

Fractal geometry: a tool for adaptability and ‘evolutionability’

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Abstract

Buildings must be able to adapt and adjust to change in order to achieve a sustainable architecture, reduce waste and keep harmony with nature. Adaptability advocates the design and organization of the built environment according to different scales and levels (layering). With this in mind, the fractal theory seems to be an interesting approach to explore architectural adaptability. It allows us to conceptualize spatial organization as a multi-scale pattern. Fractals are everywhere in natural forms. They facilitate the creation of coherent, organic and complex structures, which fit harmoniously in the natural environment and interact with it. Fractals emerge in evolution due to the natural need for efficiency and optimization. Fractals are used in different fields including architecture and urbanism. Nevertheless, most of the publications deal with urban planning (city or neighborhood levels) or with aesthetic (detail level) but little about spatial and functional configuration of buildings (architectural level). Our research focuses on the latter; it aims to highlight contributions of fractals to adaptability and evolutionability of buildings by implementing fractal geometry as an architectural ordering of the built environment.

Keywords: architectural adaptability, evolutionability, fractal geometry, sustainability, spatial and functional configuration.

1 Introduction

Buildings and their surroundings are, and should be, considered as complex systems by their need to be diverse, dynamic, adaptive and evolutionary. These abilities enable them to meet change through time and sustain while paying attention to the environmental and socio-economical issues as well as future



uncertainty. Buildings are also complex by the fact that they are made up with multiple connected components organized and interacting according to a layering process. Considering these characteristics, fractal theory constitutes a valuable tool to explore architectural adaptability and ‘evolutionability’.

In order to avoid any eventual terminology confusion, it might be more appropriate to give a definition for ‘adaptability and ‘evolutionability’ as used in this paper:

Adaptability understands the built-in capacity to adapt and adjust to change by meeting different uses and allowing various spatial and functional configurations without significant disruption (Kronenburg [1]).

‘Evolutionability’ is the built-in ability to evolve through time according to different scales and levels. It allows upgrading the building’s systems and their interrelation in order to improve their organization and functioning and preserving the coherence of the whole.

2 What is fractal

We do not intend through this section to provide an in-depth definition of the fractals, since it has been exposed widely in books and papers, but to simply introduce the paper’s subject by setting out some aspects that characterise the fractal geometry.

The interest to fractals dates back to the late 19th and the early 20th century, when many mathematicians such as Helge von Koch, Waclaw Sierpinski, Bertrand Russell, Georg Cantor, Felix Klein, etc. were investigating some iterated functions. However, the term ‘Fractal’ was not known until 1975, when it was coined by Benoît Mandelbrot from the Latin word ‘fractus’ which means ‘irregular or fragmented’ (Mandelbrot [2]).

Later, the fractal geometry was defined by Bovill [3] as “the study of mathematical shapes that display a cascade of never-ending, self-similar, meandering detail as one observes them more closely”. On this basis, the fractal geometry is characterized by many aspects from which we will enumerate the following for further development, with regard of their implementation in architectural adaptability and ‘evolutionability’.

2.1 Self-similarity and form hierarchy

“A fractal is a shape made of parts similar to the whole in some way” (Feder [4]). A fractal object is similar to a part of itself which is also fractal. This similarity is present at every scale; the small parts resemble to the bigger parts, which resemble in their turns to the whole, Fig. 1. This is obtained by the continuous repetition of a pattern according to a recursive or iterative process (algorithm).



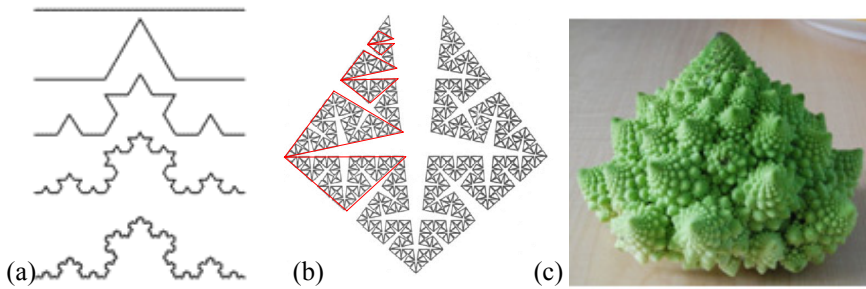


Figure 1: Examples of self-similarity in fractal forms: (a) the von Koch curve, (b) another version of the von Koch curve, (c) a cauliflower.

2.2 Irregularity, meandering and roughness

Unlike Euclidian forms which have no textural depth, a fractal object is 'non-smooth', it is rough, irregular and fragmented, and as the magnification of examination is increased, more of the roughness and meandering are revealed, Fig. 2.

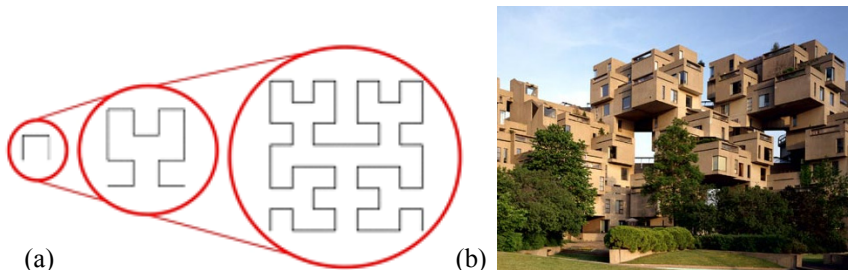


Figure 2: Example of irregularity, meandering and roughness in fractal forms: (a) the Hilbert curve, (b) the Moshe Safdie building (from: www.msafdie.com, ©Tim Hursley, reproduced with his kind permission).

2.3 Fractional dimension

The fractional dimension of an object is strictly bigger than its Euclidian dimension, which is whole (zero for a single point, one for a line or a curve, two for a plan and three for a volume). Complex systems are better described using a fractional dimension (a decimal dimension between two whole numbers). So, while a curved line has a dimension of one in Euclidian geometry, it will have a dimension between one and two in fractal geometry, depending on how much space it takes up as it twists and weaves. The more the fractal curves to fill every corner and area of a plane, the closer it tends to lose its property of one

dimension to approach two dimensions; likely, the more, it folds to fill and pack a bounded volume, the closer it approaches three dimensions, Fig. 3. The space filling property allows to an infinite length and surface to fit in a relatively small volume.



Figure 3: Fractal dimension – example of the Peano curve.

3 Fractals as a tool for adaptability and ‘evolutionability’

Fractals are omnipresent in natural forms, and they are widely used in different fields, including architecture and urbanism; the main reason may be their coherence, efficiency and optimisation (Mandelbrot [5]). However, the most of researches, in relation with our field, focus merely on urban planning (city or neighbourhood levels) or on aesthetic (detail level) but little on spatial and functional configuration of the building (architectural level). This paper aims to explore the latter aspect by explaining how an understanding of the fractal geometry, and its implementation on the architectural configuration and ordering of spaces, might guarantee the building’s adaptability and ‘evolutionability’.

3.1 Multi-scales and hierarchical evolution

The fractal structures develop step-by-step, according to an incremental, and hierarchical organic growth, rather than at once like it is in massif structures. Each level is related to at least one level above and one below, according to a control relationship based on dominance/ dependency equation: the upper level controls and dominates the change of the lower level, it determines the context, entails constraints and draws limits; as for the lower level, it encourages and fit to change, depending on the upper level. This organizing process operates continually without affecting the whole; it achieves both change and stability, thus, it ensures coherence, durability and sustainability (O’Neill *et al.* [6]).

Likely, a building which evolves progressively through multiple layers and different scales by renewing its individual cells, allows to meet future needs and adapt to change, while remaining coherent with the socio-cultural and economical conditions (Habraken [7]). Thus, each entity can be transformed,

upgraded and regenerated with a minimum of disturbance. In contrast, a building which is totally ‘finished’ and ‘perfect’ to its delivery, is considered ‘completed’, once built, and it is difficult to transform and to adapt and therefore, it becomes obsolete a few years later.

3.2 Space optimization

The fractal geometry gives a feeling of spaciousness (Crompton [8]) because it helps to increase density and optimize space without expanding the topological dimension. The Menger Sponge is an example of how fractal geometry can be used advantageously in the optimization of space and its utilization. The Menger Sponge (whose the area tends to infinity) is a structure that develops from outside to inside, by hollowing out the initial volume to create empty spaces. That allows one to multiply spaces, and provides a good way to set up hierarchy of volumes, while preserving the same exterior appearance of the initial volume. The multiplication of subspaces, alcoves, pockets, recesses, mezzanines as well as variations in heights and sizes allow to benefit of each millimetre of the space and to multiply the activities places. Thus, the space becomes complex, rich in activities places because, according to Crompton [8], the complexity of a space depends on how much varied activities is able to house.

The Menger Sponge also helps to fix landmarks which allow one to structure and configure the space, own it and adapt it (group together different spaces; separate and divide them; rearrange them, etc.). The Menger Sponge concept has been applied by the architect Steven Holl in some of his projects like the ‘Sarphatistraat’ office building in Amsterdam, Fig. 4.

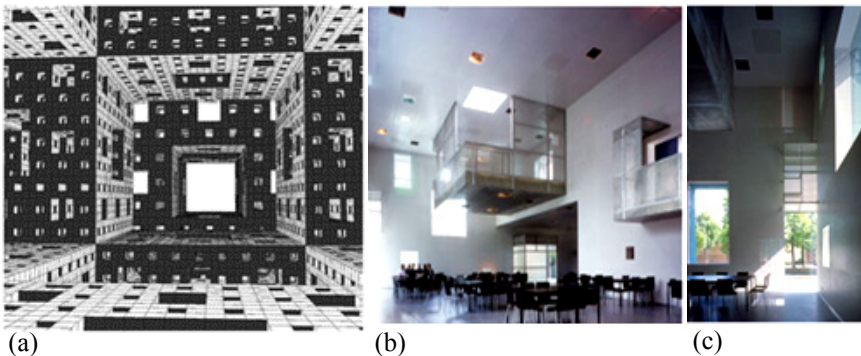


Figure 4: Space optimization according to ‘Menger Sponge’: (a) the ‘Menger Sponge’, (from Crompton [8], ©Andrew Crompton, reproduced with his kind permission), (b) and (c) the Sarphatistraat office building (from: www.stevenholl.com, ©Paul Warchol, reproduced with the kind permission of Paul Warchol Photography Inc).

3.3 Increase of permeability and accessibility

Fractal forms, compared to Euclidian smooth ones, are known by their infinite perimeter and external surface, which helps to maximize performance of the exchange surfaces. On this basis, the vegetal species develop their forms in such a manner to increase considerably their external contact area in order to facilitate exchange functions, like photosynthesis process, cellular respiration and absorption from roots (Salingaros and Padrón [9]).

By analogy, a building designed on the basis of the fractal geometry, spreads out its external skin to be interlaced with the natural and built surrounding environment and to optimize their connection. These enable the building and its different parts to breathe, and interact as well as to be better ventilated and lit, etc. Furthermore, fractal geometry allows one to enhance physical and visual accessibility and permeability while preserving a strong relationship with the centre of the built mass (Coates [10]) and keeping a harmonious relationship with the immediate environment, Fig. 5. That improves adaptability of the spaces because it makes their configuration, reconfiguration, subdivision and restructuring easier by preserving a good indoor quality, minimizing energy use and construction waste; which lies within the scope of High Quality Environmental standards (HQE).

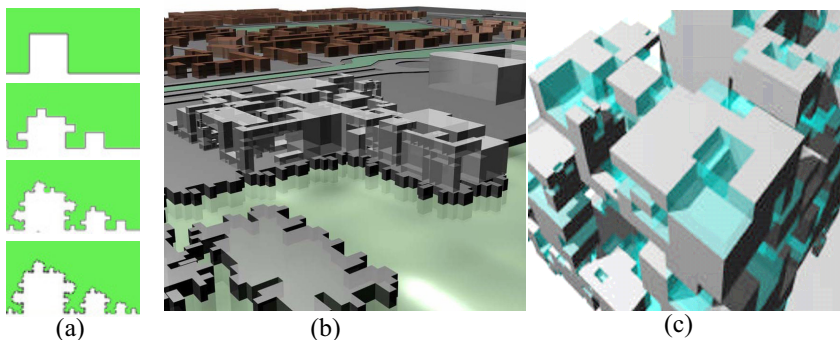


Figure 5: The use of fractal geometry to enhance permeability and accessibility, (b) and (c) from <http://uelceca.net/research/other/fractarch2004arielsmall.pdf> and http://www.generativeart.com/on/cic/ga2001_PDF/coates.pdf, ©CECA, reproduced with the kind permission of Paul Coates, the author).

3.4 Multi-centres evolution

In general, the fractal structures evolve according to ordered centres which ensure the hierarchical distribution of flows and allow the creation of several poles of life and animation. This configuration helps also to guide and direct any future extension or densification, in order to avoid anarchy and consequently to preserve the coherence and the integrity of the whole, Fig. 6.

This configuration around centers allows subdividing the space into distinct entities when necessary, preserving each one its own centre (animation, access, lighting, ventilation, view, greenery, services, etc), and thus, preserving the building's architectural quality, its ambiance and its integrity, Fig. 7.

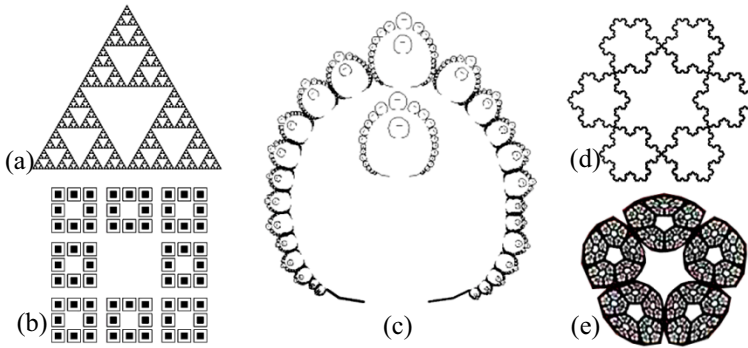


Figure 6: A multi-centres evolution for a coherent whole and ordered extension, (a) the Sierpinski triangle, (b) a Sierpinski carpet, (c) the Ba-Ila African settlement (from: Eglash, R., *African Fractals: Modern Computing and Indigenous Design*, Rutgers University Press: New Jersey, p.27, 1999, ©Ron Eglash, reproduced with his kind permission), (d) a Koch snowflake, (e) simulation of a natural fractal form.

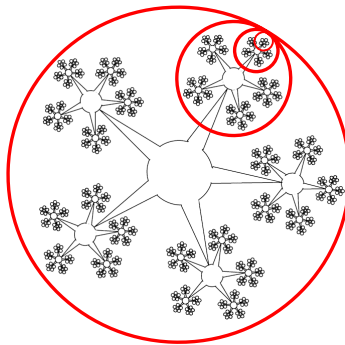


Figure 7: Multi-centres evolution: possibility of many subsets distinction.

3.5 Diverse, dynamic and complex modularity

Modularity is essential to architectural adaptability because it allows essentially saving time and money, but also it facilitates updating, upgrading and

maintaining the building, as well as introducing new technologies and suiting aesthetic tendencies. However, the identical repetition of a module with the same scale creates monotony and uniformity. Façades based on empty rectangular panels repeated without respect of the building hierarchical scales, i.e. housing schemes and 'HLM' of the 20th century, create a disconnection from the environment, and act negatively on human perception (Salingaros [11]). In the same way, an overloaded design and tightly spaced scales may scramble the façade coherence and destroy the scales hierarchy.

The fractal geometry constitutes a good alternative; it helps to create different configurations based on the same module by developing it on various scales, and to introduce a visual balance between the different systems of the façade from the largest scale to the smallest one. Consequently, the fractal geometry helps to create mixed, dynamic and personalized façades (Salingaros [11]).

In order to come up with a coherent façade, the hierarchical subdivision of the architectural scales must be clearly defined, and the small units should be coordinated with the large ones. Basing on empirical researches of Christopher Alexander (Salingaros [12]) proposes a specific ratio for the consecutive scales in the hierarchy, given approximately by the constant $e \approx 2.7$. This constant constitutes the base of natural logarithms and arises in the most successful and psychologically comfortable buildings.

4 Conclusion

Fractals have significantly influenced current scientific thinking. Architecture also benefits from the use of this tool in the way it helps architects and designers to express complexity. Within this context, the present paper sets out an attempt to implement fractal geometry in architectural adaptability and 'evolutionability' by looking to the building as a complex structure made up with different layers and multiple connected components. The study has shown that the fractal geometry contributes significantly to a positive and progressive transformation of the building, to the optimization of its spaces and their use, as well as to the increase of permeability and accessibility which lead to a better connexion with the immediate environment in addition to a better indoor quality and energy optimization. Furthermore, the fractal geometry allows to design the building according to hierarchically ordered centres which ensure a rational distribution of flows and a constant human and environmental ambience and services supply - even when the spaces around are reconfigured or restructured- preserving thus coherence and integrity of the building. Finally, using fractal patterns may help to avoid monotony and uniformity of façades by creating personalised and dynamic façades with a visual balance between its different components.

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