New 3D architecture and urbanism, a physicist's view

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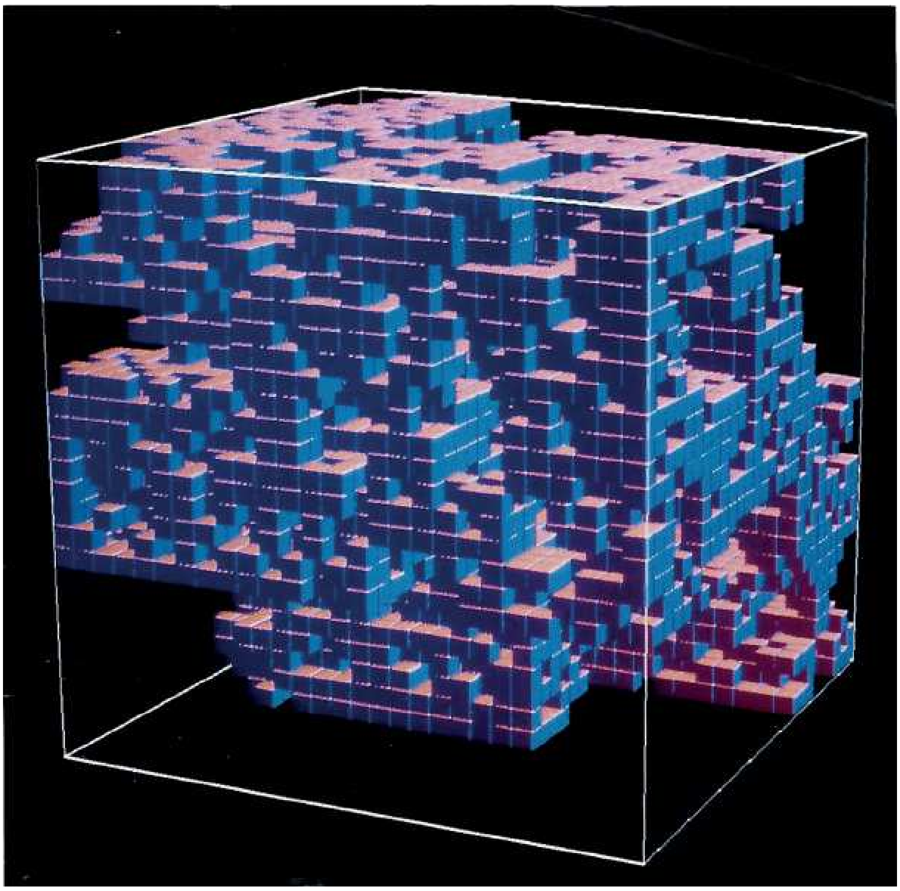
Architects and urbanists use a nearly infinite number of materials, techniques and shapes in quite interesting new buildings. This technical abundance increases part of art in everybody's life. Yet such powerful techniques enable us to ask for even more results, with extra goals like ecology, energy saving, free time saving and the design of a new life, a new art of living, the traditional goal of architecture[1] since Hellenistic era. And this new way of life must agree the coming new social organization.[2]



Wraclaw Sierpinski was a polish mathematician (1882-1969) involved on set theory who also created fractals. Here we consider Sierpinski cubes which are derived from an initial cube divided in 8 equal smaller cbes of which 6 are retained in a random way. In this Figure iteration steps are used. This is an example of such a tree or cloud which contains many voids of different sizes together with a level of connectivity.

For the reductionist view of a physicist, this optimization problem is easily solved. With a low technical level, people were obliged to deal with strictly flat 2D cities. Later a higher technical level enabled people to use "thick films" with the typical case of Haussmann's six-story building city. Soon after that, the possibility of making skyscrapers revealed that a full 3D city was already possible. And the actual overall look of the central part of cities, such as Singapore, New York, Paris la Défense or Dubai, appears as a part of a sphere, a spherical cap, even if connections between the different parts of such huge cities remain restricted to the basic level. As a conclusion, fully connected 3D buildings, with highest density and connectivity can be built. Such a solution would improve density and connectivity together with a reduction of transportation constraints. Such a link between urbanism and geometry results directly from cross-disciplinary events. For instance, in physics the controlled growth of 2D samples as well as of 3D samples has numerous applications such as semiconductor devices or magnetic devices in the general challenge of minimizing size, material and price. And sophisticated mathematical models of percolation which percolate themselves through classical disciplines has been developed. For example, the "diffusion-limited-aggregation model"[3] was achieved for understanding the tree-like shape of atomic clusters and enforced interest in fractals[4] and has been further connected with the Schelling's model of segregation within cities![5] The very concept of growth, a biological one, is common to aggregation of atoms and molecules as well as to aggregation of other units such as individuals or houses, even if interactions are different. This so-called concept of "self-organization" or spontaneous order works in many different disciplines. These cross-disciplinary concepts lead to realistic applications in techniques as well as in art. For instance, the concept of fractals has been used to improve the design of antennas[6] as well as to build new artistic objects.[7]

The development of cities enjoys a long history. The historian and linguist Dumezil proposed a social trilogy for Indo-European world based upon army, religion and economy.[8] Such a simple organization is helpful to derive the main features of cities. As a matter of fact, urbanism keeps numerous tracks of this social organization. Castles and their walls, which often became large avenues, are still present in cities as well as churches and markets or factories. Other urbanistic rules come from the technical means and from the art history. About churches and religious buildings, whatever the local religion, it was important to be seen from far away. This search for tall religious buildings has numerous examples, starting from pyramids, in Egypt as well as in Mexico, with spires in Christian churches, where the narrow shape seems reminiscent of pyramids, and with minarets in Muslim countries. A height of 100 meters and more has been reached since Antiquity.[9] Religious buildings were also renowned for their beauty, and art early appeared with these religious buildings. New architectural shapes such as pediments were early introduced for temples in Greece and the later architecture remained reminiscent of this classical style at the Renaissance.[10] Nowadays this search for height, original shape and outward appearance remains in civil architecture.

Modern skyscrapers result from this competition towards taller and taller buildings. The general elongated shape of these buildings is reminiscent from the spire shape. The new building shape satisfies different criteria such as diversity and aesthetics. For instance, there is a strong trend to make elongated complex rocket-like building with an obvious reference both to high technical level of aerospace and to classical churches. An example of this complex structure is the Art Deco Rockefeller center in New York (1930) with numerous copies in the whole world such as the Lomonosov State University in Moscow (1953) or the Palace of Culture and Science in Warszaw (1955). Other original skyscrapers are made of different parts or blocks at different levels. One example could be the Chrysler Building in New York (1931), with its wonderful top. Recent original building shapes used non-plane surfaces, as sails of the CNIT in La Defense (1958) where Zerhfuss and colleagues used reinforced concrete. Oscar Niemeyer also achieved such curious shapes with concrete in Le Havre as well as in Brasilia. Gehry realized numerous buildings with non-plane external surfaces such as Guggenheim museum in Bilbao (1997) where titanium, a light metal already used in aeronautics, was used with its curious aspect, or Louis Vuitton museum in Paris (2014), where a special software called "Catia" derived from software used for airplanes was used. Zaha Hadid used it in Dubai (2006), with fantastic new shapes. The aspect and nature of external surfaces was also varied. Gehry already quoted, used titanium and reinforced glass. Quite a lot of materials are used for surface since insulation is now left to basic materials.

So, Jean Nouvel used "moucharabiehs" a complex metallic mechanic aperture as a decorative unit in the Arab World Institute in Paris (1987), introducing Islamic art. More recently Nouvel put an Escher-like tiling on the Philharmonie in Paris (2015). Several architects played on avenue de France in Paris with colored reflecting metallic surfaces and their slight deformations in order to induce painting effects as Monet or Soulages before. This interplay between reflecting surfaces introduces the notion of light well as in a patio where light comes from the inside of a building. A first point to be noted about urban density is the notion of a unit cell, i.e. of a required living volume per inhabitant taking into account all activities, home, work, leisure. This idea was introduced by the philosopher Proudhon in 1870.[11] This averaged individual volume is the occupied volume of a city divided by the number of its inhabitants. For example, within a circular city of radius 3km and 20-meter-high buildings, the volume of this city is 0.6 billion cubic meters. These data correspond to a city like Paris where the number of inhabitants is 2 or 3 millions. As a result, the natural volume per inhabitant is about 300 cube meters. This result agrees quite well with other calculations.

For a flat city with a height of 2 meters with the same number of inhabitants this radius would be ten kilometers. In flat cities, the city radius grows as the square root of the number of inhabitants. This remark explains the extension of flat "megapoles" like Istanbul or Mexico City.

For a cubic city with the same number of inhabitants the edge is 840 meters. All points in the city are reached within a 10-minute walk. Transportation problems for persons, fluids or materials are easily solved. Buildings of such a height have already been done! Such a city can be realized!

A city of the same number of inhabitants with a less concentrated structure and a dimension 2.8[12] instead of 3 for a full 3D structure would be contained within a cube of 1350 meters edge. Such a self-similar structure admits voids of all sizes which can be used for many purposes like light wells, large meeting spaces, or even free space which could be used later in other ways for transformation. Thus, this city could be evolutive. A big city in the modern sense, i.e. a city of a few millions of inhabitants can be realized in a full 3D version or in a 2.8D version within a small space with new 3D connections.

A few approaches of 3D buildings already exist. The six-story Holmdel building made by Saarinen in 1962 for Bell labs was quite extended and was completely renovated recently. Saarinen was also the architect of the IBM Yorktown Heights Thomas Watson center in 1961. The massive shapes of these two buildings were used to develop links between searchers and between disciplines as initiated by Edison who created the Naval Research Laboratory (NRL) in 1923 in Washington D.C.… Johan Otto von Spreckelsen initiated the Great Arch in La Defense (1989). This arch, made within a cube of more than 100 meters edge, with a large void is devoted to offices.

The advantages of such 3D buildings in terms of circuitry: electricity, fluids as well as in terms of transportation are obvious since all distances are strongly reduced. Connecting people within the same volume is obviously easy and not restricted to a phone call or a mail. However, this high level of connection, of competition, can introduce a negative mental stress with effects such as Babel's tower or Teotihuacan's collapses. So, this level of connection must be controlled. A classic example of a controlled connection level occurs in a reactor where the critical mass could be reached and is avoided by introducing inert parts. Similarly, a fractal geometry in this 3D lattice will break the uniformity.

Another drawback as observed on Bell Holmdel building and its 44-year life is the need for evolution, the need for changing environment from time to time. A massive 3D urbanism gives no freedom and must be rejected. So, a necessary requirement in urbanism is the need for urbanistic evolution as well as for diversity and art in order to obtain a real way of life.

Different free spaces with different sizes are necessary. For instance, training rooms are required for all activities, by small groups as well as by larger groups, and very large rooms for performance are also necessary with a large number of admitted people. So, voids of all sizes are necessary for different activities. This is already the description of a self-similar fractal space[13] where voids of all sizes can be used either as a free space or for new activities. A direct advantage of such a construction with quite numerous and various voids which can be filled or not is the very large number of involved possibilities, a thing like a large "entropy".

The idea of living in a real 3D space has many consequences. For instance, the new acoustic challenge for concert halls consists in taking the shortest distance between actors or musicians and spectators. Now this is realized by means of sound wells, i.e. more or less cylindrical shapes. But the 3D answer is a spherical shape with actors at the center. In cities where skyscrapers are dense natural light is provided by means of reflective facades which define effective light wells. In the fractal 3D space, these reflections can be quite numerous and leave natural light captive as within a diamond. A climate or micro-climate effect is observed in dense cities and must be studied for future fractal cities. A traditional question in urbanism is the organization of activities where both necessity and freedom must interplay.[14] For instance, heavy activities must take place at the bottom of such cities. Quite similarly, common activities must be located near the center. A fractal city with real evolutive three-dimensional connections without being devoted to be an ant-house could solve many problems.

[1] There are many references to such a goal, from artists such as Paul Valéry in *Eupalinos ou l'architecte* (1923), or from architects with Athens charter (1935).

[2] See for instance J.-C. S. LEVY, « Human society evolution: a physicist's view », *LINKs* 2.

[3] Diffusion limited aggregation (DLA) is a concept based upon Brownian motion, i.e. the result of random walker meeting, with a direct biological meaning and numerous art applications. It was developed in the early eighties. It started with a famous paper from Witten and Sander.

[4] Fractal means a state of matter with more or less slow connectivity and scale invariance. This concept was proposed by B. B. Mandelbrot in the seventies and had many applications.

[5] The economist Thomas C. Schelling derived in his 1971's Dynamic Models of Segregation paper, a mathematical model in order to explain how ghettos appear in modern cities. T. C. SCHELLING, "Dynamic Models of Segregation", Journal of Mathematical Sociology 1, 1971, 143-186.

[6] Fractal antennas enable to deal with a quite extended frequency domain because of their multiscale property.

[7] Fractal art takes advantage of fractal algorithms to create new self-similar objects with a wink to recent technology.

[8] Georges Dumézil published *L'Idéologie des trois fonctions dans les épopées des peuples indo-européens* (1968).

[9] Kheops pyramid was built 4500 years ago. Its height was 146m.

[10] Andrea Palladio, a famous architect, published in 1570, *I Quattro Libri dell'Architectura* and this book was soon propagated everywhere with a strong influence up to now on neoclassical architecture as well as on "art deco".

[11] P. J. PROUDHON, *Contradictions économiques*, Paris, Rivière, 1939, 256.

[12] A fractal dimension can be non-integer as 2.8 and is defined from the common ratio of the logarithm of the number of cells over the logarithm of the size when this ratio does not depend on the selected size.

[13] Some famous people about fractals and disordered structures, as B. B Mandelbrot (IBM) and P. W. Anderson (Bell Labs), worked in these famous Saarinen's buildings!

[14] M. ARNOUX, "L'Europe de la 'Grande transformation'. Le développement paradoxal d'une société en crise", in P. BOUCHERON (dir.), *Histoire du monde au XVème siècle*, Paris, Fayard, 2009, 740-755.