The Fractal Urban Coherence in Biourbanism
The Factual Elements of Urban Fabric

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Abstract: During the last few decades, modern urban fabric lost some very important elements, only because urban design and planning turned out to be stylistic aerial views or new landscapes of iconic technological landmarks. Biourbanism attempts to re-establish lost values and balance, not only in urban fabric, but also in reinforcing human-oriented design principles in either micro or macro scale. Biourbanism operates as a catalyst of theories and practices in both architecture and urban design to guarantee high standards in services, which are currently fundamental to the survival of communities worldwide. Human life in cities emerges during connectivity via geometrical continuity of grids and fractals, via path connectivity among highly active nodes, via exchange/movement of people and, finally via exchange of information (networks). In most human activities taking place in central areas of cities, people often feel excluded from design processes in the built environment. This paper aims at exploring the reasons for which, fractal cities, which have being conceived as symmetries and patterns, can have scientifically proven and beneficial impact on human fitness of body and mind; research has found that, brain traumas caused by visual agnosia become evident when patterns disappear from either 2D or 3D emergences in architectural and urban design.

Keywords: Biourbanism, Thermodynamic Architectural Models, Complexity and Patterns, Architectural Life and Harmony

Introduction - Biourbanism versus pure Fractal Urbanism

By observing satellite images of the surface of our planet or by reading modern geographical representations of it, almost immediately we become aware that, above all, some important features of urban fabric have been lost for good. Modern urban design and planning turned out to be not only stylistic aerial views, but, also, as some author puts it, urban form nowadays expands in a way similar to *"malignant neoplasms"* (Hern, 2008, p1) . Although rapid expansion of modern large settlements has developed over the past two centuries, this becomes particularly evident mainly during the last couple of decades, when we examine the randomness of that expansion on the surface of our planet (Hern, 2008). Satellite pictures reveal frightening images of urban sprawl, which can easily be assimilated to enlarged imagery of terminal illness viruses. Thus, modern cartography and mapping can easily turn into three-dimensional mapping or modelling, focusing not only to good cases, but also to mainly random and uncontrollable developments of urban spaces.

In his article "Urban Malignancy: Similarity in the Fractal Dimensions of Urban Morphology and Malignant Neoplasms" in the *International Journal of Anthropology* (Hern, 2008), Dr. Hern argues that, even a physician trained in basic pathology would be able to recognise resemblances to malignant lesions in noticeable patterns of growth of urban settlements. The morphology of the cities, such as London, Chicago, New York city and others are offering images of mapping, which are comparable to those of malignant neoplasms in organisms. The most alarming sign though is given by several classical characteristics of both neoplasms and urban patterns today. According to the author mentioned above:

> "Malignant neoplasms in organisms have several characteristics: a) rapid, uncontrolled growth; b) invasion and destruction of adjacent normal tissues; c) metastasis (distant colonisation); and de-differentiation (loss of characteristic cell and tissue appearance unique to each kind of tissue)." (Hern, 2008, p4)

As a matter of fact, in the article abovementioned, the author affirms that, not all fractal structures could be malignant. Unfortunately our modern cities are growing as malignant organisms, because they show largely de-differentiation; most of them present similar outlines and no tribal settlements or medieval walled cities' characteristic patterns, which reflect the local culture. Even if we consider the comparison of the growth of cities and cancer as a metaphor or possibly exaggerated, Dr. Hern (2008, p12) affirms that, a city *"has all the characteristics of a cancer on the landscape",* because cities have become:

> "… complex (non-linear) [thus fractal entities], dynamic (growing), topophagic (space-devouring" heterotrophic process that displays rapid, uncontrolled fractal growth, distant colonisation, invasion and destruction of adjacent natural ecosystems, and de-differentiation".
> (Hern, 2008, p12)

Several authors, like Batty and Xie (1999, p109) affirm that, after the emergence of industrialisation, new theories on urban expansion emerged; they also insist that, during the first quarter of the 21st century, we may see an increase in population up to sixty percent of the population (considering it from the end of the 20th century onwards). These authors also affirm that, at that time, urbanisation is going to reach some kind of *"self-organised criticality"* (Mesev et al., 1999, p111), because an addition on new activities in cities, such as births and immigration, will trigger changes of *"the pattern of development through processes of redistribution"* (Mesev et al., 1999, p111). The same authors assert that, *"self-organized criticality is a theory built around interaction effects"* (Mesev et al., 1999, p112) and, thus, new activities occurring can initiate reactions which follow power laws. New activities, as critical, respond to thermodynamics in order to re-establish equilibrium. For example, sudden high urban density (critical condition) by high rise of population due to large numbers of immigration can be only regulated by urban fractal growth (Mesev et al., 1999, p114). These authors in synchrony with few others (Mesev et al., 1995) also prove that, we can measure urban morphology by means of fractal geometry, *"a geometry of the irregular"* (Mesev et al., 1995, p727). By using fractal theory and development of remotely sensed data of urban form, these scholars started measuring and mapping not only urban form, but also socio-economical growth all over our planet. Finally some more authors (Ryan et al., 2010) believe that, not only patterns of cancer invasion and clonal expansion are similar to modern urban growth, but also the cancer wasting syndrome of cachexia, causing death, is an analogous phenomenon with urban decay/ blight effects to urbanism. Fractal patterns of urban blight are thought to be similar to fractal patterns of human cancer behaviours. Thus, *"Predictions from a Systems Biology-Based Comparison"* (Ryan et al., 2010, p11) on cancer can be the same as those occurring through the loss of structural integrity and change of human behaviours in urban decay areas within cities.

However, new urban theories and practices, such as Biourbanism, attempt to find a way in which, not only early diagnosis can take place in malignant fractal growth of the cities, but also new methods of care and restoration to health may succeed to establish wellbeing in both cities and surrounding setting. Biourbanism attempts to reinstate lost values and balance, not only in urban structure, but also in reinforcing human-oriented design principles in both macro and micro scale. Biourbanism as a discipline (and also as a School and intellectual movement) operates as a vehicle of theories and practices in both architecture and urban design to guarantee high standards in services, which are currently fundamental to the survival of most communities worldwide. By considering as top items in its agenda the humankind well-being and the dynamics of the urban organism, the discipline of Biourbanism approaches sciences and ecosystems in a particular way and with intend to appreciate "*'optimal forms' defined at different scales (from the purely physiological up to ecological levels) which, through morphogenetic processes, guarantee an optimum of systemic efficiency and quality of life of the inhabitants"* (www.biourbanism.org/research, last accessed on 20/07/2013) of the built environment. In fact, amongst the main aims of Biourbanism, we can see *"the identification and actualization of environmental enhancement according to the natural needs of human beings and the ecosystem in which they live"* (www.biourbanism.org/research, last accessed on 20/07/2013) and *"deepening the organic interaction between cultural and physical factors in urban reality"*, such as *"the geometry of social action, fluxes and networks study"* (www.biourbanism.org/research, last accessed on 20/07/2013). Therefore, it is evident that, this talented discipline studies and manages complex systems of geometrical fractal patterns. Therefore, it emerges during diverse human interactions with nature and the built environment. Healthy interactions may be able to offer the final cure to avoid death of the urban space, because:

> "Biourbanism is based on the following groundwork: (i) Epistemic foundation and the needed scientific paradigm shift; (ii) New Life sciences, as biological roots of architecture and urbanism; (iii) Peer to Peer Urbanism, as an innovative way of conceiving, constructing and repairing the city; (iv) Morphogenetic Design Processes, based on real recognition of 'optimal forms', defined at different feedback scales (from physiological to ecological) which, through morphogenetic processes, guarantee an optima systemic efficiency, and therefore of the quality of life."
> (Caperna, 2011 at www.journalofbiourbanism.org/2012/caperna, last accessed on 20/07/2013)

Urban space is often related to information theory, as its use is in agreement with information context, which initiates from surfaces rising from the ground; this information can be perceived as logic signal and also be accepted by human beings, navigating through it, by means of pedestrian and often preferential pathlines (urban navigation indicators). Successful spaces should offer perceptible hints from local structural emergences; standing and seating signals, for example, may determine the most advantageous pedestrian paths and nodal points associated with them. Hence, human life in cities emerges during connectivity via geometrical continuity of grids and fractals, via path connectivity among highly active nodes, via exchange/movement of people and, finally via exchange of information (networks). Back in the 1970s, when the author of this paper had the opportunity to attend some special workshops in urban design in the University of Florence, Italy, she discovered some important findings about diagnostics on urban nuclei and connectivity nodal points. Christopher Alexander was invited by the Institutes of Urbanism of Rome and Florence to deliver specific brief workshops based upon his then recent project for the University Campus in Oregon (1975); many scholars had attended and took part in discussions related in particular to his ideas of adoption of 250 flexible patterns (*A Pattern Language*), which were envisaged in a way to be capable to satisfy the needs of any urban area thought as neighbourhood (Alexander et al. 1977). In fact, Christopher Alexander's theories had such an impact, that his *The Oregon Experiment* was translated in Italian (Coppola Pignatelli et al. 1977) and also a special preface was written by Paola Coppola Pignatelli from the *Gruppo di Ricerche sull'Edilizia per l'Istruzione Superiore – GREIS* (=Higher Education Research Group of Construction). For the first time, community participation in the developing cities was introduced in Italy by Alexander in a more radical way, where before, urban studies and masterplans used to pursue long bureaucratic procedures based upon mainly specialist knowledge.

With his pattern language, Christopher Alexander (Coppola Pignatelli et al. 1977) offers a diagnostic method of investigation on growth of urban fabric, which is defined by active pathlines and human activities along them. At the same time human behaviours and movement may define areas of 'dead' urban fabric and new opportunities may arise in them to be used again according to public demand by local communities with some help from experts. Pathlines of human energetic flow do form crosses and powerful nodal areas, which make fractal connections easier and systematic rather than random, as we can see in Figures 1. & 2. New activities usually create more pressure at peripheral nodal points, which are able to unfold to a new fractal border expansion of new paths capable to generate more buildings and spaces available for further public utilisation. With his fourth principle of the pattern language, Alexander affirms that, any project and any new build will be imprinted by a common set of urban design codes, which are defined as patterns and have been adopted by a community (Coppola Pignatelli et al. 1977, p16). With his sixth principle, he also insists that, the efficiency of new interventions will be safeguarded eventually by an annual diagnosis that will show in detail which areas are still alive and which ones are inert ('dead'), no matter what the moment of life is inside a certain community.

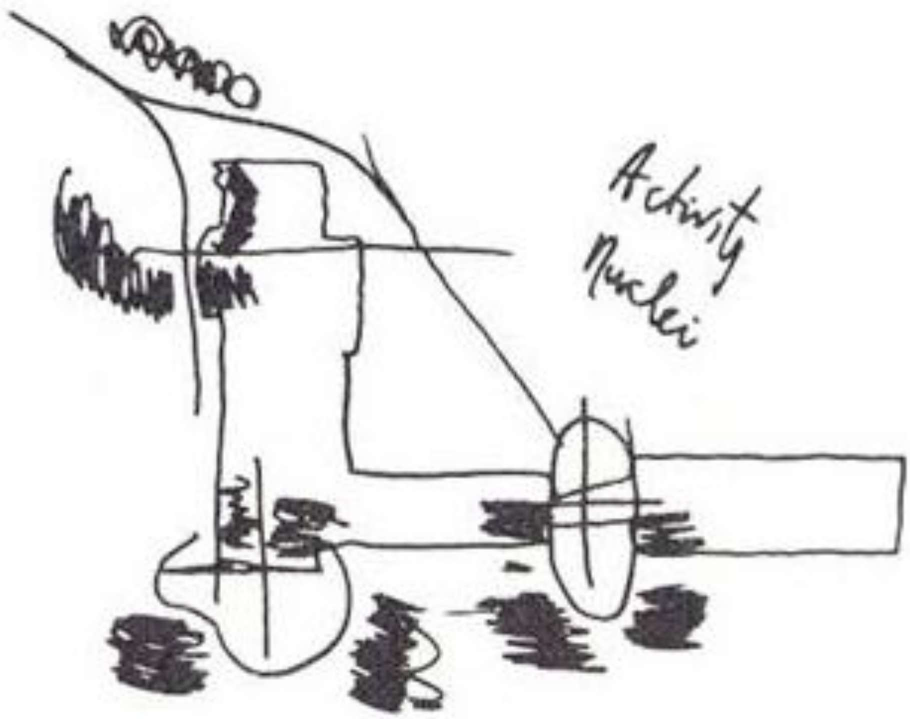

Figure 1. Alexander's diagnosis on urban fabric at stages and on different days (Monday sketch); new build is made of bubble areas connected by active paths, hence, activating the nuclei/buildings - Oregon University Campus Democratic Project (Coppola Pignatelli et al., 1977, p49).

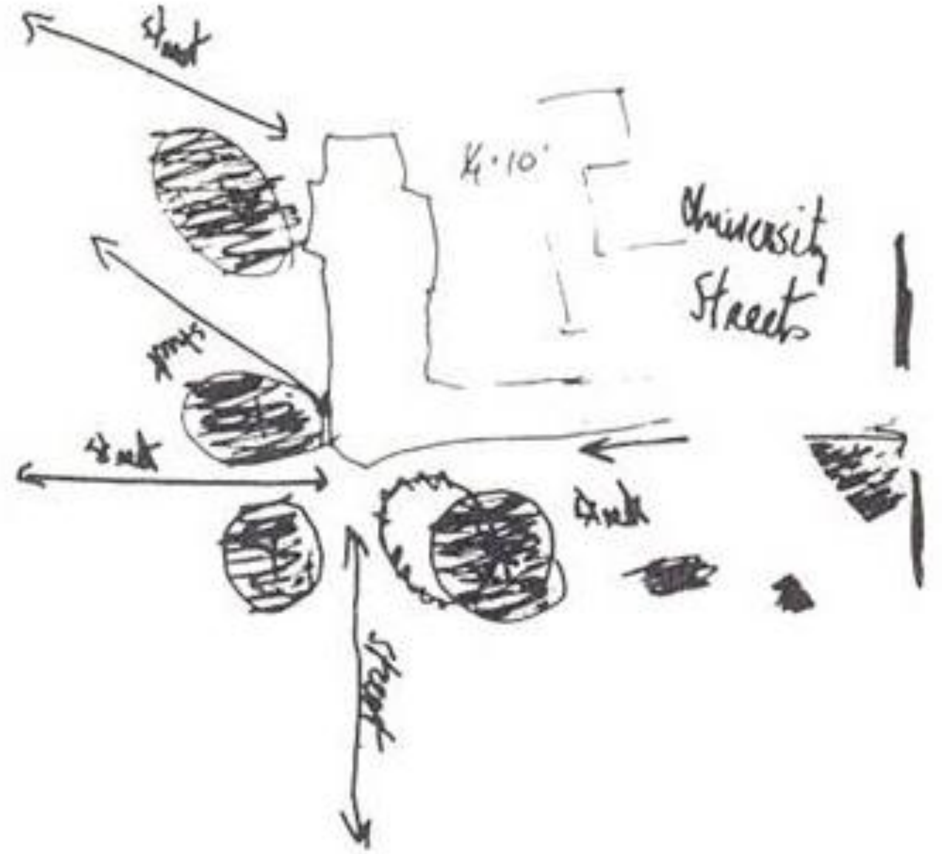

Figure 2. Alexander's diagnosis at stages and on different days (Tuesday sketch): The sketch on Monday indicates the areas of possible new build, whereas open spaces create centres for activities in the sketch executed on Tuesday in the same week - Oregon University Campus Democratic Project (Coppola Pignatelli et al., 1977, p50).

Other authors later, like Nikos Salingaros, also affirmed that, evidently 2D information shown by a plan is not so relevant for people to perceive and receive information from complex 3D surroundings and surfaces created by architecture (Salingaros, 1999). *"Architecture"* acts as *"extension of the human mind to the environment"* (Salingaros, 1999, p29). Therefore, we can construct or draw and even model 3D structures to connect with them by being conscious to our immediate surroundings. If the human mind does not detect any connections, the next impulse we get automatically is to leave that unfamiliar environment. People define their living space by becoming aware of the particular existence of solid margins through their emotions as well as through physical contact and through the senses. As we should show further, a fine fractal emergence is able to define an ideal outer border between urban space and rural regions. Hence, urban space should be considered more complex scientifically than the formal geometry of a plan proposed by architects and urban planners today. This may prove that mathematics can contribute more than ever through diagnosis of healthy cells ready to generate growth.

Thermodynamics of architecture: life and harmony

Urban space encloses built environment, which is defined by boundaries/filters and open interactive and multifaceted areas, being originated by bounding fractal skins of the surrounded buildings, as we mentioned before by referring to Christopher Alexander's day-by-day schemes and sketches. By referring to architectural scales inside the built environment, we discover that natural complex systems (to which both architecture and urban space relate closely) present some kind of hierarchical structure any way. The hierarchical structure of natural complex systems has been explained by several authors, like Simon (Simon, 1969) and Smith (Whyte et al., 1969) in the 1970s. Material stresses into inorganic crystalline materials generate conventional cracking patterns, which show a hierarchy of scales (from macro to micro scales) (See Figure 3.)

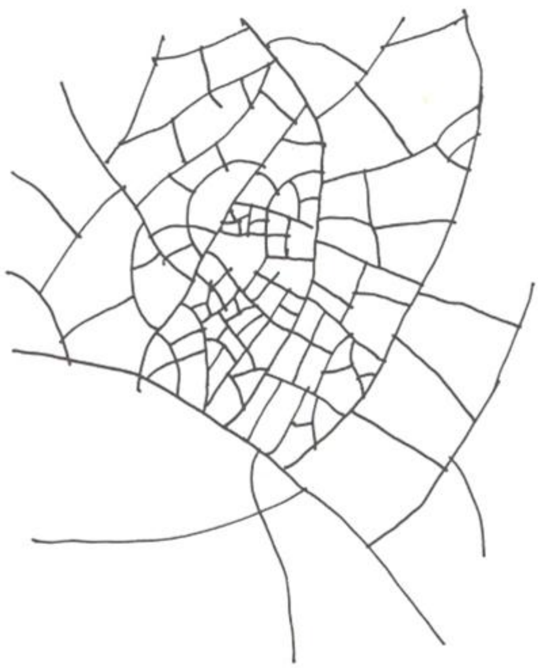

Figure 3. *"Material fractures create a hierarchy of scales"*
(Salingaros, 2006 & 2008, p48)

Smoothness and uniformity, which are the main visual characteristics of long-range ordering, are unfamiliar to natural materials, because they do not survive on the largest scale. Natural structural qualities show a variety of scales (from macro to the micro scales, including also intermediate scales). Scaling hierarchies define forms *"as a result of internal and external"* (www.math.utsa.edu, accessed 20/07/2013) interacting energies. Natural forms, such as communities of organisms in an ecosystem, organs, cells, etc reveal a distinct *"scaling hierarchy in decreasing order of size"* (www.math.utsa.edu, accessed 20/07/2013) with more structure as the scale becomes smaller. This is the most important manifestation of biological survival, to which 'Bios'=Life relies on. Therefore, Biourbanism investigates within these hierarchies to find out laws which should govern the growth of urban fabric in modern cities in a more all-inclusive way.

Structurally coherent units will define a particular scale at different sizes; these scales are distinct and included inside a complex structure that exists in large scale. Some natural shapes and forms on the surface of Earth can be seen now at different scales by enlarging and/or reducing available satellite imaging, which develops high quality of geographical mapping. The same principles of coherent structural units at different sizes apply to the built environment. According to Nikos A. Salingaros, "*architectural scales arise from the materials, structure, and functions of a building, and their distribution expresses an architect's organizational ideas"* (Salingaros, 2006 & 2008, p66). In fact, design units cooperate to achieve scaling coherence when a distinctive feature connects them visually; that is, for example, if they have got similar texture or colour.

Architecture influences people's lives often in a very conventional way. Therefore, as a discipline, architecture should strive to guarantee physiological comfort, without being deprived of its powerful psychological dynamics. It is obvious that, by conversing with human body and psyche at the same time, architecture should be considered a comprehensive discipline, which deals with a large spectrum of matters related to humankind. Moreover, we can suggest that, the transformation of the natural environment to offer more space to the urban sprawl today is not a completely new phenomenon; it has always been dictated by pre-established laws of nature rather than laws made by people working in urbanisation processes.

Architecture is considered as an expression and application of geometrical order, although it is not often clear how structural order can be achieved. In *Pattern Language* (Alexander et. al., 1977), Christopher Alexander suggested a set of experimental rules, which were mainly analysed and proposed as fundamental theories in urbanism; his geometrical *"rules that govern architecture, derived from biological and physical principles"* (www.math.utsa.edu, last accessed 20/07/2013). According to Alexander's hypothesis, structural order requires that *"forms be subdivided in a certain manner and the subdivisions be made to relate to each other"* (www.math.utsa.edu, last accessed 20/07/2013); the cells/buildings of the built environment interrelate by mimicking the micro scale interaction of elementary units, or better, the biological growth and multiplication of cells. Hence, architecture may be a follower of laws, which are analogous to the ones of physics. Human sensory systems respond to both tectonics and visual designs; these two aspects of the built form define structural order and they differentiate by scale.

By all means, human perception plays a vital role on how human beings envisage structural order in architecture. Thus, structural order cannot be identified through abstraction, as the observer becomes part of and also influences the behaviour of. As a result, architecture exists because of the existence of the humankind and cannot be isolated into an abstract world. In his *A Theory of Architecture*, Nikos A. Salingaros revises the fifteen properties of Christopher Alexander's *The Nature of Order* in Book 1 in order to formulate a set of three main laws to approach structural order slightly differently:

> "Law 1. Order on the smallest scale is established by paired contrasting elements, existing in a balanced visual tension.
>
> Law 2. Large-scale order occurs when every element relates to every other element at a distance in a way that reduces *entropy*.
>
> Law 3. The small scale is connected to the large scale through a linked hierarchy of intermediate scales with a scaling ratio approximately equal to e = 2.7"
>
> (Salingaros, 2006 & 2008, p30)

Salingaros discusses entropy as the technical term for randomness or disorder; he refers to scaling of links/components of different sizes. He affirms that, hierarchy *"refers to the rank-ordering of all those sizes"* (Salingaros, 2006 & 2008, p30). The same author affirms that, in physics, order of the small *"scale consists of paired elements with the opposite characteristics bound together"* (Salingaros, 2006 & 2008, pp30-31). By explaining paired elements, he affirms that, coupling/order in pairs separates opposite elements found closely, so that they could not overlap and, as a result, they should not be able to vanish. This close separation of the opposite elements creates a dynamic tension. Also in physics, keeping units of the same type next to each other (opposite units) does not result in binding.

Salingaros affirms that coupling of opposites applies to architecture as he expresses it in his Law 1. Thus, structural order on the smallest scale can be a result by coupling basic elements, such as, for example, contrasting in colour and geometry between coupling elements by differentiation of materials. During this process of ordering contrasting coupled scale pairs, we often find them interlocking. The concept of contrast appears in different scales; high detail couples with plain, empty regions (being evident in built areas and finishes) are necessary to complement the areas, which are sparsely built and finished. Each component of a contrasting pair needs to encompass an equal degree of coherence and complexity. Coupling for interiors and exteriors of a building *"does not occur via a glass curtain wall, but through the geometry of its plan, as it is formed so as to enclose outdoor space. This process leads to the definition of urban space."* (Salingaros, 2006 & 2008, p33).

Again in physics, order on the large scale means that, non-interacting objects are simply juxtaposed and nothing occurs. An interaction encourages rearrangements, which lead to a reduction of the entropy/disorder, such as alignment along one axis. According to Salingaros' in Law 2, *"large-scale order occurs when every element relates to every other element at a distance in a way that reduces entropy."* (Salingaros, 2006 & 2008, p33). As a result *"similarities and symmetries appear between different sub regions"* (Salingaros, 2006 & 2008, p33); large-scale order occurs by ordering colour and/or geometry. By reducing entropy/disorder, we help people to perceive a structure; a complex structure can be recognized, if it appears to be rational by means of associations and proportions. Human beings envisage a structure in its entity; they find it extremely frustrating, when a structure appears with unrelated pieces. *"Thermodynamic entropy* [links] *different arrangements of the same number of particles according to the probability of occurring."* (www.math.utsa.edu, last accessed 20/07/2013). According to Salingaros:

> "Structural order in architecture is inversely proportional to the entropy of a fixed number of interacting components. The higher the entropy (geometrical disorder) among the components at hand, the lower the structural order. Conversely, the lower the entropy, the higher the structural order. The entropy of a design could be lowered instead by reducing the local contrasts, but it also reduces the structural order … (thereby reducing architecture to an empty minimalism)."
>
> (Salingaros, 2006 & 2008, p34)

Structural order reveals unambiguous units on a common grid. A degree of connectivity is clearly shown by continuity of patterns; different regions can be tied together by means of repetition of the same minor pattern in some parts of them. For example, visual correlation can tie two or more design elements or parts of a building through common colours, shapes and sizes. In this case, structural order harmonises local contrasts without reducing them to an empty minimalism in any way.

The third law of structural order proposes the scaling similarity by imposing a hierarchical linking between Laws 1 and 2; that means the dissimilar scale elements need to be close enough in size, so that they can be envisaged by comparison to each other. The connecting is achieved through structural resemblance, such as repeating forms and patterns. The scaling ratio for which two dissimilar scales are still related in mathematical calculation is found to be approximately 3; this is clearly found in some elements of fractal geometry. In fact, self-similar fractal patterns, most closely resembling natural objects, present scaling ratio equal to 2.65, supporting the universal scaling ratio of 2.7 proposed by the hierarchical linking via Salingaros' Law 3. This hypothesis reveals a fundamental scaling phenomenon seen mostly in organic structures. The secret of natural growth is scaling, which is generated by $e = 2.7$ (very evident in Fibonacci sequence). Efficient growth in fractals is likely to happen, when simple scaling reveals basic repetitive replication processes to create arrangements at varied phases. *"Different scales must exist, and they must be related, preferably by only one parameter, the scaling [proportion] e"* (www.math.utsa.edu, last accessed on 20/07/2013); this parameter fits both natural and manmade structures, such as buildings and other artefacts.

Fractal interfaces in Architectural Life, Harmony and Complexity

Nature follows fractal geometrical patterns, often attracting the attention of artists and photographers, such as in Figure 4. below.

Figure 4. Sancti Petri-La Barrosa, Chiclana, Cádiz:
"Deposits of fluvial-marine sediments crossed by a complex network of secondary channels subjected to a process of fluctuating tidal flooding." – Photograph by Héctor Garrido/CSIC ©, as seen in http://fractaldonana.blogspot.com/, last accessed on 20/07/2013)

Nature prefers ordered complexity to guarantee its biological life, as in this case of the Iberian Peninsula wetlands. Many authors, like Christopher Alexander believe that, *"the texture of space is governed by the same rules at all scales; from the scale of the planet, down to the scale of a pebble"* (Salingaros, 1999, p30); that is, as a projection of what nature offers us and by fractal qualities, found in historical urban fabric. Although urban space and architecture could be complex and fractal, the processes which generate successful spaces should be summarized in only three axioms dealing with urban space. As Salingaros puts it:

> "By encapsulating the essence of why similar structures arise repeatedly around the world and throughout history, 'patterns' represent the most intelligent decomposition of architectural and urban systems that has ever been attempted. Alexander's *Pattern Language* was misunderstood as being a catalogue of modules, whereas in fact many of the patterns identify interfaces that govern how modules connect to each other."
> (Salingaros, 2000, p305)

According to Salingaros, *"urban space is bounded by surfaces that present unambiguous information"* (Salingaros, 2005, p42) - axiom 1; its spatial information field defines *"the connective web of paths and nodes"* (Salingaros, 2005, p42) - axiom 2 and the *"core of the urban space is pedestrian"* (Salingaros, 2005, p42) - axiom 3. The axioms provide the basics for urban planning by referring to more basic level rather than large scale decisions often revealed by complex network grids. Thermodynamics in architecture are related mainly to bounding surfaces or better, to *"structural pieces surrounding an open space"* (www.math.utsa.edu, last accessed on 20/07/2013); they should show the maximum information to the people who use that geometrical urban space. Thus, the urban spatial boundaries act as generators of positive space stimulating the human senses. Therefore, the geometry of these boundaries should guarantee coherence in positive urban space.

Towards the end of the 20th century, *"fractal theory has become popular in urban geography"* (Tannier et al. 2005, p9) and planning. Many authors insist that, successful urban forms should be fractal, although mainly they refer to large-scale urban design based upon pathlines' connectivity. Nevertheless, by considering urban space as defined by special boundaries, which transmit specific information (exterior fractal architectural elements) and by developing the *"information field through geometric subdivisions"* (www.math.utsa.edu, accessed 20/07/2013) we are able to provide building surfaces *"with fractal scaling, from the size of the buildings"* (www.math.utsa.edu, accessed 20/07/2013) down to the materials, hence, being in plain control of fractility in peripheries. A *"typical town is not a pattern of streets, but a sequence of spaces created by buildings"* (Salingaros, 2005, p53). Thus, we escape from the negativity of plane fractals by creating fractility in a smoother way and by strictly considering harmony.

A design based upon fractility deals with natural scaling hierarchy and it is capable to influence the viewer, as it helps with the process of human perception. Human beings can *"perceive a complex structure by reducing it to a number of distinct levels of scale"* (www.math.utsa.edu, last accessed 20/07/2013) and, in this way, excess of information can be easily avoided. In the 1990s, the effects of computation to the human eye and brain started being studied and research proved that, at first, the human brain forms clusters of *"similar units of the same size into one scale"* (www.math.utsa.edu, last accessed 20/07/2013) and then, it starts comparing sizes and scales between them. Thus, the human brain can easily perceive fractal self-similar shapes, forms and structures by clustering them at different sizes and scales; the human brain has been trained to distinguish patterns found in nature and also perceives accurately the natural scaling hierarchy of fractility. The eye gets signals and the brain analyses them according to a certain set of rules for recognising hierarchical cooperation of self similar patterns; the latter can be easily mapped and visually identified as such.

By considering architectural comfort some authors, like Salingaros, have tried to examine how the small and large scales contribute to the accomplishment of architecture whatever its coherence could be. Salingaros uses methods of quantifying architecture according to geometrical and visual content and also claims that, it is possible to compare two buildings based on intrinsic, computable values of their design. The same author also insists that, these scientific values can influence the importance and feeling of a building (how residents and/or users feel about it); he also identifies some architectural tools for dealing with and understanding the organisational component of design. This latter point of his has reinforced the belief of the author of this paper, on every occasion she teaches studio design practices to students in Higher Education at all levels, from Level 4 to Level 8. During this kind of teaching, theories and histories of design and architecture can provide some important experiential tools to both architectural and urban design solutions. Nevertheless, these tools should be reinforced further by vigorous quantifying tools also linked to relevant sciences, such as mathematics, physics and biology.

Nikos A. Salingaros has set a simple mathematical model, which draws on analogies of thermodynamics and can be considered as an innovative approach to design; he has identified two distinct qualities and has provided some basic information how to measure them. He describes small-scale structure as the architectural temperature *T*. The higher the architectural temperature *T* is, the higher the intensity of the design and the degree of visual stimulation is also revealed. He identifies the architectural harmony *H*, another measure, as the degree of symmetry and visual coherence of forms, capable to measure visual organization. Salingaros has related the hypothetical architectural life *L* and architectural complexity *C* to a variety of combinations of *T* (Temperature) and *H* (Harmony). His architectural life *L* is defined by the formula $L=TH$ and his architectural complexity *C* by the formula $C=T\,(10\text{-}H)$.

The architectural life *L* refers to the quantity that, a user can recognise critical qualities in a building that make it seem alive. He refers to Christopher Alexander's ideas about critical qualities that connect us *"with a building in the same way that* [we connect] *emotionally to trees, animals and people"* (www.math.utsa.edu, last accessed 20/07/2013). Complexity *C* can be a positive or negative value; it depends on the fact that, it can trigger interest and excitement, which may reach the highest degree of anxiety. The final part of Salingaros' model demonstrates how to fill a building with life by adjusting individual elements of forms; he starts with the perception of uniformity and tries to explain why a form, differentiating in terms of the geometry and colour, follows the laws of physics and considers uniformity. He affirms that:

> "In physics, uniform states in fluids and gases are associated with low temperatures. Raising the temperature often breaks the uniformity, leading to gradients and standard cells… this suggests that, we refer to the degree of detail and small-scale contrast in a design as the architectural temperature *T*…The architectural temperature is determined by several significant factors, such as the sharpness and density of individual design differentiations, the curvature of lines and edges and colour hue" (Salingaros, 2006 & 2008, p107)

Salingaros distinguishes five elements/components, *T1* to *T5* that contribute to Temperature *T*. Each quality is measured on a scale by assigning a value of 0 to 2 according to a rough judgement, as follows: very little or none=0, some=1, considerable=2. The quantity *T* would range from 0 to 10. Therefore, he explains that, the result has been according to his mathematical computations on emotional response mainly and proposes:

> "T1= intensity of perceivable detail
> T2= density of differentiations
> T3= curvature of lines and forms
> T4= intensity of color hue
> T5= contrast among color hues"
> (Salingaros, 2006 & 2008, p107)

In a similar way, architectural harmony *H* is associated with visual organisation and measured as the sum of five components; it measures in reality the lack of randomness in design. Thus, H=H1+H2+H3+H4+H5. The same values 0 to 2 are considered for each component again:

> "H1= reflectional symmetries on all scales
> H2= translational and rotational symmetries on all scales
> H3= degree to which distinct forms have similar shapes
> H4= degree to which forms are connected geometrically one to another
> H5= degree to which colors harmonize"
> (Salingaros, 2006 & 2008, p110)

It is explained that, there is a deep connection between architectural harmony and information in thermodynamics, which is carried over to architecture. As Salingaros affirms, *"any symmetry in a design reduces the amount of information necessary to specify shapes"* (www.math.utsa.edu, last accessed on 20/07/2013). Disconnected forms positioned close to each other across an interface or gap may create uncertainty and, as a result, they lower the architectural harmony. The brain continues though to seek visual information in order to establish some necessary connections. Usually brain recognition is frustrated whenever architectural structural information is mainly missing.

> "Conjecture on perception; the brain works combinatorially; tries out all possible geometric combinations, deciding which is more effective of understanding; in the absence of explicit groupings, this process leads to stress and fatigue"

> (Salingaros, 2010, p31)

Hence, we strive for raising architectural harmony of a variety of structures, which are unrelated, for example, by scaling through transitional regions of links. A geometrical link connects two separate structures and will become a boundary for both of them, sometimes a path. At this point, we can understand how fractility of urban space manages to maintain continuity and healthy uninterrupted human activities to reinforce boundary expansions around preferential human activity nodes:

> "Scaling symmetry creates coherence; similar shape when a fractal's particular details are magnified; the brain handles information encoded in a fractal than if random." (Salingaros, 2010, p39)

Architectural Life of a building is given by the formula *L=TH* (Life equals Temperature times Harmony) and this takes values from 0 to 100. A low value for L *"means that, people may not connect to that building on the same emotional level that, they would with a living organism"* (Salingaros, 2006 & 2008, p115). The optimum *"value for the architectural harmony is below its theoretical maximum. Every great building has some degree of randomness"* (www.math.utsa.edu, accessed 20/07/2013); the randomness is required to define new scales, or to create new couplings between opposites, hence, new fractal boundaries, because *"repeating parts are actually perceived as interacting; combinatorial complexity increases with the number of identical parts; solution is to iteratively partition sets of parts into coherent groups."* (Salingaros, 2010, p32)

Finally architectural complexity *C* equals *Temperature* times *Randomness* (disorder), according to the formula *C=T (10-H)* and also takes values between 0 and 100. The impression of a building's complexity can vary from very low *C*=0 (dull), to medium *C* (exciting), to very high *C* (incoherent). Thus, too much complexity detracts from a building's adaptivity to humans, as it extends from positive excitement into anxiety. And again, we should consider a complexity threshold, whilst designing both architecture and urban space nowadays:

> "By sacrificing the structural complexity needed for metabolism, viruses gain an unbeatable advantage over more complex, metabolizing life forms that they

> infect… Any style that attempts to adapt itself to human physical and emotional satisfaction, as well as to local materials and climate, will necessarily exceed a certain complexity threshold. In neglecting those needs … modernist architects crossed the complexity threshold going downwards. This brought it an unprecedented advantage, but removed an essential quality that we associate with life … biological life consists of two components: metabolism and replication. … A virus replicates its encoded genetic information without being able to metabolize … In an analogous manner, modernist structures, though immensely successful at replicating in the built environment, do not posses the same degree of life (measured in terms of organized complexity) as do more traditional architectural styles that adapt to human use and emotional needs."
> (Salingaros, 2006 & 2008, p126)

Conclusions

All the theories, practices and computation methods and tools mentioned above were taught by the author of this article to her students through Designing Environments, a module at Level 7, in MSc in Sustainable Architecture and Healthy Buildings in the autumn semester of the academic year 2011/2012. The students produced either theoretical schemes or proposals of design and wrote critical essays/papers on a topic related to the materials taught and discussed during peer reviews. Not only architectural complexity was investigated, but also harmony and viability of urban space was measured in connection with infrastructures and geographical randomness which affects both cityscapes and landscapes. Some empirical models were produced, such as the model shown below in Figures 5. & 6. The main intend for the near future is to produce composite three-dimensional mapping during further research and exploration by working closely with our departments of geography and mathematics. The educational and development processes for the projects in Designing Environments were also presented in Theoretical Currents II Conference in Lincoln University, UK on 5th April 2012; very useful feedback came from this presentation (Author, et al., 2012) to help us with further advances in geographical and urban 3D mapping of socio-economical growth of many regions around the globe.

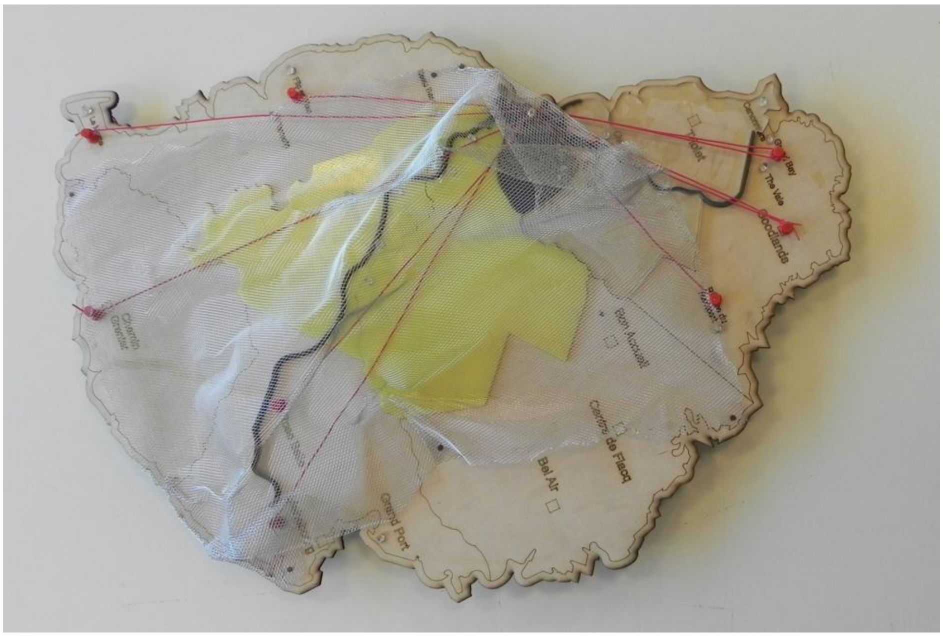

Figure 5. Model of Mauritius Island by Madhoor Bissonauth Pritz for the module Designing Environments, taught by the author in autumn 2011 for the MSc Sustainable Architecture & Healthy Buildings, School of Technology, University of Derby.

Figure 6. Model of the Mauritius Island by Madhoor Bissonauth Pritz for the module Designing Environments taught by the author in autumn 2011 for the MSc Sustainable Architecture & Healthy Buildings, School of Technology, University of Derby.

The educational plan is not only to include recent information collected in modelling, but also, by juxtaposing missing links (often historical) of either networks of connectivity or fragmented and/or lost fractal boundaries in urban space to stimulate further discussions and interaction with users of urban spaces. Evidently the next step will be to use these models in order to test possible solutions dictated by new fractal boundaries, before proceeding to proposals of sustainable urban and economical growth in some regions/case studies. Growth will be interrelated strictly to current and future intensive models of fractal and healthy urban sprawl. The word life is going to encompass architectural life of a building and urban space as a multiple of architectural buildings, which integrate themselves with the rest via coherent fractal intermediate regions. The graphs of economical growth are also juxtaposed to other emergences to enhance randomness, often conflicting with harmony in development master plans proposed by regional and/or state governments. During specific seminars, it has been often discussed that *"human sensory systems have evolved to respond to natural geometries of fractals, colours, scaling, symmetries; fine tuned to perceive positive aspects (food, friends, mates) and threats; also fine tuned to detect pathologies of our body, signalled by the departure from natural geometries"* (Salingaros, 2010, p28) and also that *"scaling symmetry creates coherence; similar shape when a fractal's particular details are magnified; the brain handles information encoded in a fractal than if random… Physiological wellbeing; self similarity endows visual coherence –important to human perception; the brain evolved to handle self-similar natural structures."* (Salingaros, 2010, pp39-40). As a matter of fact, urban space and architecture should be closely following laws of biological complexity in order to be able to guarantee an ongoing evolution of more inclusive cities through human-oriented spatial and urban designs. We may also highlight the following, which will be an important starting point for our 2D and possibly 3D new mapping and measurements:

> "By escaping rigid rules of Euclidean Geometry, fractal objects allow the development of useful tools for the description of observed spatial patterns. In the case of urban systems, many properties which have been formalised as major concepts of geographical theory can be related to the framework of fractal geometry. Indeed, the main properties of fractal objects are the same as

> the properties of urban patterns." (Tannier et al., 2005 at cybergeo.revues.org, last accessed on 20/07/2013).

We have been also encouraged and supported by the first studies on urban analysis based upon cities' visualisation in terms of their geometric forms and especially upon the development of fractal geometry with clear relevance to detailed spatial systems for cities. And we conclude by referring to these milestone theories in the 1990s, when several authors (Mesev et all, 1995) started measuring and modelling socioeconomic data with the use of remotely sensed data/imagery, which provided detection and measurement of urban morphologies:

> "The notion that cities are self-similar in their functions has been writ large in urban theory for over a century, and is manifest in terms of relations such as the rank-size rule, hierarchical differentiation of service centers as in central place theory, transportation hierarchies and modes, and in the area and importance of different orders of hinterland… All these relations which form the cornerstones of urban geography can be described and modeled by using power laws which are fractal. What this new geometry is beginning to do is to tie all these notions explicitly together in a geometry of the irregular, a geometry of the real world."
> (Mesev et all, 1995, pp760-761)

Therefore, nowadays we are planning to work for real communities in our real fractal world.

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