Self-design and Ontogenetic evolution.

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Abstract

The context and long term goal of the project is to develop design environments in which the computer becomes an active and creative partner in the design process. To try to set-up a system that would enhance the design process by suggesting possibilities, has been preferred to an approach that emphasises optimisation and problem-solving.

The work develops around the general concept of morphogenesis, the process of development of a system's form or structure. Besides the obvious example of embryological growth, biological evolution, learning, and societal development can also be considered as morphogenetic processes.

The aim is to set a foundation from where latter work can develop in the study of how form unravels, and the implications and possibilities of the utilisation of such processes in design. Some basic principles are established, regarding the idea of Ontogenesis, the study of the development of organisms, and Epigenesis, the mode Ontogenesis operates.

Drawing on D'Arcy Thompson's ideas and inspired on the models and approaches developed in the recent field of Artificial Life, this work explores the possibilities of using a model based in bone accretion to develop structural systems. The mechanisms by which bone is able to adapt are relatively known and simple, and at the same time they address a sensible problem, such as it is the case of the static performance of a structure. This may seem contradictory with what was mentioned above regarding problem solving. The problem is anyway approached not with the intention of finding optimal solutions, but challenging and creative ones. It is not answers the computer should provide, but questions about the problematic of the design. It is in this context of "problem-worrying" (as opposed to problem solving) that the work has been carried.

Only through the mutual interrogation and conversation between designer and computer a fruitful working process can unfold. Remarkably, some of the conclusion from the study of Ontogenetic processes can be extrapolated to the design process as a whole, and concepts such as Chreode or

Homeorhesis can be understood as referring to the development of a design work. These concepts are not very different from Gordon Pask's ideas on the "sprouts", through which he explained not only design processes, but also conversations and interactions in general [1].

1. Concepts.

1.1.Ontogenesis.

Ontogenesis describes the origin and the development of an organism during its live. There exists an old discussion in developmental biology on the precedence of Ontogenesis or inheritance in the generation and development of form. A Philogenetic, inheritance based, approach to morphogenesis can account for the great diversity of biological life, but 'Fortuitous variation' and selection can not alone acknowledge for all the variation and difference in the world of forms [2].

There are many other mechanisms by which organisms react and adapt to their environment, of which perhaps the most extraordinary example is the brain. But is not only the brain that develops through is capacity for reconfiguration and plasticity, many other parts of our body (for example) are also able to "learn" and adapt to different circumstances and events in our life span. Plants offer many other examples of the capability of reacting and adapting to the conditions of their environment through changes in their form: from mechanisms as photo-tropism (the tendency of plants to steer their body towards the sun) or the hill-climbing-like behaviour of their roots in search of water, to structural changes in the fabric of their fibres in order to increase their strength.

Artificial models of Ontogenetic adaptation also offer the possibility of studying the emergent aspects of form, pattern and structure, and a chance for examining their complex relations with function and meaning. Their difference in essence with other models, is that the evolutionary capacities of the system are intrinsic to the form and structure. They are not external to the form, and constitute a separate generic evolutionary process, that provides, in the other hand, a generality that is often one of the biggest strengths of Genetic Algorithms.

1.2. Declarative versus procedural descriptions.

One of the drawbacks of the general use of Genetic Algorithms is that usually the description of the form is declarative and closed to interpretation. There is a one to one mapping between genotype and phenotype, the translation process from one to the other being reversible (it is in most cases possible to find out exactly the genotypic description of a given phenotype). In nature, on the contrary, the information of the growth of an organism is in general procedural, the description of a process. It is impossible to map exactly phenotype in to genotype, since this is the result of epiphenomena, a visible consequence of the overall system organisation [3]. In Genetic Algorithm, there is in the system another level of representation (the genotypic coding), in which evolution operates. What happens in Ontogenetic models is that those levels are collapsed in to one, and there is not difference between the form that is evolving and the processes of evolution themselves.

“Philogenetic” evolutionary models are constituted by a population of individuals, and what evolves are the characteristics of those individuals. An Ontogenetic model is also made of a population of individuals, but in this case what evolves is the way those individuals are organised. What evolves is the overall structure, a concept that shares many similarities with that one of “Gestalt”.

1.3. Homeorhesis.

One of the most important theories in this sense of embryogenesis and Ontogeny is that of C.H. Waddington. Waddington suggested that the developmental processes themselves are the objects of selection of evolution. 'The organisms undergoing the process of evolution are themselves processes...’ He stressed the development of the organism through Epigenesis, or its formation through a series of processes in which unorganised cell masses differentiate into the different organs.

Waddington developed some very important concepts to explain how this happens, especially those of Chreod and Homeorhesis. Chreod refers to the stabilised or buffered pathway of change that the nature of a system directs it in, and Homeorhesis refers to the stabilisation of a course of change. Homeorhesis can be defined therefore as the co-ordinated changes of body tissues to support a physiological state.[4]

Waddington came up with the idea of the Epigenetic Landscape to explain these concepts of development. A ball rolling down the landscape represents the fate of the organism. The valleys are the different fates the organism might roll into. At the beginning development is plastic but as development proceeds, certain decisions cannot be reversed. The epigenetic landscape depicts the branching patterns of development and the different stabilities of these pathways. This constitutes a representation of development "not as a branching line on a plane but by branching valleys on a surface". The valleys on the landscape constitute the Chreods of development, and Homeorhesis the tendency (through modification of the body) to keep inside those development paths [5]. It is possible to establish a link also between these concepts and the idea of a “structurally determined system” of Maturana.

Homeorhesis is therefore equivalent to the physiological notion of “homeostasis”, which refers to a permanent equilibrium of the internal medium and its regulation. But in the case of Homeorhesis there is a self-regulation of the dynamic processes of development of the organism, instead of its internal states (temperature, oxygen in blood, etc).

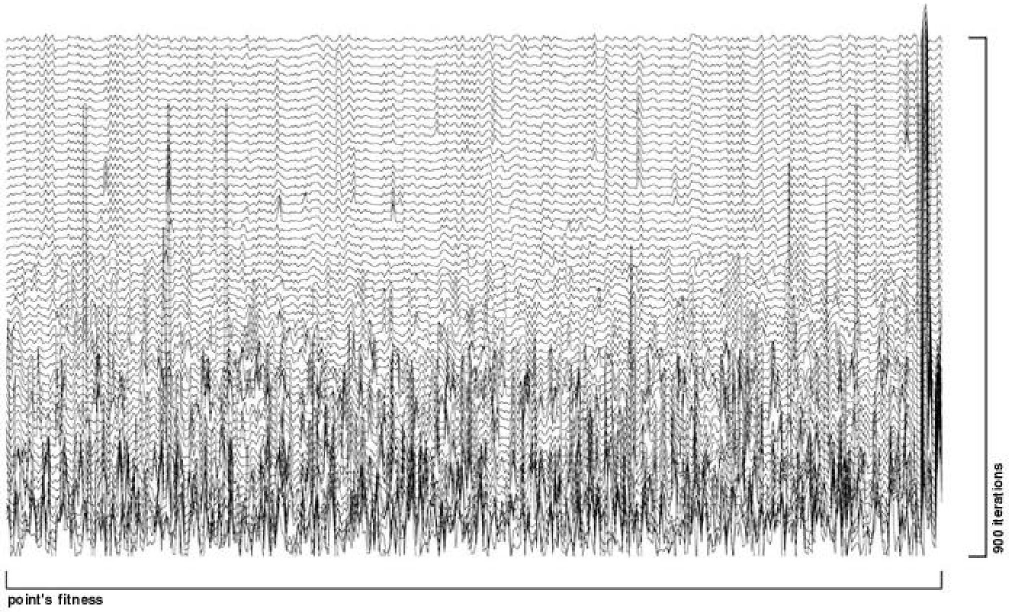

Fig. 1 ‘epigenetetic landscape’, evolution and smoothing of individual fitnesses.

1.4. Gestalts.

Gestalt theory emphasises the qualities of the assembly or form of complex objects (a melody, a face…). It basically states not only that there is a property of the whole as such, but also that the quantitative value of the whole is in any way equal to the addition of its parts. The concept of Gestalt is essential in trying to develop a generative approach to form, since it is opposed to mechanistic explanations in which form is just the sum of its parts.

One relevant aspect of Gestalts in relation with the above mentioned concept of Homeorhesis is their tendency to take the “best form” possible (law of the imposition of the “good forms” of the Gestalts). These self-imposed forms are characterised by their simplicity, their regularity, their symmetry, their continuity, etc. They are a result of the effects of the physical principles of equilibrium and minimum action (as in the case of the *Gestalt* of the soap bubbles: maximum volume for minimum surface).[4]

In this sense, it is worth mentioning the work of Gaudí and Frei Otto [6] and [7]. Both of them used "analogue" processes for the development of to some extend self-designed buildings. In the case of Gaudi, he developed the analogy of chains hanging as models of structures working on compression. Frei Otto extended this models (in fact he is responsible for the reconstruction of some of Gaudí's models), and developed his own, based for example in soap film and their tendency to form minimum tension surfaces. These analogue devices would find the minimum-energy configuration for a defined problem (the tensile structure of a roof, for example in the case of Otto's soap films), showing some type of elementary self-organising capacity. They are also an obvious (almost literal) example of what has been suggested regarding the Gestalts and the idea of the "best form".

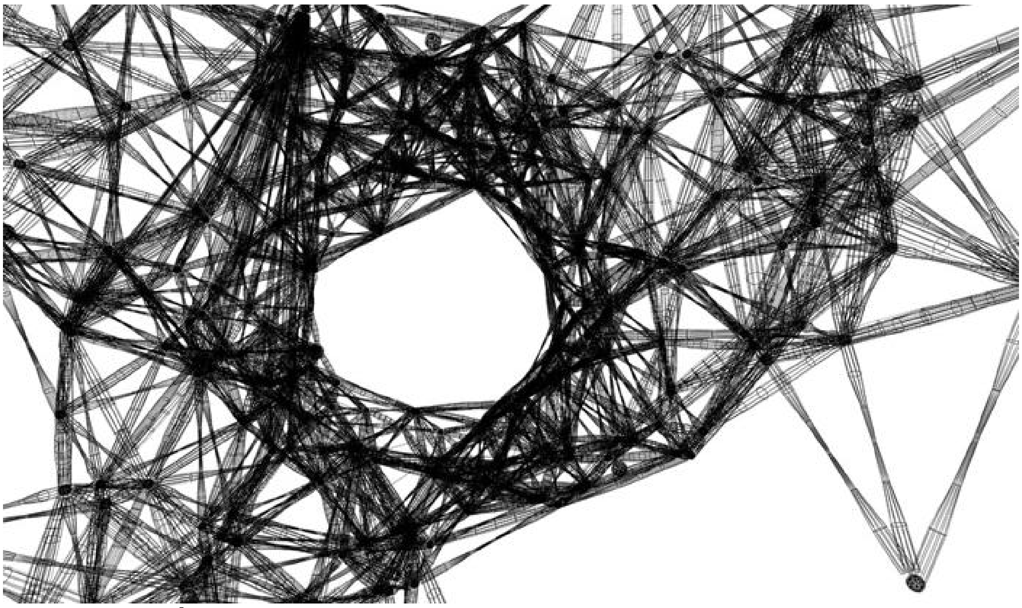

Fig. 2. Structure bearing a torsion moment.

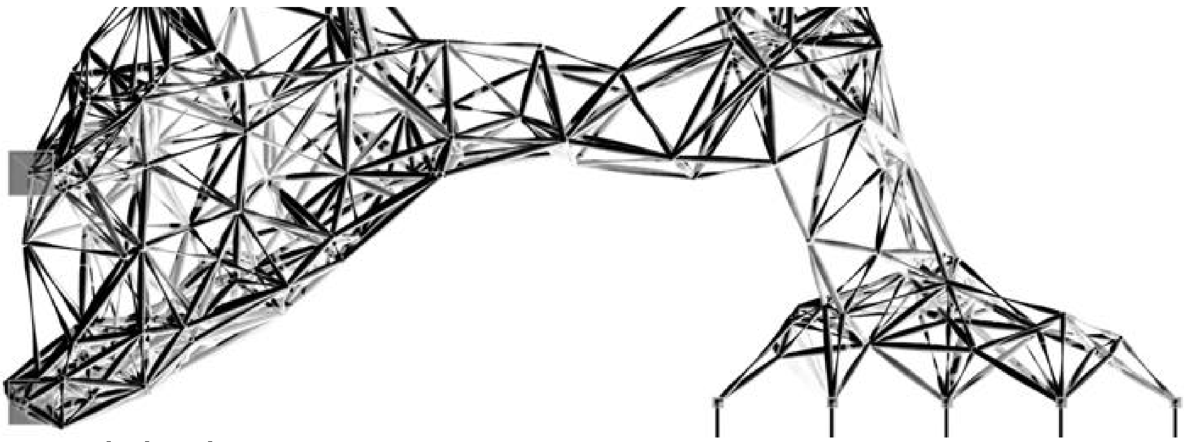

Fig. 3 Evolved cantilever.

2. The model.

2.1.The mechanism of the bone.

One of the clearest examples of Ontogenetic adaptation is the case of the travecular bone.
The structure of cancellous bone, as it is also known, is quite remarkable: It is constituted by a lattice of small cancelli and trabeculae, either in the direction of that weight they support, or as to support and brace those cancelli. They remind very clearly a series of “studs” and “braces” in a construction.

The trabeculae of the bone are able to adapt to changes in the load conditions acting upon them. Besides showing capacity for self-repair in case of fracture, bone can modify its form in order to improve its efficiency for carrying different weights. If the bone breaks, for example, and it is repaired slightly out of its previous alignment, the whole system of cancelli will have readapt to the new arrangement of forces only in weeks, the process being able to extend and affect the lattice even in distant extremities far from the fracture. [2]

The trabeculae of cancellous bone are constantly being formed and demolished. Strain works as a growth-promoting factor, the structure being stimulated by pressure to grow, and thus increasing the amount of trabeculae in areas of high stress. In areas of low stress the traveculae will get slowly dissolved and erased.

This re-adaptation of the strength of the tissue does however not only happen in bone. Plant tissues seem to behave in a similar manner, being able to increase their strength without any necessary increase in their size, but instead by some histological, or molecular, alteration of the tissues. This is an example of symmetry breaking, in which ‘the original isotropic condition is transmuted more and more into molecular asymmetry or anisotropy’. [2]

2.2. Basic description.

The model comprises a population of points in space with a very basic knowledge of their immediate environment. The points are first distributed randomly in an existing environment consists of a number of fixed load vectors and supports.

An iteration of the system consists of the following basic steps:
1. A Delaunay Tetrahedralisation is performed on the space filled by the points.

2. Then, the tetrahedra are classified according to certain criteria (for example their dimensions) and all their edges given the same elastic module. If the tetra is valid, they will get a "hard" elastic module. If they are invalid they will be "soft". The edges will become, this way, linear elements of a structure, equivalent to the trabeculae in the bone.
3. All the resulting structure is then evaluated through the Finite Element Method and the stress and displacement calculated for each "trabecula". The initial points calculate then a sum of the stresses of the "trabeculae" or edges that converge in them and this will become their "fitness" or the value of their performance.
4. The points with lowest fitness values will then migrate to the neighbourhood of the of the points with higher fitness, and the algorithm proceeds again through another iteration, recalculating a new topology for the structure that acknowledges the changes of the point's distribution. Topology therefore is not fixed and is also evolving.

A Delaunay triangulation (or tetrahedralisation in the case of 3 dimensions) is the dual (or the "negative" graph) of a Dirichlet tessellation. Diritchlet tessellations or Voronoi diagrams as they are also known, identify an interesting geometric structure that has been used in geographic analysis, for example, for defining market areas around urban centres. In this particular case they offer also an obvious advantage; they produce statically rigid structures of space-filling tetrahedra.

2.3. Self-repair.

There is an explanation for dividing the tetrahedra and their edges in "soft" and "hard". In general the linear members that make the "soft tissue", comprising the parts of the tetrahedralisation that don't belong to the primary structure, don't carry more than a 4% of the minimum stress of the "hard tissue", because of their weakness. If this condition is not fulfilled by one of the members, it means that the "soft tissue" has been forced to carry the loads, and it is understood as a fracture (there are not hard member that are able to carry the load). When this happens, the soft member under stress adds a high value to the fitness of the nodes that define it; this therefore stimulates growth around the fracture area.

2.4.The process as aggregation.

The system constitute a basic aggregation model: points tend to aggregate in areas of high stress, but since they are "competing" for the loads, over a certain density a saturation level is reached. They have to share the loads and their individual fitness then decreases, making the area "less attractive" and thus regulating its density. When areas of low stress, in the other hand disappear, they reinforce zones of higher fitness to even increase it, since the loads carried by the weak elements, even if small, will have to be re-routed through the stronger ones.

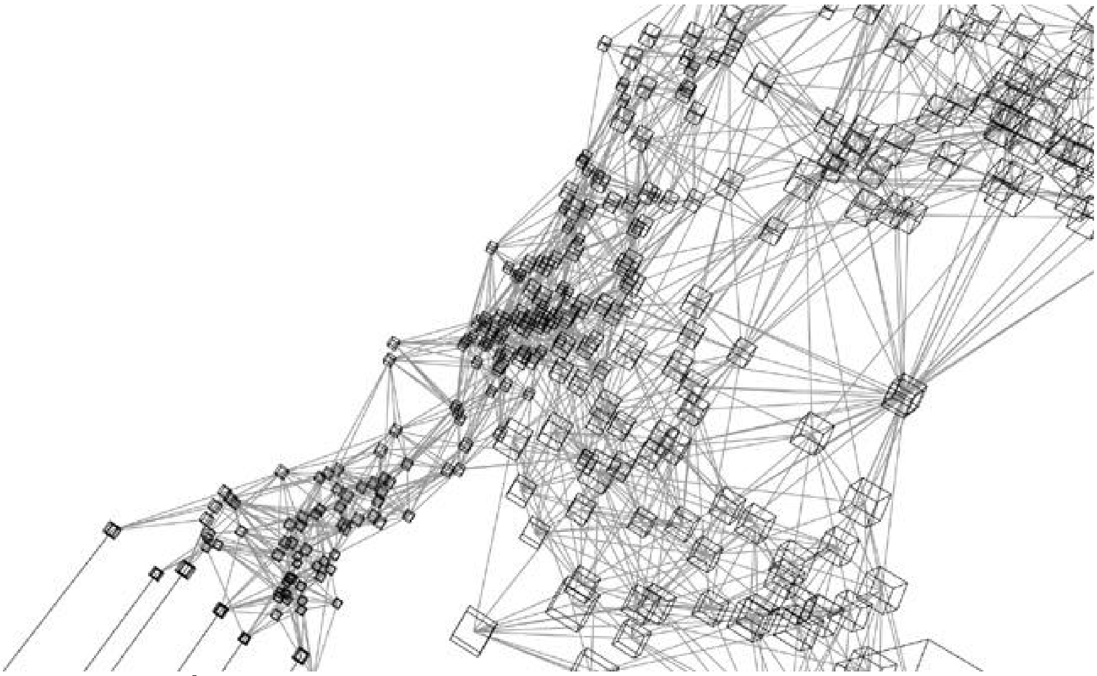

Fig. 4. Aggregation and structure.

Alan Turing provided a hypothesis to explain the generation of pattern in a wide variety of settings including the formation of leaf buds, florets, skin markings, and limbs. According to this hypothesis, chemicals called morphogens generate organs when present in sufficient density, and the patterns that generate them are created through mechanisms of reaction and diffusion of the morphogen.
Stress, in relation to a diffusion-reaction model, works in bone accretion as the “morphogen” or growth promoting agent, and the form of the network (its topology as well as other factors such as distance and orientation) as the decisive factors in the propagation and distribution of the morphogen. Each point, therefore, works two ways: depending of its position in the structural network, its fitness will be evaluated according to the amount of stress it receives. In the other hand, as a node in the network, it will affect how the stress or morphogen propagates through itself to other points.[8]

2.6. Structure determined system.

The unfolding of the adaptation process has key distinct similarities and convergence with Waddington’s Epigenetic development process mentioned above. Each of the changes in the structure pushes the development in a determined direction, similar to the way the ball rolled through the Chreods of the Epigenetic landscape. Maturana and Varela explain a similar concept, which they refer as the ‘structure determined’ systems. Since an organism’s structure at any point in its development is a record of its previous structural changes, and since each structural change influences the organism's future behaviour, this implies that the behaviour of a living organism is determined by its structure, formed by a succession of autonomous structural changes.

In this respect, S. Kauffman has explained a similar process in relation to coevolutionary self-constructing communities of agents. The individual points in our system bear many parallelisms with the agents described by Kauffman. Instead of an epigenetic landscape of the whole assembly we have in his explanation individual "fitness landscapes" for each agent. In his model the adaptive moves of one agent deform the fitness landscapes of its partners. Endogenous coevolutionary processes allow agents, each adapting it's own selfish "fitness" to tune their couplings and fitness landscapes, so the entire system achieves a specific self-organised critical state.[9]

Conclusion.

All this work is intended as a starting point for the development of processes in which the form and structure are the responsible and the result of the evolution dynamics of the system. The work intends to expand in different research directions, to identify other situations and design contexts where the ideas are valid and developable, and to explore in depth the possibilities of interacting with such a system during the design processes. We are currently working on a computer vision based interface that will allow us to interact through body movements with a similar environment, so we can define spaces of movement, forces and gradients in which the system will evolve, and to which it will adapt.

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