SUSTAINABILITY THROUGH BIOMIMICRY
Discovering a world of solutions inspired by nature
Dammam University, College of Design
28Th - 30Th November 2011

PATTERNS IN NATURE, EMERGENT URBANISM AND THE IMPLICATE ORDER

ABSTRACT:
This research is about the scientific understanding of the concept of "life" in urban space and its main purpose is to explain the underlying order that is present in organic cities. It was found that this order is emergent (bottom-up), a product of a self-organization, a fractal geometry that characterizes the geometries of Nature which is substantially different from the visual order (top-down) we are used to look at our cities. The biological metaphor in city planning has been used since the sixteenth century. However, this analogy has been made mainly because of its shape and appearance rather than by the investigation of their geometric properties and laws of formation. Checking the parallel between the geometries of Nature and the geometries of the organic city, through the recognition of a set of patterns and emergent properties I conclude with this work that these forms and structures emerge for the same reason: the constraints of physical space and the laws of nature are the same everywhere. These fundamental laws which govern all live-systems phenomena show that in spite of apparently amorphous growth of urban sprawl, resilient patterns emerge. Once we know the principles we can use them to improve our plans and designs. We should trust to the self-organizing principles of cities rather than impose ideas of what they should look like.

Conference theme: Philosophies, theories and concepts of biomimicry/sustainainability
Keywords: Patterns in nature, Order, Life, Emergence, Self-organization, Construtal law

Introduction

This paper is about the scientific understanding of the concept of "life" in a spatial structure and its main purpose is to explain the underlying order that is present in organic cities. By other words, it is the “conviction that the organic development does not follow a number of disparate factors, only connected by adaptive requirements. There should be general laws, which articulate fewer and simpler factors”, (Prigogine and Stengers 1993, 119).
The investigation is based on the perception of reality that brings to light the close relationship between organic and inorganic matter. The organic is born of the inorganic .There is no living matter different from physical -chemical matter (Morin and Cassé 2007). What distinguishes life from non-life is the kind of organization, the relationships, the interconnections and the interdependencies. Studying these linkages is therefore to understand the geometry of life. And if life is a certain pattern of organization, we can learn about it in order to produce more sustainable cities in the future “because live creates conditions conductive to live” (Benyus 2007).
In the history of architecture and urbanism researchers have been particularly interested in regular plans produced by the human rationally rather than phenomena of irregularity present in organic cities. Perhaps such study requires the knowledge of more general properties which

are not present in Euclidean geometry. However, in the last few decades there has been a growing recognition that cities are complex and not entirely predictable systems. Within this new background the study of organic cities becomes a scientific approach rather than a metaphor used to describe the appearance of some cities. Despite cities are not entirely predictable entities, a limited set of patterns emerge as a product of self-organization. Like in other patterns in nature, design emerges without an intelligent designer.
The scope of this paper is not about the form of organic cities in abstract. I rather want to know, why the cities take the form they take, when they growth up spontaneously in space and time. Is there any implicate order in nature? Some set of natural laws that affect all forms of self-organization? What is life in a spatial structure? Is there any geometric quality – pattern, that we can enunciate, create? What is order? These are some of the questions I intend to discuss in this paper.
This paper starts in Section 1 with the explanation of the concept of order and how it influenced our traditional conceptions of space. In this context it is discussed how the concepts of life and self-organization can be applied in a scientific way to the study of cities. Section 2 discusses further the concept of cities as living systems in an ecological and physic perspectives. Section 3 will discuss why nature has preference for some patterns like spirals, meanders, explosions or branch structures and how design emerges in nature based on fundamental laws of physic with special emphasis to construtal law. Section 4 present the case study of the city of Lisbon which enable us to observe the universal patterns product by self-organization of flows in space and time. The paper ends with some conclusion and topics for further discussion.

1. What is Order?

When comparing two different forms of organization: imposed and emergent as it is represented in Fig. 1, the following question arises - What is the order? Despite the question is so vast and immense in its implications, we all know what order is and there is no need for a precise verbal definition (Bohm 1990, 115).
Order is a subjective definition, because it is a selection of a series of appearances at the expense of others, as they give more meaning to the reality behind appearances. And any selection itself implies and requires an interpretation of each observer, (Doxiadis 1968, 32).
In urbanism, the concept of order has been restricted for cities of pure and rational geometry. However this is only a very limited kind of order which is associated with predictability and the regular arrangement of objects like those we can see on the top of Fig.1: The image shows order imposed by a spectacle where people and chairs are organized according to a model, repetition of parts positioned within the same intervals – the whole is then the sum of the parts and the spaces between them. This is a visual, mental, simple order, imposed by top-down. It is explicit and folded.
But we can consider, instead, a much more general order, more complex and subtle, which in essence is not related to predictability, like the (self) organization that underlines all living systems and societies represented by the image at the bottom of Fig. 1. The image shows a new order created by people when they leave the spectacle – the whole is then more than the sum of its parts because relationships matter. This is a hidden and complex order, emergent from bottom -up. It is implicit and unfolded.
We then can contrast the implicate order, appropriated for the study of the indivisible wholes, like living organisms and the organic cities, with the explicate or mechanistic order, like a machine or the city of pure geometry, which consist of independent parts, modeled on a regular

basis in different regions of space (Bohm 1990, 172-173). In the organic city, each part grows up in the context of the whole, so that it does not exist independently in different regions of space, nor one can say that it merely interacts with the other parts without affecting itself in this relationship, through a feedback loop.

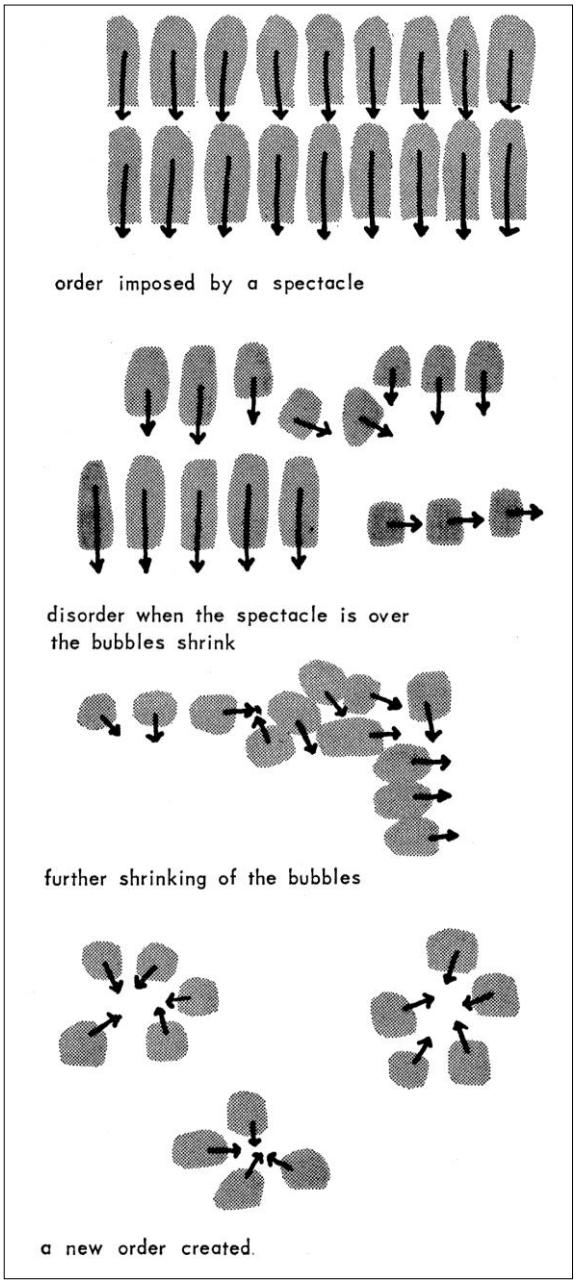

Fig.1 Two different kinds of order, planned or imposed by a mental process and emergent or self-organized. The image shows at the top the order imposed by a spectacle where people and chairs are organized according to a repetition of a model (parts) with the same intervals – the whole is the some of its parts- top-down, explicate and folded order. At the bottom of the image we see a new order created by the relation between people – the whole is more than the sum of its parts – bottom-up, implicate and unfolding order (Source: Doxiadis 1968, 303)

In general, the formulation of urban models, have referred almost exclusively to explicate and mechanistic order. In fact the original function of Euclidean geometry was precisely to provide a clear description of the explicate order. Before the advent of chaos and complexity theories,

the study of irregularity was highly unlikely. The disorder and the irregular phenomena were without any scientific interest. New scientific approaches propose to give primary importance to the implicate order rather than the explicate order. As the whole is more than the sum of its parts it becomes more important to realize the set as a whole than the parts separately. By other words we are shifting our attention from objects to relationships in order to understand why "the whole is more than the sum of its parts" (Aristotle). As a consequence of these new way of thinking, the study or organic urbanism (as a whole), self-organization and life in a spatial structure (as relationships), became a scientific approach.
From the discussion of this new kind of order a new question arises: How design emerges without a designer? It is the propose of this paper to answer that question in section 3 after a discussion of the concept of cities as a living systems.

2. The City as Living System

As stated by Jonah Lehrer in his article "A Physicist Solves the City" we usually describe cities, after all, as local entities defined by geography and history, (2010). Studying cities as living organisms is still for many a biological metaphor. This analogy in city planning has been used since the 16th Century mainly because of the appearance and shape of cities rather than by the investigation of fundamental laws of formation which governs all live-system phenomena. The new concept of life exceeds the biology field and is broking down the traditional separation between disciplines as well as the traditional separation between organic and inorganic matter.
So, what is life? The "constructal law" as defined by Adrian Bejan defines life in physic terms, and it covers all live-system phenomena (Bejan 2012, 7). According to the constructal law "Life is movement and the constant morphing of the design of this movement. To be alive is to keep on flowing and morphing. When a system stops flowing and morphing, it is dead. Thus, rivers basins [like cities] configure and reconfigure themselves to persist in time. Motion is the cause of every life. When they stop flowing and morphing they become dry riverbeds, that is, the fossilized remains of earlier 'live' flow systems." (Bejan 2012, 6).
The ecological perspective identifies other forms of life called super-organisms or ecossitems: "a community of organisms and their physical environment interacting as an ecological unit" (Capra 1997, 33). The maximum expression of that assumption is the Gaia Hypothesis of James Lovelock which spread the idea of the planet earth as a living organism. The idea of life according to biological perspective is related with individual organisms. The ecological perspective as extended it to communities of organisms and to ecosystems.
Cities are therefore super organisms or bodies of a higher order. According to Julian Huxley, human societies, like other colonies of animals are biological individuals of third order, being the first and second order, cells and bodies, respectively. However and as pointed out by Doxiadis, the biological individuals complete this third order, are not simply human societies, but the settlements - cities. If we deprive society of its physical structure, it cannot develop or even survive, (Doxiadis 1968, 42). However, these settlements seen as biological individuals are very recent when compared with the first body created by nature 3.5 billion years ago. There is the perspective that life has various stages. It is necessary to remember that human culture and its artifacts are young and immature when compared with nature. Biological life itself has evolved from inanimate matter (prebiotic evolution). In other words, life is an emergent property of the matter, the most fantastic and emergent property of matter.
The new systemic and ecological understanding of life includes the perception of communities of individuals in symbiosis with its environment - the ecosystem. This systemic understanding

is based on the assumption that life is endowed with a fundamental unity and that the various living systems exhibit similar patterns of organization: The network pattern is a specific geometric feature common to all living systems whether they are composed of organic or inorganic matter.
The application of systemic understanding of life in the field of urban studies is related with the application of our knowledge of standards and principles (emergent properties) of life organization - and in particular the understanding of the organization of living networks - to the city (social reality). However while understanding the organization of biological networks can help us understand the city, does not mean to transfer to the city, our material understanding of biological networks.
Life is structural. Networks, connections, interconnections, are the basic pattern of organization of living organisms and this is also a discernable quality in space. However, the city is more complex than the natural organisms - It is inhabited by sentient beings who created it. Plants do not decide their destination, but the cities, as human settlements, can make decisions about their future, controlling their movements, their transformations and their expansions, both in space and time. Still, the cities do not escape to the same laws as all other living organisms, once their organization have strong similarities with the geometry of nature, especially the organic cities. The big difference between human settlements and natural organisms is that the settlements are the product of forces, natural and conscious and their evolution can be guided while natural organisms are simply the result of natural forces and their evolution cannot be guided except within very strict limits (Doxiadis 1968, 42).
Only after considering these forms and stages of life, we can understand organic cities, taking into account its specific organization as a higher order and also much more recent than the animals or plants, and therefore in a primitive phase of its development. It is therefore on this basis, that we can draw some comparisons in terms of physical structure, properties and geometric patterns between organisms in general and the city.

3. Form and Context

"Nothing is experienced by itself, but always in relation to its surroundings…" (Lynch 1999, 11).The properties of the urban form are not intrinsic properties. In other words, they can only be understood in the context of a larger whole. This way of thinking is contextual, systemic and ecological, because explaining things in terms of its context is to explain things in terms of its environment (Capra 1997, 37).
The context is the field of attraction that leads to a structure of operation (pattern) which in turn influences the content (form). Invisible energy fields operates to manufacture urban form, such as gravity, sun, wind or topography. This is just to refer physical forces, because there are also social and psychological forces which are even harder to visualize. Without understanding these forces, it becomes very difficult to interpret correctly the urban form. Thus the understanding how forms emerge in its surroundings it is a problem of design.
I believe that much of our urban problems and space are essentially a problem of perception of the context. This happens because people are not awakened to the hidden fields in action in the city and in our own lives. The cause of this difficulty is mainly due to our fragmented vision of the world. If we think the reality in a holistic manner, we would see as the separation of things is an illusion and that indeed all things are part of the same inseparable continuum – this is the idea of the holographic universe appointed by David Bohm (Bohm 1980, 143-147).
The context is a template of the form. While the form is that part of the world upon which we have control, the context is that part of the world that imposes restrictions on this form. Anything that restricts the form is context. The good form is that one which results of mutual

acceptance between these two worlds, i.e. the result of how the form fits into the whole. (Alexander 1964, 17).
In organic cities as well in all living organisms, the solution to the problem is defined by the context. Thus when we talk about this type of urbanism, the discussion is not about the form itself, but on the assembly comprising the form and context.
Thus, to understand the patterns of nature, the Cartesian idea that the shape is independent of its context, i.e., that reality can be broken down and understood by the parties shall be replaced by the holistic idea that the shape is molded by the context, i.e. the idea that everything is connected to everything else, by a set of forces and relations that are apparently responsible for the way things happen.
Like living organisms, organic cities, develop strong relationships of interdependence with the natural environment. From this interdependence of relationships a self-organized and homeostatic qualities emerges. These qualities are responses to the natural environment and they are not the result of a deliberate scientific reasoning. They were born of countless experiences of generations of builders who continued to use what worked and discard what does not work. This produced a phenomenon of a feedback loop that is common to all living beings and that can undo the excesses that constantly tend to form a system and lead it to a state of dynamic equilibrium and order.
In response to natural contexts, the urban morphology takes the form of the Genius of the Place such as plants or animals in the desert, wetlands or in cold areas. With time these features became the symbols of the cultures and civilizations which some researchers insist to separate from its physical context. So the organic urbanism is not just a product of self-organization but a form of self-eco-organization, according to the idea that the form of organization depends on the relationships that the organism has with the ecosystem (Morin et. al. 2009, 45).

4. Patterns in nature

"If we lived on a planet where nothing changed, we would have little to do. There would be nothing to understand. There would be no need for science. And if we live in an unpredictable world, where things change at random or very complex, we would not be able to clarify them. And, once again there was no science. But we live in a universe where things change indeed, but according to patterns, rules, or as one call it, the laws of nature. (...) And so it is possible to understand things. We develop science and with it improve our lives "(Sagan 1984, 60).
It turns out that these rules investigated by Peter Stevens, are peculiarly restricted: The vast variety created by Nature emerges from the organization and reorganization of just a few basic formal principles. This limitation brings harmony and beauty to the natural world (Stevens 1974, 3). Thus, among the preferred forms for Nature, which appear in many different contexts, we have the spirals, meanders, explosions and ramifications. The reasons why this happens are due to the limitations of dimensional space, the required relationship between the size and shape of things, the tendency for the simplicity and balance, as well as the prevalence of the law of least work.
Examining the properties of almost regular geometric patterns we will be able to better understand the preferences of nature for certain patterns. We can also understand why certain things look so much like others in a completely different context or scale. For example the shape of our galaxy or the shell of a snail. Why are such a things so similar? Why they present the same pattern, a logarithmic spiral?
As pointed out by Peter Stevens we can accept the principle that the existing patterns in nature tend to the configuration that requires less energy, the most well adapted to the context and that

consequently most likely to exist – having in account all the other possibilities (Stevens 1974, 37). Each geometry has its relative advantages: Fig. 2 shows how an equidistant chain of points disposed in a regular manner can be connected to the midpoint in a more or less directly way. This exercise assumes the existence of a property in Nature which is the growth from a center that radiates to achieve each of the peripheral points of the pattern. Spirals, for example are a very uniform pattern. The line which draws its structure perfectly fills the space with great economy of material (line lengh). However, the average distance between each point and the center is great. The meander is more chaotic and less uniform but like the spiral it covers the space with great economy of material. Nevertheless the relation of each point with the central point is very indirect. Explosion pattern is uniform, since it keeps constant angles between the beams. However unlike the spiral and meander this pattern cannot fill the space very well - is much denser near the center. Moreover, the sum of their radii constituents is very high – so it needs more material, long length line. However their connections to the central point are very direct. This is the reason why many cities exhibit this pattern of growth as we can see next section for Lisbon city.

Thus, we can conclude that the explosion needs more material (line length), but is more direct to the center than the former patterns. We can also conclude that, explosions and spirals represent two extreme standards. The spiral needs less material (line length) but is very indirect to the center so there is not a suitable form for a tree that needs to transport nutrients from the central stem to the leaves and the fruit through a longer path. Instead, the explosion pattern is far a more direct route between the center and the outer points. However a tree cannot sustain each of its leaves through a separate branch. That is why the ramification, a standard variation of the explosion pattern is more suitable for this objects in nature.

The ramifications are a form of compromise between the single spiral path and multipath explosion. With great variety they fill well the space allowing economy of material (line length). This is therefore a more standard optimized, the most economical, combining the best of both worlds: less distance and greater direction.

The example showed on Fig. 2 (bottom right) is a special form of ramification. Besides being a uniform pattern with good access to the center, it has an overall length smaller than any standard displayed. It is characterized by branches joining within angles of 120 º forming hexagonal structures. Although there is no more efficient pattern than another, different geometries have different advantages and therefore emerge in different contexts.When considering the city as a self-organized entity, it is natural that these patterns also occur because they bring certain benefits and efficiencies, in relation to the form and size of each system.

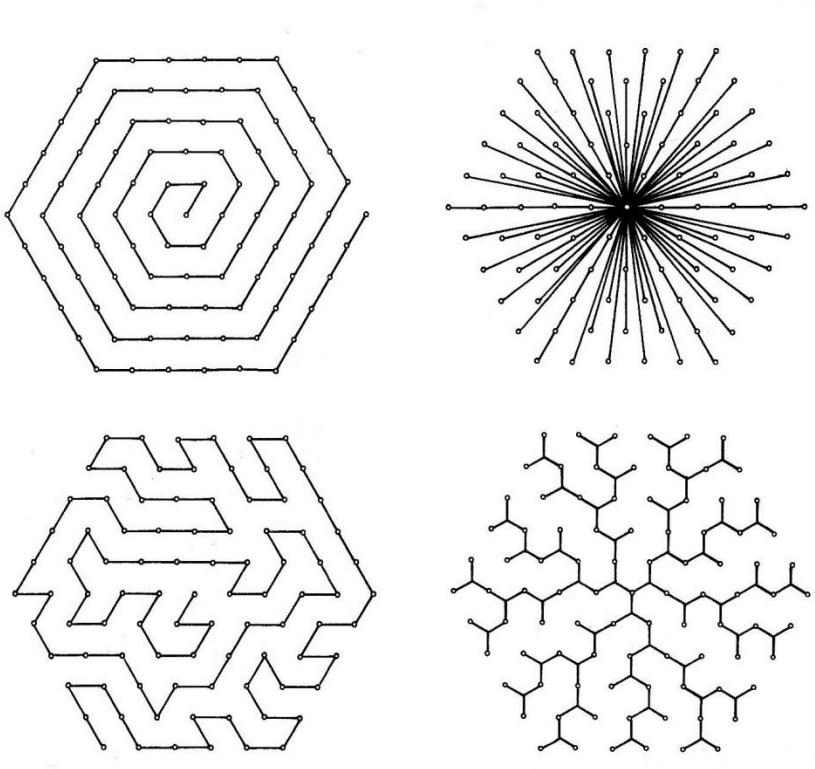

Fig.2 Some basic patterns of nature, spirals, meanders, explosions and ramifications.
(Source: Stevens, 1974, 39,41).

How design emerges without a designer? How the laws of physics shapes design of all around us? "According to the ancient philosopher Heraclitus, the sole actuality of nature resides in change. All things are becoming. All things are flowing" (Stevens 1974, 53). So, if we want "to know how things look the way they do, first recognize what flows through them and then think of what shape and structure should emerge to facilitate that flow. The configuration of a flow system is not a peripheral feature. It is the defining characteristic", (Bejan 2012, 9).
According to Adrian Bejan, all designs in nature arise and evolve according to the constructal law: "For a finite-size flow system to persist in time (to live), its configuration must evolve in such a way that provides easier access to the currents that flow through it", (Bejan 2012, 3).
The patterns mentioned above are not formed by random accidents or chance. They arise naturally in time in order to enhance better and better access to flow.
Constructal law considers that everything that moves is a flow system, weather material or organic. All flow systems generate shape and structure in time in order to facilitate this movement, (Bejan 2012, 3).
Constructal law is the law of design in nature. Its formulation is based on the idea that freedom is good for design. What emerge are very efficient and resilient patterns of flow which persist in time and space across all things of the universe which unites the inanimate with the animate. Fig. 3 shows how self-organization explains some ubiquitous patterns in nature. Explosions emerge in branches of trees as in street networks breaking down the traditional separation between organic and inorganic matter as well as extended further the concept of life outside biology. Self-similarity and flow are the fundamental aspects of those patterns.

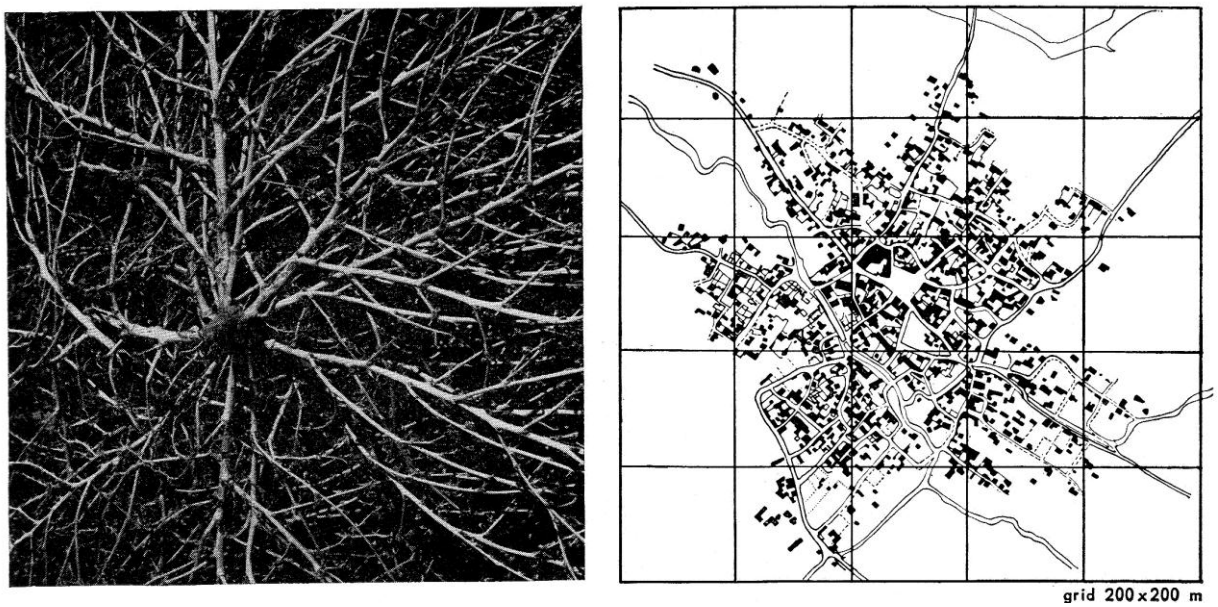

Fig.3 All things flow. An example of how design in nature unites the animate with the inanimate. The left side shows the branches of a plant. The right side shows a city plan. Both designs follow the same physical law - the constructal law which explains some ubiquitous patterns in nature. Self-similarity and flow are the fundamental aspects of those patterns. (Source: Doxiadis 1968, 141,142).

5. Emergent Urbanism and the implicate order: Lisbon case study

I have studied organic settlements for many years where I found these patterns within a range of scales. The big surprise is to see that the reasons why it happens are the same: The city grows in a pattern explosion, because this is the most direct way to the center, or it just branches out to have a more uniform distribution of flows in space. A winding road increases the surface contact with the outside. The hexagonal structures are the most typical way of packing or cracking and it reflects the structure of centers and sub-centers of the city as it get denser in space.

By way of explanation, Fig. 4 show how explosions emerge in the city of Lisbon from the self-organization of flows (pedestrians movement) according to constructal law. The image on the right side as present originally by Peter Stevens (1974), shows a series of splashes of drops of ink released from different heights: three inches, six inches, twelve inches and twenty-four inches - each height being double the preceding one. But the splashes not doubled in size, they rather change their form to better accommodate the flow of the system. Instead, the diameters increase more slowly and splashes generate regular spikes, first as slight undulations in the perimeter, then with small bumps and knobs and finally developed spines. Dropping the ink from a still greater height does not increase the length of the spikes (bottom splash). Instead new and small splashes appear in the surroundings with a similar shape. Form and size continue to change and the pattern evolves in a sequence of ever improving design to facilitate the flow.

If one compares this process to the process of Lisbon growth, we can find the same patterns and laws: Until the middle ages the city was shaped by its walls in a circular shape. After that and as the topography is not uniform, the expansion starts first along the lines of more favorable conditions for pedestrian flow. Early 20th Century the typical star-like shape can be seen at the map on the left of Fig.4. After that the dynamic growth of the city led once again towards a circular shape with radials and circulars improved by the 20th Century city plans. By

the end of this century the city presents a shape similar to the last splash of the Fig. 4 (right side) showing self-similarities across a range of scales.
Interestingly this is the same pattern founded by Bill Hillier, the father of Space Syntax theory, who for over 20 years has searched for emergent laws of the city. He calls it "deformed wheel": A center linked by radial spokes to a surrounding grid of residential areas. This pattern, which can be discerned from many cities across the world, repeats at different scales - in local districts as well as in metropolitan area. It represents the understanding how different arrangements of buildings shape patterns of movement and social function.
Fig. 5 represents the axial map of Lisbon according to the theory of Space Syntax. It shows local integration of streets and nodes which represents the potential for movement and co-presence of each place (axial line). Dark lines are the most integrated which means the possibility to have bigger flows of people and goods. The smaller the network components (white lines), the less integrated and more numerous they have to be to improve the system flow. In this way the distribution is more uniform in space with good access to the center. Street networks also show geometric self-similarities over a range of scales. The constructal law, the physical law of design and evolution is present. The pattern evolves in a sequence of ever improving design to facilitate the flow.

Fig.4 Lisbon explosion pattern of growth according to Constructal Law. The left side shows a map of the city from early 20th Century where spikes of growth represents the most efficient distribution of the flows through the space do it the size of the system of the time. The map also shows self-similarities over a range of scales. On the right side, splashes of drops of ink released from different heights. The constructal law, the physical law of design and evolution is present. The pattern evolves in a sequence of ever improving design to facilitate the flow, (Source: Levantamento de Silva Pinto 1904-1911 - CML).

Fig.5 Interpretation of Lisbon axial map (2012) showing local integration of streets and nodes. Dark lines are more integrated which means the possibility to have a bigger flow. The smaller the network components (white lines), the less integrated and more numerous they have to be to improve the system flow. Street networks also show geometric self-similarities over a range of scales. (Source: Teresa Heitor & João Pinelo)

6. Conclusions and discussion

The biological metaphor in city planning has been used since the sixteenth century. However, this analogy has been made mainly because of its shape and appearance rather than by the investigation of their geometric properties and laws of formation. Checking the parallel between the geometries of Nature and the geometries of the organic city, through the recognition of a set of patterns and emergent properties I conclude with this work that these patterns and these structures emerge for the same reason: the constraints of physical space and the laws of nature are the same everywhere.

There has been a growing awareness of the importance of network and system thinking in order to improve sustainable planning and urban design. This fact is associated with the growing recognition that cities are complex and not entirely predictable systems. This has a major impact in planning theory, as well as the actual top-down structure of planning law, practice and administration, all based on the assumption that cities are essentially predictable entities (Portugali 2008). With this work I have tried to show how cities as self-organized systems produce a kind of order, which is emergent and bottom-up, following the deterministic laws of nature. Constructal law, as a fundamental law of physics which governs all live-systems phenomena shows that in spite of apparently amorphous growth of urban sprawl,

resilient patterns emerge. In face of this, urban development and regeneration requires new creative responses based on complexity theories and bottom-up approaches. The design of cities should start within an entirely new field, emerging in response to the major changes in society. Design with fundamental laws and patterns of nature changes the terms of the intelligent design debate because this principles describes how shape and structure emerge without a designer. Once we know the principles we can use them to improve our plans and designs. Like Philip Ball quoting Bill Hillier and Jane Jacobs says: If we are going to design cities, we need first to observe them scientifically to deduce their fundamental rules. Instead of design cities we should grow them. We should trust to the self-organising principles of cities rather than impose ideas of what they should look like, (Ball 2004).

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