}{\left[\log\left(N\left(\frac{1}{s_2}\right)\right) - \log\left(N\left(\frac{1}{s_1}\right)\right)\right]}$$

Thus the concept of Fractals have been extended to many well known Architecture which includes many buildings of F.L. Wright such as Falling Water, Robie House, Palmer House. Fractal geometry has a holistic approach and we design and built in an environment that is complex and largely fractal.

Robie house by FL Wright



Elevation overlaid on square grid

From the "Fractal Geometry in Architecture and Design" the fractal Dimension of the Robie house by Frank Lloyd Wright is shown below.

$$D\ (32 \text{ to } 64) = \frac{[\log(380) - \log(140)]}{[\log(64) - \log(32)]} = 1.441$$

Like wise the Fractal dimension of many buildings have been calculated:

Antonio Gaudi Sangrada Familia - the Fractal dimension being 1.698

Kandariya Mahadev temple (Khajuraho, 1030 A.D) the Hindu temple - the Fractal dimension being 1.762

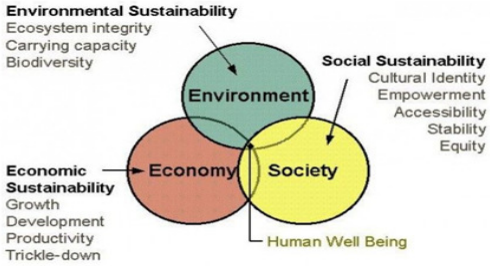
Fractal patterns are built up over time. Fractal in nature show statistical self-similarity (SSS) rather than exact self-similarity (ESS) that is; under different levels of magnification the object may reveal different patterns which can be described by similar statistics.

Sustainability and Architecture

The concept of sustainable development can be interpreted in many different ways, but at its core it can be said as an approach to development, that looks to balance different, and often competing,

needs against an awareness of the environmental, social and economic limitations faced by a society.

The era of sustainability and social health when discussed, the architectural processes need to emphasize on optimization, efficiency enhancement, minimizing wastage, energy conservation, integration of man by nature.



When discussing the most important characteristics of the design in a sustainable system one will come across four important terms:

- Holistic–as they consist of interconnecting systems at multiple scales
- Diverse-because in ecological systems, diversity is the generator of health.
- Fractal –as the processes and forms involved are self – similar at many scales
- Evolutionary-because through iteration and feedback they create diversity & efficiency

Aesthetics of sustainable designs

The three basic design elements of harmony, proportion and scale are applied to space, volume, function, structure and material, constructing composition having the characteristics of sequence, rhythm, order & form. in addition to the three basic elements, additional elements of sequence, rhythm, order and form are essential basis of aesthetics of sustainable design. Aesthetics of sustainable design is life oriented, integrative and focusing on process in design.

Sustainability and fractal architecture

Complexity can be said as an integral part of aesthetics and it reflects the surrounding place, and aesthetics again being a part of cultural dynamics**.** Main aim in a sustainable design should be a disease free and a healthy society through thoughtful activities treating each place as an integrated whole. Talking about Fractal geometry it is observed that each formation is new and amazing only because fractals are like natural objects which are universally beautiful. Similarly it is necessary that an architecture should be able to extract the essence of fractal geometry which encourages adapting to the context and time.

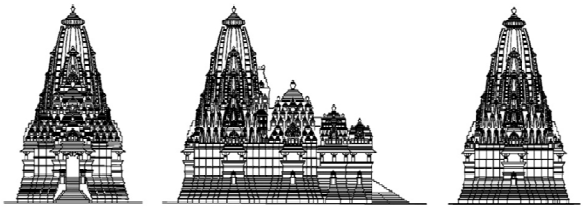
Prototypes of sustainable design: as proposed by Haggard & Cooper, (2006), the cultural framework need to have the following antecedent attitude as prototypes of sustainable design like:

1. Reality is a unity that has infinite variety
2. We should have “Scalar integrity” where parts affect the whole and vice versa

Harmony between wholes and parts is possible and desirable. Fractal geometry is based on hierarchical principle, which is an essential element of urban Planning. The different scales in an area may be House, Housing colony, Panchayat, Taluk/Block, District, State. When the geometric pattern of the spatial system is achieved with accessibility and piling which means that every space is connected to each other as well as itself it can be considered as a fractal structure.

Fractal in Architecture

Here the relationship between Hindu cosmology Fractal theory is manifested where Fractal geometry acts as a language

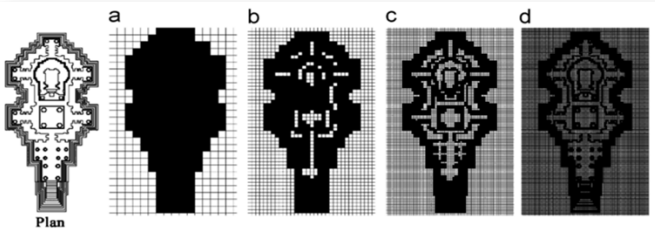


About the Temple:

- Kandariya Mahadev temple has height about 31 m, elevated above a lofty plinth.
- The structure is 30.5m long and 20m wide.
- The whole structure is divided into four equal parts- Garbhagriha, Pradakshinapth, Mandapa, Arthamandapa.

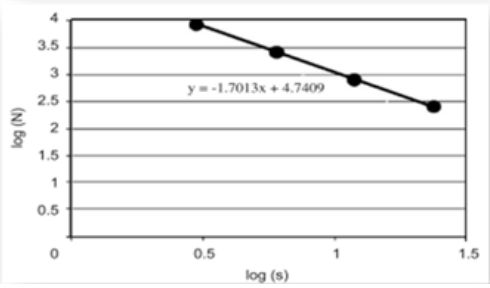
Box Counting Method

Pitha Mandala placed within the 100 square grid in the centre.



Plan super Imposed on different grid sizes which is growing denser.

Step	Grid size (S)	Marked boxes (N)	Log (S)	Log (N)
1	24	249	1.380	2.396
2	12	806	1.079	2.906
3	6	2554	0.778	3.407
4	3	8627	0.477	3.936



Plotting the values of log(S) on X axis and log (N) on Y axis we calculate the Fractal Dimension= 1.70 which shows high degree of roughness or detail and uniformity of its roughness.

The same method has been employed for the Shikhara as well and the Fractalness has been calculated. The temple depicts the Fractal behavior not only in the exterior but in the interior as well. Fractals help to determine the structure of the cities, building geometry and design pattern. Fractal geometry play a key role in developing new forms of design of sustainable architecture and buildings as the sustainable design integrates the balance of human geometry and the natural ones

Conclusion

Changing perspectives in geometric framework is mandatory for a shift from industrial culture to one that aims at sustainable designs. The knowledge of Fractals has far reaching impacts. Being fractal can definitely not be the sole criteria for judging a building in terms of sustainability. However a fractal approach would definitely make a building more efficient. They actually help to quantify the natural world eg. Frankhauser fractal model can be one of the tool to analyse an urban formwork. The aesthetics of a place would be done at various scales, from planet to place from setting to specific material. Thus the 'same' or the 'regular' part of the fractal definition suggests that patterns, rules, and knowledge all repeat, at all scales: this part is sustainable or constant. In the present era sustainability is a rising concern and it encompasses various elements that needs to be addressed in a holistic way. Here fractal architecture can be taken as an evolving concept that would guide in design decisions.

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