Re-thinking Architectural Form:
The Emergence of Self-organized Architectural Form

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Introduction:

This work focuses on the creation of architectural forms using a new approach based on scientific principles. The three main parts of the paper embrace the ideas behind the ontogeny of architectural forms.

Part one introduces the concept of the architectural phenomenon as part of the emergence of a living process, where *architecture is not only a process in change; it is a phenomenon*. The natural living process is a flux of complex but smooth transformations and phases of transitions which reveal the form, e.g. the formation of an embryo, the evolution of a splashing drop, the structures produced by a colony of social insects. In all these cases, we find the sequence of development to be what Christopher Alexander refers to as a,

> "*sequence which is essentially smooth in character*" (Alexander, 2004).

Part two explains the properties, self-organization and adaptation, which the paper consider as the most effective properties in a living process. The overlapping of external and internal effects is the generator of these properties. For Steven Johnson, however,

> "*a system may self-organize but not be adaptive; it is independent of its surroundings; that is a closed system. An adaptive system on the other hand whether it self-organizes or not, develops according to inputs from its surroundings*" (Johnson, 2001).

In order for the form to emerge and grow from its living process, self-organization and adaptation are essential properties. This open-ended living process allows unpredicted outcomes to exist.

Part three explores some of the principles exhibited in natural and artificial systems that can be exploited in order to achieve adaptation in architectural form.

> "*In natural systems there is nothing else but "coming into being", everything is coming into being continuously*" (Alexander, 2004).

The paper focuses particularly on the developmental processes of the embryo, cell growth running through phases of self-replication and differentiation until the form emerges. Artificial self-organization as found in cellular automata like Conway's game of life is described. Finally, a model is presented that describes theoretically a way of growing architectural forms, focusing on the idea of creating complex structures from simple inputs.

The Architectural Phenomenon: Emergence of a Living Process

> "*Everything that is static is condemned to death; nothing that lives can exist without transformation*" (Nio, Suybroek, 1996).

Living processes are difficult to interpret because they are non-linear dynamic phenomena. Architecture has formed a great part of such phenomena. It is not only a constantly changeable process but it also involves high levels of overlapping, interaction, emergence of certain events and phases of transition that lead to many aspects of the form which I prefer to call the *temporary form*. Each temporary form is a product of emergence that is unleashed after phases of transformation in the process of becoming. It is one image of the form, one aspect for each time in each space.

This phenomenon is dynamic and constantly in flux. Alexander echoes much the same observation when he argues,

> "*process is the transformations from moment to moment which govern order in a system*" (Alexander, 2004).

The process runs through phases which are considered the transformational periods that form and guide the coherent whole in a complex system to create a series of distinct images for the form. These periods are image leaps of a certain system, which are followed by a new emergence and confusion in the course of the system. Hence, they become the main generator for the dynamic continuation and change in any system. These images are temporary forms of transformations; in Alexander's words,

> "*living centers have properties and they are the way in which centers appear in the world, come to life and cooperate to form other living centers*" (Alexander, 2004).

They may be a shape, a function, a movement or a force. The combination of a number of images in one phase leads to the formation of a certain shape, that changes if another image is added or changed. A change in their arrangement creates a dynamic tension state. That is why architectural form is a thought and artefact with changing relations and transformation of connections. Alexander similarly argues that the emergence of new structure in nature is brought about by a

> "*sequence of transformations which act on the whole, and in which each step emerges as a discernible and continuous result from the immediately preceding whole*" (Alexander, 2004).

Alexander refers to these transformations as a living process until they reveal the form: the outcome. He calls them living centers because they interact with the context where they belong in a conceptual way, his centers do not transform physically but conceptually.

This phenomenon is therefore born after a number of processes accompanied by transformational periods and phases to reach a near-equilibrium. Yet, this phenomenon begins to change in order to attain another near-equilibrium and all this is accompanied by a formalistic multiplicity and reaches its aim in a non-linear manner. This *process* as Kas Oosterhuis describes it, is in action, it never stops because it is part of a great action which is life.

> "*If we think of it as data that carries information then this data is always in action, exchanging places with other data somewhere else and spreading action all over*" (Oosterhuis, 2002).

Lebbeus Woods, however, describes the *process* in a more radical way when he refers to it as multi-transformations in architectural form where,

> "*composition is gone, because the process continuously recomposes itself within an almost infinite range of possibilities. Furniture is gone, because it is unknown in advance. Structure is gone, because it is entirely fluid – dynamic, nonlinear, even mathematically chaotic*" (Woods, 2001).

All that remains is an intimate and unpredictable interaction between the users and the architectural form on one hand and between the components of the form itself on another.

A living process always embeds the temporary form - the state of what exists - and is always anxious to push itself forward to preserve the structure of what exists, and it grows and adapts itself as it creates change or evolution or development. This is the creative process: the living process.

Self-organization and Adaptation

The most distinguishing factor of the universe and its phenomena is the one that is always anxious to push itself to the threshold between order and chaos. This threshold is unstable and it gives, at the same time, a formalistic multiplicity that generates dynamism in the system. The inability to predict the outcome is associated with the cyclic nature of the phenomenon. Self-organization is one of the properties of dynamic complex systems which push themselves to the threshold between order and chaos in an attempt to organize their complexity so as to optimize energy flow. Nikos Salingaros puts it in a very interesting way when he refers to this organization as a kind of "learning process" where,

> "*the system uses internal forces to influence its own structure or growth*" (Salingaros, 2000).

We can witness self-organization in many natural systems, for example snowflakes, or the shape of a pile of sand. Any natural pattern that shows organization at every scale is a consequence of some mechanism of self-organization.

Processes in this type of phenomenon overlap in a way that can be seen only after the form emerges. The entire process is but a complex organization of components with internal and external effects that guide the process in non-linear directions. These processes involve complexity and hierarchy with continuously overlapping transformations in their structural formulation. This finally leads to the formulation of the form: the temporary form. These internal and external effects that guide the process are actually the self-organization and the adaptation that is embedded within the complex process. This argument draws on the work of Salingaros as he distinguishes between self-organization and adaptivity and contends,

> "*Whereas self organization is driven primarily by internal constraints, adaptivity is driven by external constraints, so the system has to be open*" (Salingaros, 2004).

The most significant feature of a living process is that it grows, unfolds and adapts gradually to allow the temporary form to emerge from the coherent whole with the help of feedback. Without step by step feedback, there is no way for a process to be complex and living. By creating a small system of 30 variables, Alexander suggests two possible approaches to achieve adaptation. He takes 30 coins which he considers successfully adaptive when they are all heads and non-adaptive when at least one is tails. His goal is to get them all heads. In the first possible adaptive mechanism "*The All-or-Nothing Approach*", he tosses the coins all together at the same time and then he looks to see whether they have all come down heads. If not, he spins them all again, looks at them all again, again checks to see if they are all heads. In this approach, the essential rule is that they must all come down heads together. Even if 29 come down heads, but one comes down tails, it is not good enough. In this approach, it will obviously take a long time to achieve a properly adaptive configuration. In fact it will take on the order of 2^{29} trials (about 10^{10}). After calculating the whole process he found out that it actually takes 10^{10} seconds or some 150 years with one trial per second. The second approach is "*The Step-by-Step Approach*". In this case he spins one coin at a time. When it comes down heads he leaves it on the table and spins another one. Here the adaptation is happening step by step, one step at a time. In this approach, it will take on the order of about 2 seconds per coin, or about 60 seconds altogether-roughly one minute to complete the adaptation. The step-by-step approach works while the all-or-nothing approach does not, (Alexander, 2004). This is the secret of biological evolution. Ross Ashby equally argues

> "*During the course of evolution, the adaptation of the thousands and millions of variables that must occur to make one successful organism happens gradually*" (Ashby, 1960).

Richard Dawkins echoes much the same observation when he sees cumulative adaptation is the only possible way for evolution.

> "*It would be impossible for nature to "design" a system as complex as an organism all at once*" (Dawkins, 1989).

Generative Natural and Artificial Complexity

In 1917 D'Arcy Thompson described the origins of biological form as a necessary result of biological growth, he struggled intellectually, showing again and again by examples, that biological form could only be understood as a part of the "*growth process"* (Thompson, 1942). Now, and at the turn of the 21st century, insights into the "process" are finally being revealed in most scientific disciplines where *transformations from moment to moment* through time and space are governing order in a system. However, and despite all the progress made in many scientific and humanities areas, the idea of living process has not yet become part of the way we think about architecture. Ilya Prigogine's criticism of mainstream 20th century physics could still be applied equally on mainstream contemporary architecture.

"*Our current view of architecture rests on too little awareness of becoming as the most essential feature of the building process*" (Prigogine, 1980).

Current architectural structures represent a planned descriptive organization of self-interest (architect's will) where forced structures result in a static form. The outcome (architectural form) is predicted and even if it has the ability to adapt (e.g. removable partitions, self cleaning glass) such adaptation will be limited and stereotyped because it is not an outcome of a generative process.

The difference between a generative and a descriptive program is fundamental and crucial to any living process. A descriptive program, such as a blueprint or a plan describes an object in some detail which tell us what the outcome is supposed to be, whereas a generative program describes how to make an object, what actions to take, step-by-step to unfold the form. And this is exactly how architecture limited itself; instead of using a generative process that allows the form to grow and adapt; it designed and planned pre-images for the outcome.

The best generative natural living process this paper focuses on is the developmental processes of the embryo that contain a generative rather than a descriptive program. The fertilized egg contains all the genetic information required for embryonic development. Lewis Wolpert asks some crucial and rather important questions:

"*How is this information interpreted to give rise to an embryo? One possibility is that the structure of the organism is somehow encoded as a descriptive program in the genome. Does the DNA contain a full description of the organism to which it will give rise? The answer is NO. The genome contains instead a program of instructions for making the organism-a generative program-in which the cytoplasmic constituents of eggs and cells are essential players along with the genes like the DNA coding for the sequence of amino acids in a protein*" (Wolpert, 2002).

For Wolpert, this process is like origami: the art of paper folding, whereby folding a sheet of paper in various directions you get a paper hat or a bird from a single sheet.

"*To describe the final form of the paper in details with its complex relationships between its parts is very difficult. Much more useful and easier to formulate are the instructions of how to make it. The reason of that is that simple instructions about folding have complex spatial consequences. In development, gene action similarly sets in motion a sequence of events that can bring about profound changes in the embryo*" (Wolpert, 2002).

That means the genetic information in the fertilized egg is equivalent to the folding instructions in origami: both contain a generative program for making a particular structure. It is just like what happens in football games, when all the players know the rules and the boundaries but each time you see different performance.

Essentially, the same thing can be said about the way – and the only way – to generate architectural forms that can adapt to their context during and after emergence; is that, they are generated from a living process. From conception, designing the first sketches, detailing here and there, to playing with the material;

are all unfolded processes that happen gradually in space and time. After generating these temporary forms gradually; these forms will then *coordinate* to adapt to one another and to their surrounding to form a coherent whole: a living architecture.

Another essential aspect of the living process is that all its components and its outcome/forms are *geometrical.* The gradual unfolding of the developmental processes throughout the division and the differentiation, the DNA, each cell's shape, the protein's shape, on all different scales have geometry in their forms. Alexander has similar beliefs as he argues,

> "*The unfolding is geometrical in its essence, although there are many side features to living process, it is fundamentally the unfolding of coherent geometric form, even when it appears loose and organic*" (Alexander, 2004).

After pointing at different aspects in living processes that are worth mentioning, now the focus will be on the famous five developmental processes involved in creating an embryo.

It all starts with a *fertilized egg* followed by a rapid *cell division* that is not yet accompanied by growth; it is all positional, mass division. Each of these cells contains a copy of the genome (which contains the entire generative program). At the start of this process, the geometry will reveal and will never stop not even after the embryo comes to the outside world. *Pattern formation* is the second process that comes after multiple phases of division; this process will allow a spatial and temporal pattern of cell activities to be organized so that a well-ordered structure will develop. It involves laying down the overall body-plan defining the main axes of the embryo and allocating the cells to different germ layers. I call what reveals from each stage of the process; a temporary form, because it is subject to transformations and changes where all the germ layers will acquire different identities throughout the whole process, so that the organized spatial pattern of the cell differentiation emerge, such as the arrangement of skin, muscle, and cartilage in developing limbs and the arrangement of neurons in the nervous system. The third important process is change in form, *morphogenesis*. It is a process of 3D changes, transformations and migrations that involve multiple-complex phases. For example, most of the cells of the human face are divided from cells that migrated from the neural crest, which originates on the back of the embryo. The fourth process is *differentiation* in which cells become structurally and functionally different from each other, such as blood, muscles, and skin cells. Differentiation is a gradual process where overlapping and interaction can be witnessed during the process of pattern formation. These interactions as Wolpert describes them,

> "*are very closely interrelated, as we can see by considering the difference between human arms and legs. Both contain exactly the same type of cell-muscles, cartilage, bone, skin and so on-yet the pattern in which they are arranged is clearly different. It is essentially pattern formation that makes us different from elephants and chimpanzees*" (Wolpert, 2002).

The fifth process is *growth* – the increase in size which can be brought in a variety of ways like cell multiplication, increase in cell size, and deposition of extra cellular materials such as bone and shell.

We may see some of these processes and aspects such as *replication*, *coordination*, *pattern formation*, but not differentiation in creating artificial complex systems using nanotechnology. Differentiation is not possible using the current technologies in artificial systems even if using living materials such as tissue and cell culture. Thus, in order to control the growth of living culture, experts use moulds and leave the tissue to grow. This can be seen in the art work of Oron Catts the director of SymbioticA and Ionat Zurr at the *Tissue Culture & Art Project* in their attempt to grow a semi-living jacket to create "*victimless leather*" (Catts). This project highlights the possiblity of wearing leather jackets without killing an animal. Catts and Zurr grow a living tissue into a leather-like material and have it mature in the form of a miniature, stitchless, coat-like shape. There is also the field of cellular automata like Conway's game of life where each unit is following a rule that produces emergent behaviour in the system as a whole. All the cells in Conway's game of life follow simple rules which capture coordination between the cells to form a certain pattern.

> "*A cell can be* live *or* dead*. A live cell is shown by putting a marker on its square. A dead cell is shown by leaving the square empty. Each cell in the grid has a neighborhood consisting of the eight cells in every direction including diagonals*" (Paul Callahan, 2000).

By counting the number of live neighbors for each cell, we can tell what will happen next.

> "*A dead cell with exactly three live neighbors becomes a live cell (birth), A live cell with two or three live neighbors stays alive (survival), in all other cases, a cell dies or remains dead (overcrowding or loneliness)*" (Callahan, 2000).

The life game is an excellent example of emergent complexity and/or self-organizing systems.

How do these principles apply to architecture? The most outstanding pieces of architecture evolved to be the living centers of their context. This can be seen in the Sumerian ziggurat, the hanging gardens of Babylon, the Egyptian pyramids, the Basilica and Coliseum in Rome and even in some architectural pieces created as recently as a hundred years ago. These artifacts grew in a gradual living process and are immortal through their presence. They grew in their contexts each at a certain time for a certain cause using technologies that were the cutting edge at that time, and their startling originality evoked a sense of mystery and wonder that persists to this day. They were the emergence of revolution and evolution of new forms and any copy - lacking the properties of a living process - would not have the same effect. Here I would like to stress the fact that creating new active centers in architecture requires a massive transformation in the way we think of this process: the living process of emergence. The transformations and evolutionary changes that we've seen in biology and technology are what current architecture is lacking.

Model

Now I would like to present my model which explains most of the aspects and the principles of natural and artificial systems that I mentioned before; applied to the emergence of architectural form. The model is theoretically structured on the principles of development and the cutting edge technology of nanotechnology and cellular automata.

In the early stages of the model process there is one "*Cube*" which is a space-filling polyhedron (Weisstein, 1999). With the help of nanotechnology this component *replicates* itself but cannot differentiate and this is the threshold between scientists and engineers on one hand and nature on the other. After the component replicates itself for many times, we code all faces on each component with a codon from a complete sequence of DNA (see movie & image 1). Then I'll put the components randomly in a glass box and shake it to mess the sequence. As a result we'll find that each face in the components will try to look for the matching face that completes its sequence, just like what happens when two strands of DNA join together, where a G has to match a C and A has to match a T and vice versa. For example, CGT has to fall on GCA. They will all settle after a while to form a certain shape: a temporary form. Then we'll try to manipulate them again by changing one or two or even more of the sequences on the faces of one of the components; they'll try again to push one another to form a different pattern to match the new sequence, and this is *pattern formation* (see movie & image 2).

The whole idea is simple, there are simple rules guiding the way. These 3D components need to know nothing else but this *simple rule* which is: every face on the component has to find its match according to the given example above: high *coordination*. The ability to *grow generative structures* comes from their *self-organization* that is guided by the internal effects: the rules, whereas the change in the sequence: the external effect results in the ability for *adaptation*. This is what happens in real life, where *complicated forms grow from simple rules between the components.*

There is *high geometry* on the individual level and on the coherent whole. There is *simplicity* in this *generative complex system*, thus the model exhibits an *emergent behavior* on all levels and scales. Steve Grand reflects on the same idea,

> "*when populations of interacting structures become arranged in certain configurations, and new and surprising comes into existence, we call this an emergent phenomenon*" (Grand, 2000).

I would like to stress on the fact that the same idea works on bigger systems with millions and hundreds of millions of components and this is where it becomes a nano-form where smoothness is at its highest level.

Changing the sequence is equivalent to an external effect and if the system has the *ability to adapt* to this change then it runs through *gradual phases of transformations* and *feedback*, which is exactly what happened with the components when I tried to change the sequence.

I presented the coherent whole where complex systems arise out of simple interactions between the components: the temporary form, the living fractals that grow to a coherent living architecture.

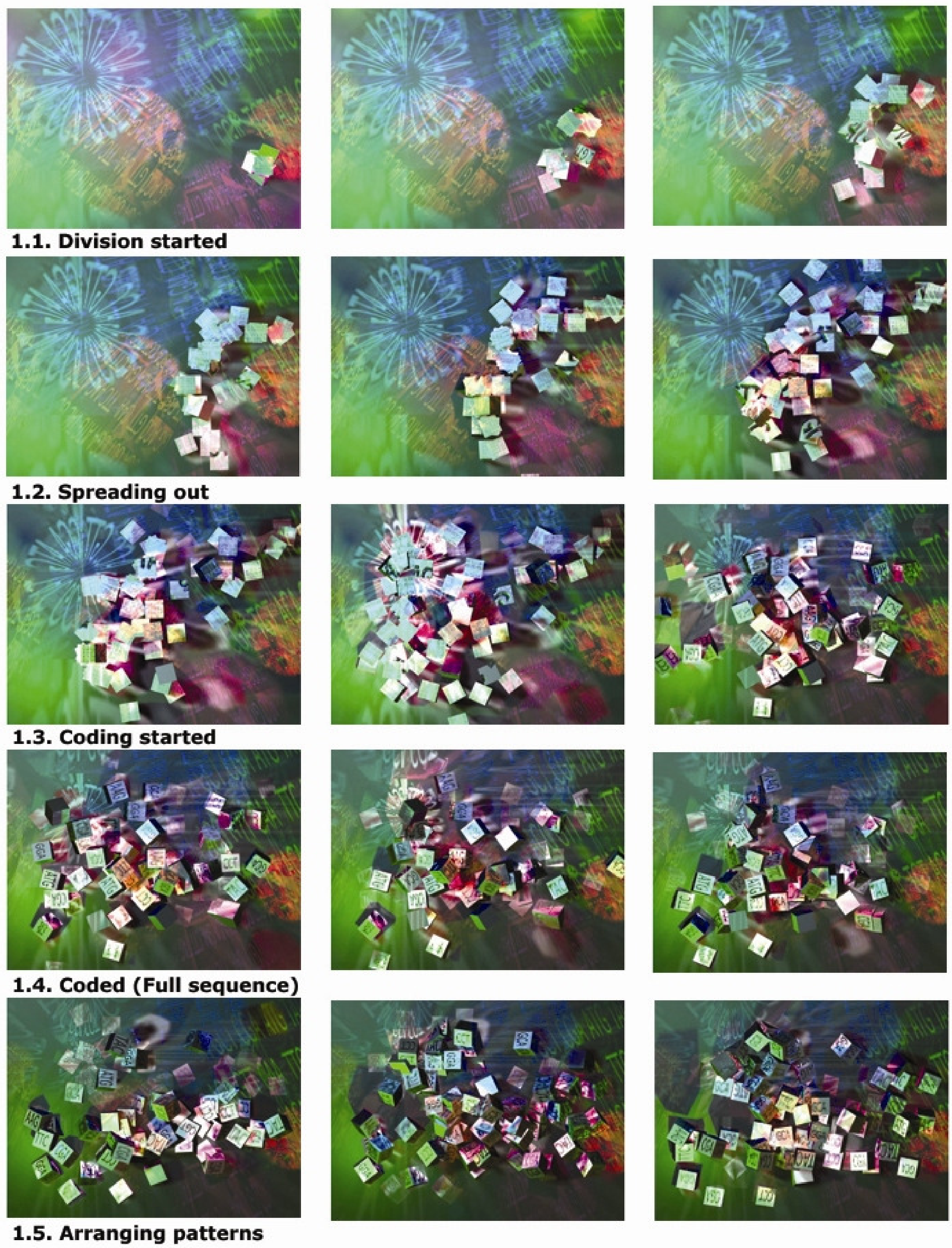

Image – 1 – Division and coding throughout time and space
For further details see movie 1: http://sanamurrani.me.uk/july05/movie1.mov

Image – 2 – Three examples that show pattern formation and manipulation of code
For further details see movie 2: http://sanamurrani.me.uk/july05/movie2.mov

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