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The Transformation of Using Fractal Forms Between Islamic and Digital Architecture from a Sustainable Approach

(Case study: King Abdullah Petroleum studies & research center, Riyadh, K.S.A)

Amr Elgohary[1]

[1]*The Higher Institute of Engineering, Shorouk, Egypt*

Abstract

Along eras and civilizations, nature as a sustainable reference always has a great role in inspiration of the architectural form by the diversity of its vocabulary, rules, and colors. . . etc. Consequently, fractals as the main natural elements appeared in the architectural morphology, since the ancient eras especially in the Islamic architecture in various levels of forms, details, and patterns. However, nowadays the new architectural theories deal with fractals concept in a different ways depending on the deep understanding of universal and cosmic nature, also the new digital techniques in architectural design and construction that enhanced the appearance of new fractal forms. In this context, the research discusses the transformations of fractal systems, concepts and applications in architecture at the resent architectural theories, focusing on the digital architecture and how it deals with fractal forms, aiming to root the new architectural theories and link it with Islamic heritage to achieve a new Arab architecture that respects and reveals the local heritage and adapt with the latest architectural theories and techniques.

Keywords

Fractal Forms; Transformation; Morphology; sustainable; Rhythm; Chaos; Architectural Software; Digital Era

1. Introduction

Fractals, this irregular forms that shows similarity in each level of magnification, can be considered as one of the most effective tools in the architectural composition, whereas it gives a new features to the architectural form like dynamic, unity and diversity. Along eras, architects used to deal with the fractal forms since the ancient civilizations specially at the Islamic eras, where they used fractals in various scales, starting with details scale, till the large urban scale.

Nowadays fractals received many changes in its aims, characteristics, and the methodologies to execute it, which occurred based on the new architectural theories and techniques that developed during the new digital breakthrough and its givens in the various fields specially the architectural field. So the research in this paper aims to determine the fractals concept, characteristics, and objectives, and how it can be inspired by nature. Finally, it determines the new features of fractal forms which have occrued during the digital era.

2. Fractals concept and definition

The term of fractal expresses any 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 [Merriam, Webster, 2016]. Also regarding to oxford dictionary it 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 (oxford dictionary, 2016). The origin of that term referred to French 'fractale', from Latin 'fractus' which means broken. On the other hand, mathematicians developed fractal dimension, to measure self-similarity through scale invariance; a it is coined by the Polish-born mathematician Benoit Mandelbrot in 1975. Figure 1 shows the basic steps of constructing von Koch curve depending on the fractal shape concept.

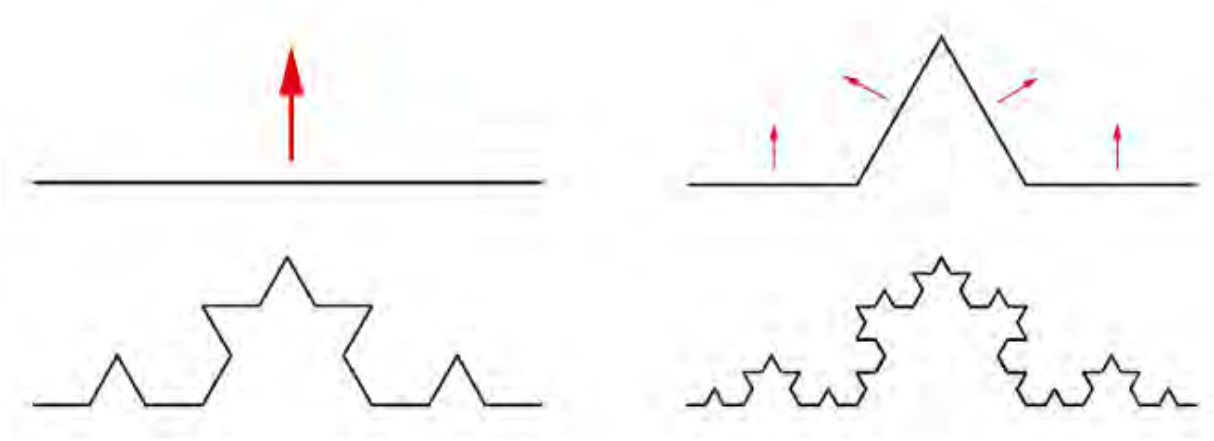

Figure 1. Basic steps of Von Koch curve

3. Fractals in Nature

It can be considered that nature always combines a great deal of irregular complex shapes, which are oscillating and occurring changes. Like leaves, mountains, clouds, and the distribution of galaxies in the universe…etc. Hence, the evolution of the mathematics and science achieving the fractal geometry, and the fractal cascades, which facilitate viewing strange and unique scenery and giant forms in nature.

3.1. Fractals in cosmic nature

The notion that the cosmic universe itself might have some form of hierarchical structure goes back at least 200 years, with astronomers such as John Herschel (1792-1871) and philosophers such as Immanuel Kant (1724-1804) suggesting that the portion of space that we can see around us might be replicated at much vaster scales (Falconer, 2013).

By the early 1980s, galaxies have been mapped up to distances of about 50 million light years away. Based on this data, Jim Peebles, Benoit Mandelbrot, and others proposed that galaxies might have a hierarchical, fractal distribution, rather than a uniform 'homogeneous' distribution across space. Very recent observations at the scales of up to 3 billion light years seem to favor homogeneity, but fractal clustering still cannot be ruled out even at large scales. Fig. 2(a) shows the fractal cascade within a spiral galaxy.

3.2. Fractals in human's body

By the deep observation of the human body, it became clear that there are so many extensive examples of branching fractal networks are to be founded within the bodies of humans or other mammals, in particular the Respiratory tract

(the windpipe splits into two bronchial tubes leading into two lungs. These tubes split into narrower tube , which continue to split repeatedly until, after about 11 levels of branching, which end in millions of microscopic thin-walled sacs called alveoli), (Falconer, 2013), Fig. 2(b) shows 3 levels of zooming in the mammalian lung which shows various scales of its fractal cascades. Another example is the nervous system, and the blood circulation, which consists of an intricate branching fractal network, comprising a total length of blood vessels of around 60,000 miles.

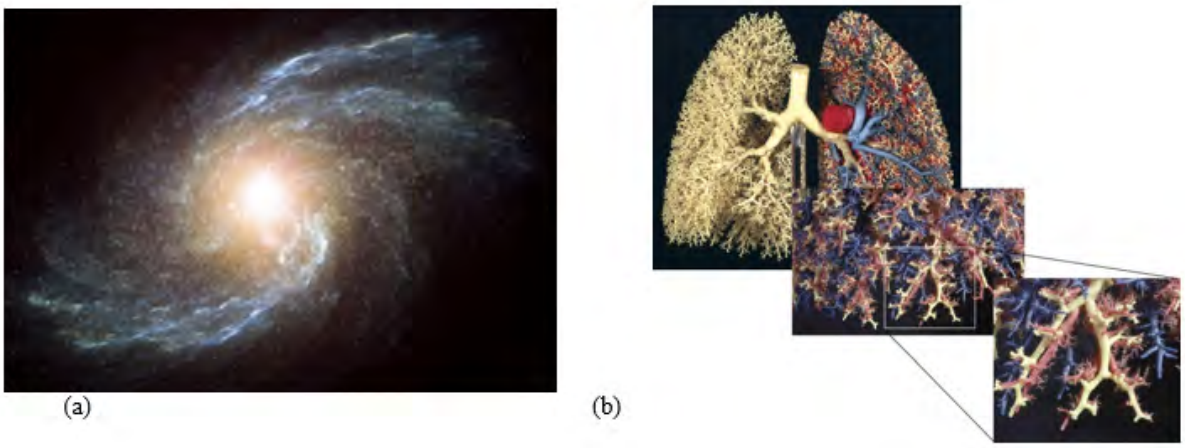

Figure 2. (a) Spiral galaxy; (b) mammalian lung.

3.3. Characteristics of Natural Morphology

Natural forms have many characteristics that can be classified into three main items (self-similarity, components, and growing geometry)

- Components geometry: If we consider the complex forms as densest forms, it will not depend only on its size, or its scale, the internal components and composition would be the basic parameter of its fractal system. For example, it is clear that the pattern of the branches of the river is a branch with constant hierarchical form, number, and distribution, independent of scale.
- Growing geometries: Nature is not specified as a fixed geometry and it's not only a physical fractal form, but the proceeding of nature changes through time is also fractal, whereas in terms of mathematics, the geometry of nature grows up. It's a dynamic cascade, where its whole form and its internal components are about to increase or decrease and decay.
- Self-Similarity: it's known that there is symmetry in nature, but by deeper observation there is also a complex diversity. For example, not all humans have the same size and shape. There is, however, a newly developed concept of symmetry that is proving it is useful in describing nature's underlying diversity. This symmetry has invariance with respect to size. It has self-similarity, in which small parts of an object are similar to larger parts of the object, which in turn are similar to the whole object.

4. Fractals in Architecture

Despite architectural forms are considered as a handmade that is very much based in Euclidean geometries, but we can find some fractal systems and components in architecture, too. Whereas architecture and design concerned with the control of rhythm that can achieved by using this relatively mathematical tool. The fractal system and techniques provides a quantifiable measure of the mixture of order and surprise in a rhythmic composition. Fractal

geometry is a rare example of a technology that can reach into the core of design composition (Bovill & Bovill, 1996).

4.1. Fractals from nature to Architecture

There is always a strong coherence between architecture and nature, where nature represents the basic reference for the architectural morphology, which appears in the most architectural thoughts and theories, like art novo, organic, Functionalism. Until the new digital architecture theories, thence it appears in inspiring the natural fractal roles and methodologies in architecture, this inspiration process can be coined into three main stages:

- Observing and analyzing the natural phenomenon to achieve the fractal concept.
- Deriving the mathematical and geometrical rules.
- Formulating the concept of architectural form, depending on its relative fractal concept.

4.2. Fractal forms Properties

Fractal forms are characterized as rough or fragmented geometric shapes that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole form. In this context, general properties of fractals can be included:

- Visual self- similarity on any scale 'Since all levels of magnification, fractals are similar', the self-similarity feature is a prominent characteristic of the fractal forms, whereas it indicates the similarity between the parts that form the shape with the whole shape, i.e. the part of the whole is so similar to that whole.

There are two terms that are relevant to the characteristic of self-similarity:

- The complete self-similarity which means that the small parts are completely similar to the whole shape.
- The statistical self similarity, which means that the small parts are roughly similar to the whole shape

- Uniformity and harmony in any measure.
- Have decimal dimensions.
- Repeating rhythm that leads the fractal shapes towards equilibrium.
- Irregularities in the appearance and more promiscuous than that can be described with the language of Euclidean geometry.
- Nonlinearity, whereas no straight line in the fractal forms, despite the internal shapes and edges are not smooth but are spongy and wraped.
- Fractal dimension property, the regular geometrical shapes have dimensions as integers, while the fractal shapes have dimensions as a fractal number which expresses the complexity degree of the geometrical shape. Dimension is a scalar quantity that when the scale becomes smaller, represents how fractal fills the space. There are many definitions of fractal dimensions, including: the hasdraf dimension, rainey dimension, box-counting dimension and correlation dimension, and etc. None of them should be used as a single global model. A pattern with higher fractal dimension is more complex and irregular than lower fractal dimension and will take up more space (Zarghami & Milad, 2015).

In fractal preferences, the fractal dimension is more important than scale. Due to the reason that they come in any size, the fractal dimension is maintained and it reflects the essence of fractals. This matter has caused fractals' application in science.

5. Fractals in Islamic architecture

Through the Islamic eras, so many sciences have been emerged and developed, including the mathematics and measuring systems, and geometric methods, which developed as a result of the pressing need to partition and calculate irregular shapes. In other words, developments in mathematics, and particularly in algebra, were a direct consequence of Islamic laws of inheritance.

Islamic succession law is believed to lie at the basis of the birth and development of both algebra and geometry in Islamic civilization. Al-Khawarizmi (780-850 A.G.), from whose name the term "algorithm" was derived, introduced algebra to modern mathematics through examples from Islamic inheritance laws (Jencks & Kropf 1997). In geometry, techniques and tools for the calculation of areas on the ground and shares of heirs were also made available to jurists and dividers (Efendi 2000).

5.1. Fractals objectives in Islamic architecture

- Unity in Diversity: Unity can be considered as one of the most important Islamic basis and thought. This is clearly evident in the art of the Islamic world. In this context, Diversity in terms of art and beauty expresses the unity and the Godhead in the Islamic vision. The Muslim artist believed that mental art represented unity to diversity in the most direct way. This matter has been carried out by repeating geometric motifs and alternates weights and symmetry in Islamic art matters.
- Dynamic stability: that achieved by the particular self-similarity, uniform rhythms, and the continuous flux of the whole system components.
- Infinity: Islamic architects used to use the fractal systems in architecture to express the meaning of continuity and infinity which inspired from their beliefs of the infinite godhead Knowledge and the infinite universe. Fig. 3(a) shows the entrance Muqarnas at Isfahan Masjid that consists of infinite hierarchal fractal system.
- Visualization of heaven: the fractal motifs that formed the building inner decorations and the outer facades details, seem as a symbol of heaven and paradise, depending on the natural inspiration of astronomical and botanical fractal cascades. Fig. 3(b) shows the botanical pattern that covers the dome of Isfahan Masjid.

Figure 3. Isfahan Masjid (a) Entrance Muqarnas; (b) Main Dome.

5.2. Applications of fractals in Islamic Architecture

Islamic architects used the fractal systems in so many various applications, which reflect the great importance of the fractal systems and techniques within the architectural design process, starting with a very small details, like

mosaic ornaments and Arabesque handicrafts, passing by architectural openings, arches…etc., and till the urban fractals, which appeared in the urban morphology, fabric, and context. In this context, we can determine some of the important features of Islamic fractals through the following applications, and the mechanisms of appling these fractals in the real-life.

– Muqarnas: one of the most unique and accurate decorative element, which reflects fractal growth in Islamic architecture, that can be named allegory of God's created universe that is like light chandelier spread a kind of spiritual light above prayer's head. It was initially built to be structural in purpose made out of stone, but later on, it became a more crafted decoration (Burckhardt, 2009), these clusters niches were used to decorate the area between the wall and the dome in Islamic architecture. Fig. 4 shows the steps of muqarnas creation, from the small basic arch (the fractal cell) till the overall form.

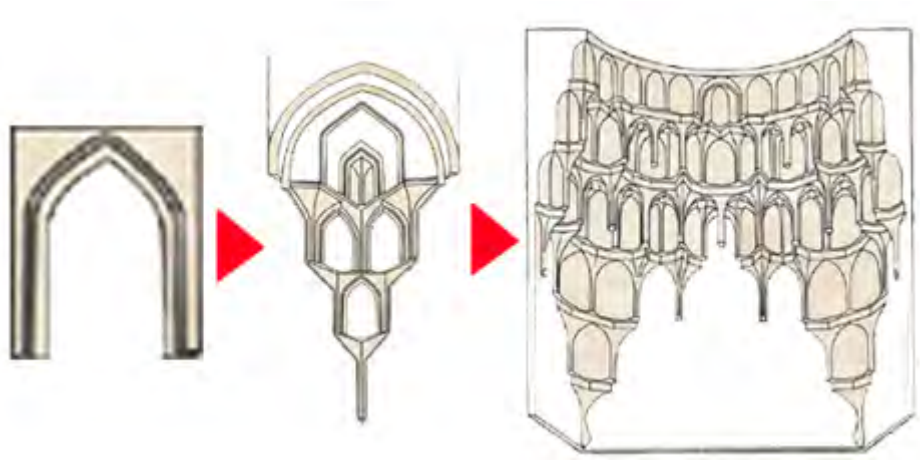

Figure 4. Mainsteps of muqarnas creation

– Ornaments: Islamic artists and architects were proficient in using geometric and floral patterns and motifs, which depended basically on repeating the primary shapes in a various homogeneous rhythms to reach the overall pattern. Fig. 5 shows three main steps that has been used to create Islamic geometric pattern.

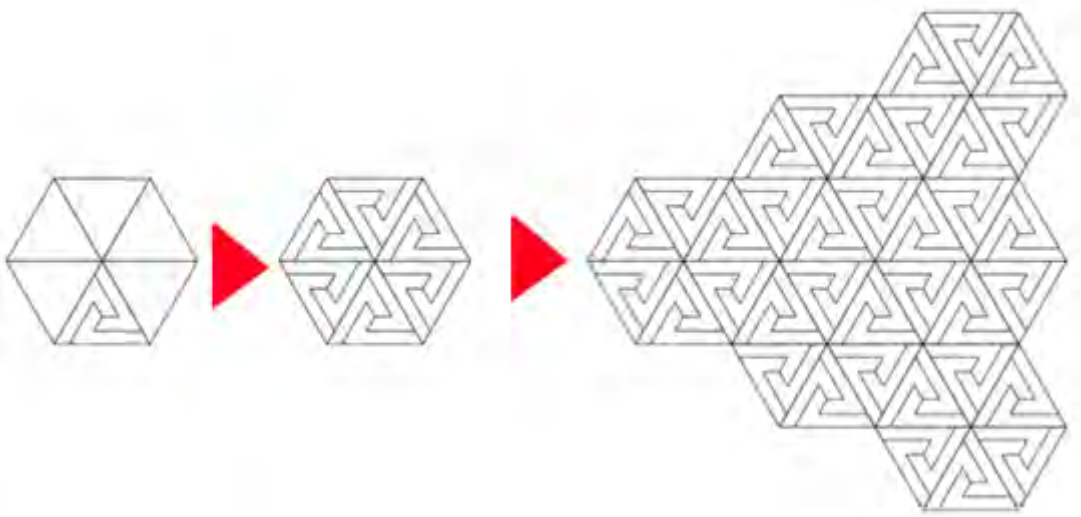

Figure 5. Mainsteps of geometric pattern creation.

– Urban fabric: the Islamic city consists of a set of hierarchal roads network and another sets of residential clusters which divided into a dense fabric of small residential buildings. Fig. 6 shows the unity and diversity at the Islamic city which appeared at any magnification.

Figure 6. Hierarchy, unity and diversity in the urban fabric of the Islamic city

6. Fractals in the digital era

The classical thoughts about balanced and hierarchical fractals (since the Islamic architecture and till the modern architectural theories at the twentieth century) transformed at the end of the Twentieth century and the beginning of the twenty-first century. Depending on the new digital breakthrough and its great impacts in architectural theories and techniques, which enhanced new aspects within the design process, like adding complexity, randomness, and dynamic. Hence the new cascades of fractal forms turned to be more dynamic, flexible, and nonlinear (Jencks, 2002).

6.1. Fractals from self-similarity to self-affine

Affine transformation is more general than a similarity, whereas the affine shape can be deformed into irregular and random deformations, without disrupting the overall character of fractal system, for example affine transformations transform square into rectangles or parallelograms, and circles into ellipses (Falconer, 2013). Thence a self-affine fractal form is one that is made up of smaller affine copies of itself which gives the self-affine system a greater ability to change and grow in nonlinear motions. Fig. 7 shows a fractal surface based on self-affine system and how it gives the surface a great deal of flexibility and roughness.

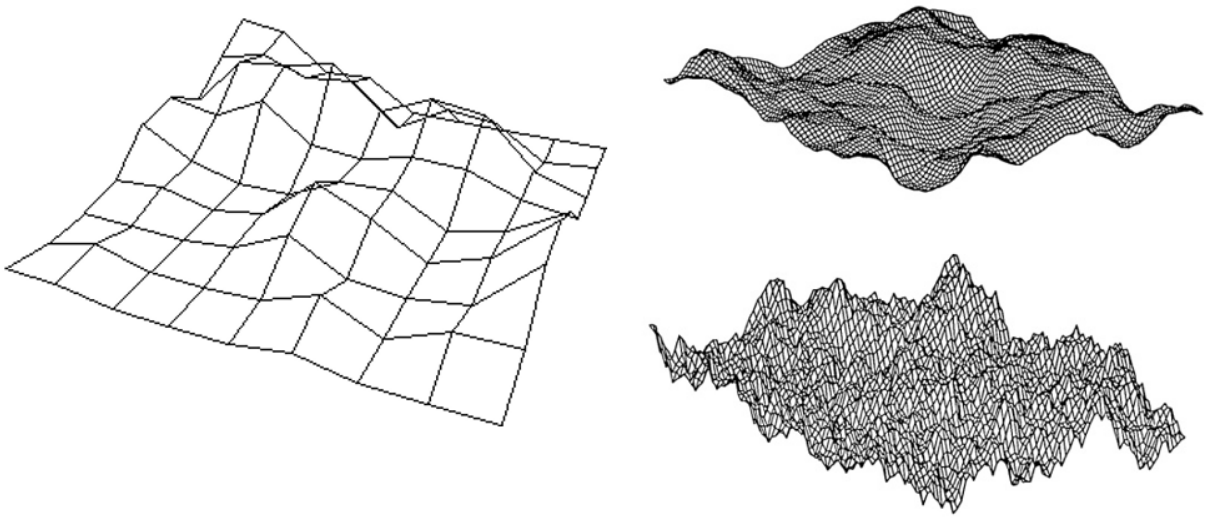

Figure 7. Three levels of deforming a self-affine fractal surface

6.2. Fractals and chaos (Including randomness):

The terms “fractal” and “chaos” became so interwoven, and together form a single, integrated theory. They are usually used concomitantly. They are concerned with irregular forms and complex objects that show self-similarity at each scale of magnification when they undergo a certain process of iteration.

Consequently, it is relatively easy to differentiate between geometric order and chaos in architectural forms, whereas the geometric order is represented by ideal mathematical forms (in 2D: e.g. line, circle, quarter, or 3D: e.g. plane, sphere, cube) and ideal relationships (e.g. perpendicularly, parallelism, symmetry, rhythm/regularity). But Chaos is the opposite of geometric order; it is represented by forms and relationships that are complex and difficult to describe with the language of classic mathematics. (Rubinowicz, 2000).

6.3. Fractals of the jumping universe :

The jumping universe indicates to the tale of cosmogenesis and evolution of the universe, which unfolded towards greater complexity and increasing sentience. In spite of this progressive slant, it is a narrative punctuated by accident, upheavals and catastrophe. The investigation of cosmogenesis would also provide a series of new themata. The basic rules of the universe (including the traditional laws of natural fractals) would become protagonists; the constants of nature and organizing units would become particular icons: black holes, DNA, gravity. All of these are the distinctive units of the universe, from the quark to the molecule of life to the great wall of galaxies, these are the main actors in the script that has lasted (Jencks, 2002).

(Charles and Karl, 2008). Fig. 8 represents three steps clarifying how Charles Jencks inspired the fractal concept of the black hole phenomenon at the landscape of Cosmogenesis Park.

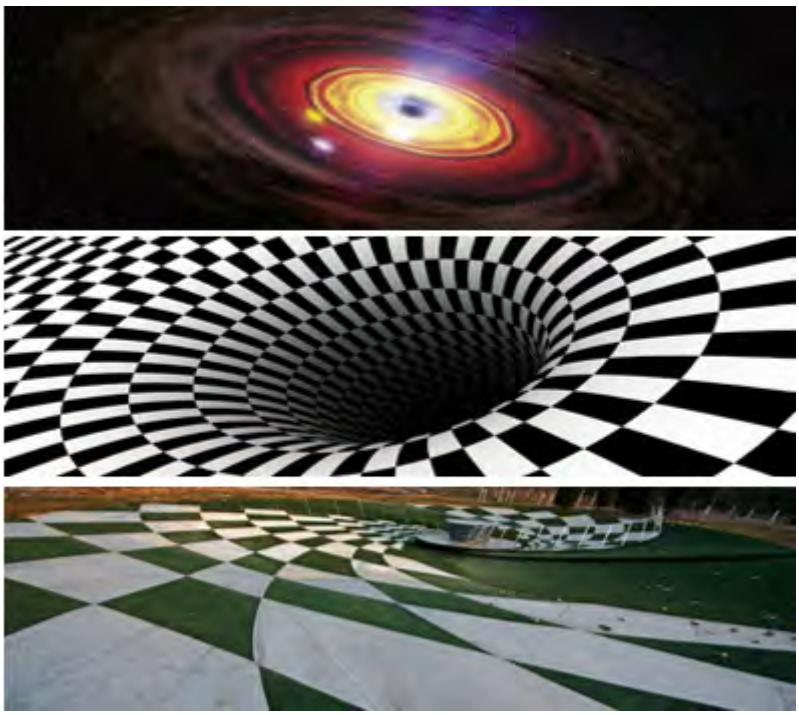

Figure 8. Three steps of inspiring the black hole phenomenon at the landscape of Cosmogenesis Park.

6.4. Cross-Coding and parity

Cross-coding notion indicates to the mixture of an iconography based on cosmogenic themes set against another set of codes based on our contingent desires. Biomimesies, or morphology, set some of these themes, but so too does our experience as cultural beings rooted in a particular historical situation, (Charles and Karl, 2008).

7. Case study: King Abdullah Petroleum studies & research center, Riyadh, K.S.A

KAPSARC, the abbreviation for the King Abdullah Petroleum Studies and Research Center, is located in Riyadh, Saudi Arabia, where it began its activities in 2010. It is an independent, non-profit institution that focuses on research in energy economics, policy, technology, and the environment. Its research areas include global energy markets and economics, energy efficiency and productivity, energy and environmental technologies, and carbon management. Designed by Zaha Hadid architects.

7.1. Design concept

The center emerges from the desert landscape as a cellular structure of crystalline forms, shifting and evolving in response to environmental conditions and functional requirements. Consistent organizational, spatial strategies drive an adaptive approach.

The modular structure is a living, organic fractal scheme where expansions to the building are allowed to grow and multiply like fractal cells – without compromising the visual integrity of the project. Composed of a network of three-dimensional six-sided cells, the project is based on the concept of connectivity. The center rises above the desert landscape, emerging as a cluster of crystalline forms, which evolve in response to environmental conditions. The spatial program of the design ensures that each component is suited to the function it serves. The exterior's shell-like façades conceal the porous interior, where sheltered courtyards bring natural daylight into the center of the scheme. These buffer zones allow a gradual temperature transition between outdoor and indoor volumes. Fig. 9 shows the fractal cells that forms the whole building.

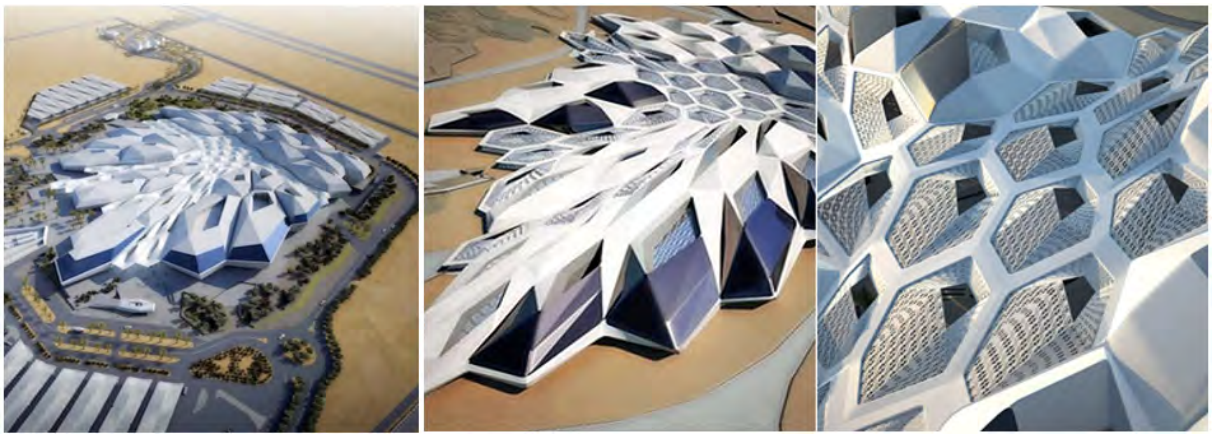

Figure 9. The fractal cells at King Abdullah Petroleum studies & research center

7.2. Analyzing the fractals cascade

The building form consists of a unique cascade of fractals, which can be clarified through the following:

- The fractal cell: the whole cascade started with a nonlinear and multi-dimensional cellular form, which represents the petroleum cells.
- The division mechanism: the division concept of the fractal cells inspired from the phenomenon of Molecular division in nature, whereas, it has been applied in the building form through a primary cell which was divided into a nonlinear and successive divisions to finally reach the whole fractal cascade. So it represents the most new features of fractal forms at the digital era. Fig. 10 shows the division stages of fractal cells that forms the whole building from the primary cell till the whole fractal cascade.

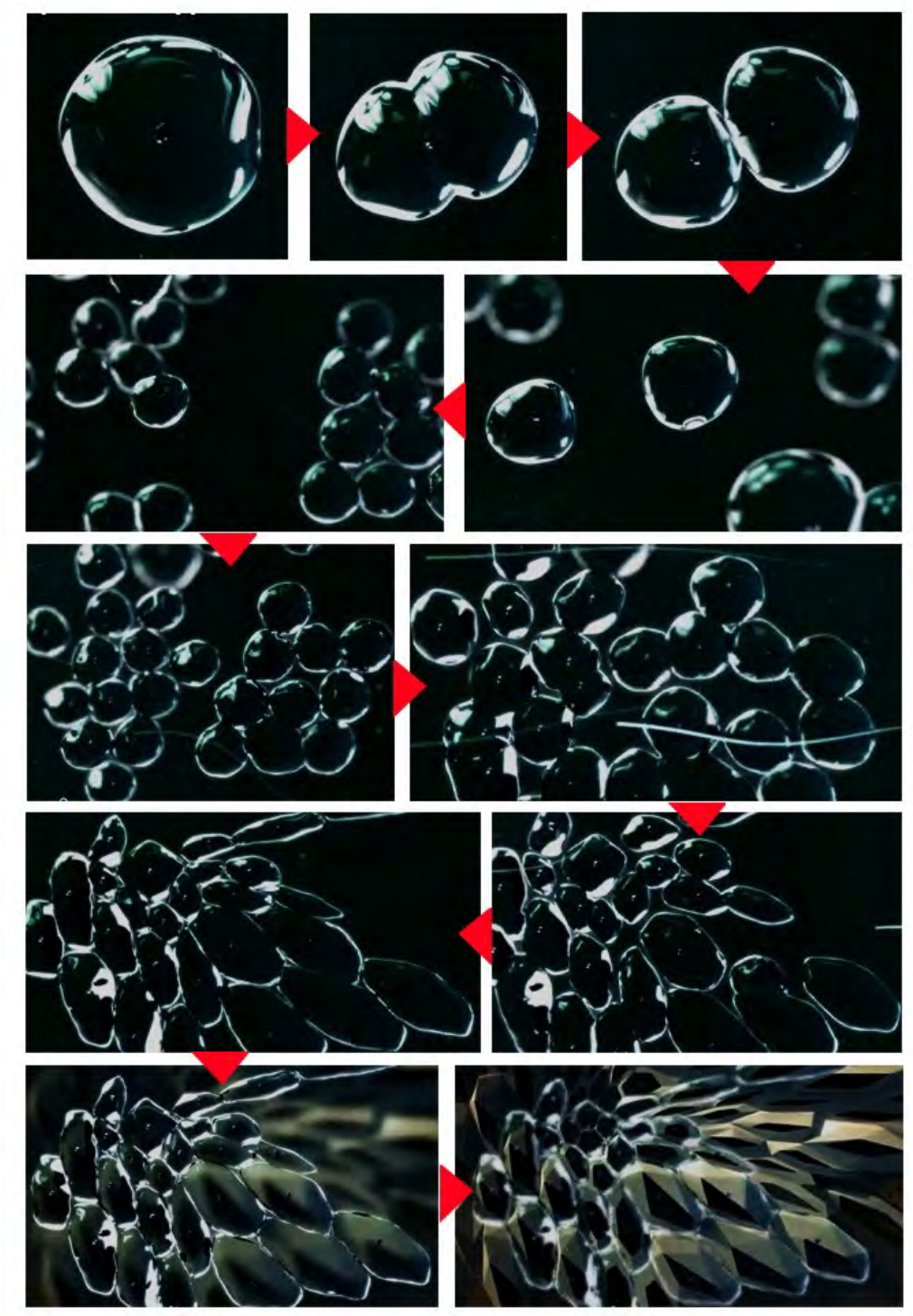

Figure 10. Thedivision mechanism of fractal cells at King Abdullah Petroleum studies &research center

7.3. Fractals characteristics of the building form

The fractals characteristics of the building form represents in every part the most digital fractals characteristics that can clarified as the following:

- Self-Affine form: whereas every cell shape can be distinguished, whilst the whole form is integrated according to whole form parity.
- Chaos system : which appears in the nonlinear and dynamic growth of the cells even in its scale or its growth direction

8. Conclusion

The research tried to clarify the essence of fractal forms, and the role of nature as a sustainable reference in inspiring its concept, and how it has been applied in architecture. Hence, the research turned to highlight the transformation of fractal forms between Islamic and digital architecture, in order to root the modern architecture that is represented in fractal forms, which considered to be one of the modern architecture features. Accordingly, the following conclusions can be coined:

- Along eras and civilizations, nature is always the most motivating factor for inspiring the concepts, roles, and techniques of the fractal forms, starting with surrounding natural phenomenon till the cosmogenesis, and the jumping universe
- At the Islamic civilization fractal concept focused in how to achieve unity with diversity through a regular and homogenous rhythms, which appeared in many various
- Fractals transformed during the digital Era, whereas it has gained new features like self-affine, nonlinearity, chaos, and Parity, which gives the fractal sets a great deal of flexibility to adapt with various deformations, and the new aesthetical and symbolic aspects.

Finally, we can determine the most transformations of fractal forms characteristics, between Islamic and digital architecture through the following table:

The transformation of fractal forms between Islamic and digital Era		
Characteristics	Islamic Era	Digital Era
Similarity	Self-Similarity	Self-Affine
Growth shape	Uniformly	Chaos
Rhythm	Regular	Random & irregular
Stability	Dynamic stability	Unstable
Smoothness	Partially smooth	Rough
Environmental Reference	Surrounding and godhead nature	Cosmic and cosmogenesis universe

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