Current work at CECA

Three projects : Dust, Plates & Blobs

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Abstract

The centre for environment computing and architecture continues to experiment with new ways to form, and this paper presents three recent projects from the MSc programme. The three projects all share underlying assumptions about the use of generative algorithms to construct form, using fractal decomposition, lindenmayer systems and the marching cubes algorithm respectively to construct three dimensional "architectural" objects. The data needed to drive the morphology however ranges from formal proportional systems and Genetic L systems programming through swarming systems to perceptive self organising neural nets.

In all cases, the projects pose the question what is architectural form. While after Stanford Anderson (Anderson 66) we know it is simplistic to say that it is an automatic outcome of a proper definition of the brief, it is also difficult to accept that the form of a building is an entirely abstract geometrical object existing without recourse to social or contextual justification. In an attempt to resolve these issues we have turned to the study of systems and general system theory as a way of understanding the mechanics of emergence and morphogenesis generally, and the relationship between form and function in objects in the world, and current theories of cognition to help understand the relationship between form space and people

DUST

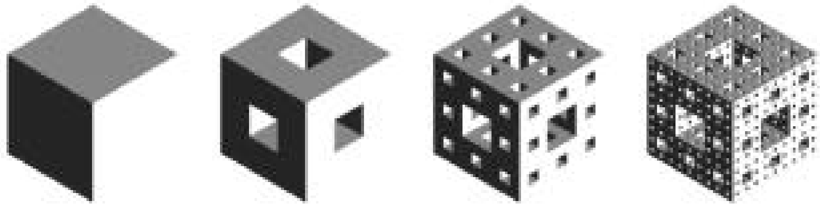


Fig 1 Menger Sponge

Tom Appels takes the abstract formal position based on the Belgian theorist Van der Laan(V D Laan 83,97) in his fractal decomposition algorithm, and we have had many discussions about the "architecturalness" of the outcomes. The visual appropriateness of many of the outcomes (one example has a close similarity to Aldo Van Eyks school designs) probably reflects the fact that many buildings do have self similarity over a range of scales, and that well chosen systems of sizes and ratios will look sensible and human scaled.

It is no surprise that these outcomes have a Dutch feel, as the system of proportionally related cuboids with everything at right angles to everything else is of course the foundation of De Stijl (Kruijtzer 98) and the austere architectonics of the modern movement Toms palette is similarly restricted, and though Van Der Laan was not known to the founders of the heroic period in Dutch and German architecture in the early 20th century, the general tone of aesthetic purism was certainly a shared goal of many designers at the time.

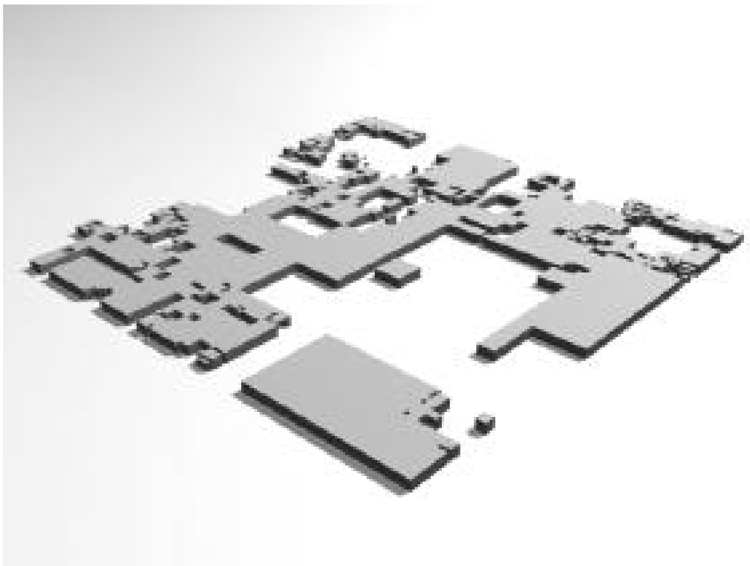


Fig 2 fractal decomposition of a plate

Van d laan's idea, in common all theorists who propose such things (Vitruvius, Corbusier etc)(Corbusier 1955) is that townscapes, buildings, rooms, furniture and details should be derived in succession from each other, with the fundamental constants being human sized numbers and proportions; architecture after all is habitable space, and the inhabitants are human beings.

Tom's research began with defining the proportional systems and thus the library of forms to be used at various scales. These were taken from Van de Laan's "FormBank".

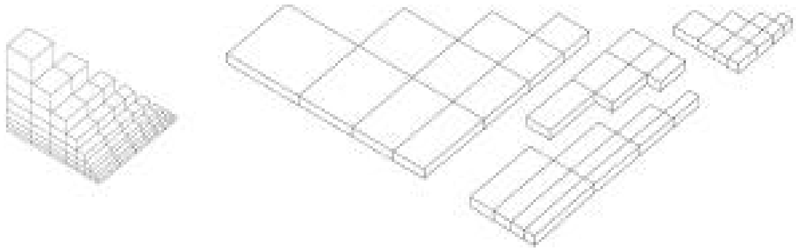


Fig 3 Van De Laan's Form bank

To begin with we adapted the CECA Genetic Programming program (Coates Makris / Hazarika / Jackson / Braughton 95,96,99) to experiment with random collections of such forms with the intention of evolving "hopeful" agglomerations.

In this system the s-expression is made up of functions (such as move copy delete union

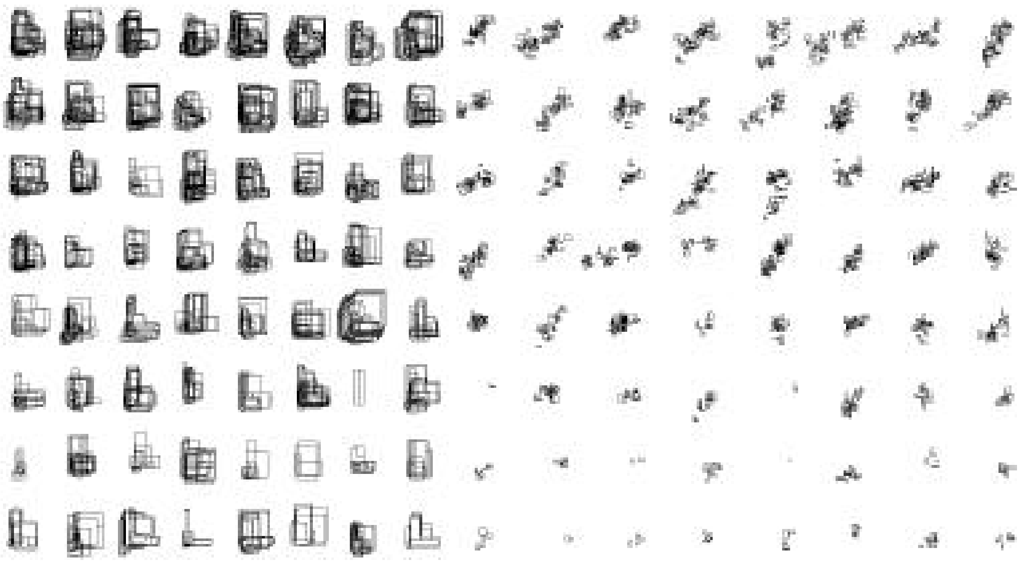


Fig 4 views of 8 generations of the GP using FormBank items (top view)

difference etc) and terminals (the library of VDLaan's form bank). Individuals are generated by evaluating the s-expression as a lisp function, which as a side effect instantiates the solid geometry as an object (Coates 1999). While this may have been eventually possible, the need to define a very large number (> 500) of primitive objects as terminals meant that very long trials would have been needed to search the design space, and the alternative (generating random combinations of length width and height from the library of forms) compromised the integrity of the genome, leading to unpredictable results and lack of useful inheritance between generations. (See appendix 1 for a discussion of this problem)

Instead of an agglomerative approach (building up form by agglomerating collections of library forms) it was decided to adopt the decomposition strategy instead, where, starting with a cuboid of given (building size) dimensions, the block is sliced up into rules based (library shape sizes) chunks, some of which are retained for further slicing recursively. This is the equivalent to generating a fractal dust in 3d, where the dustyness is determined by the user defined proportion of lumps thrown away.

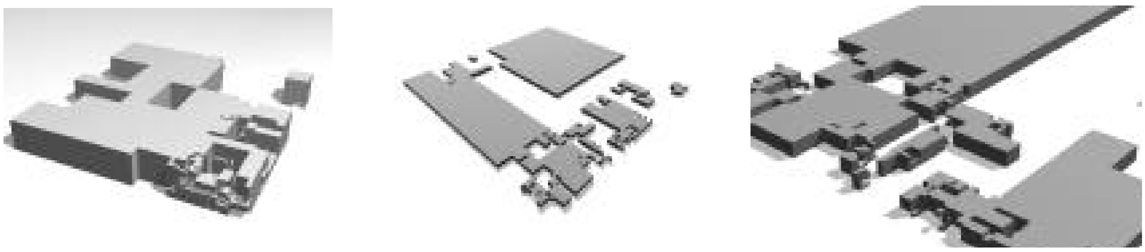


Fig 5 block and plate decomposition experiments

The system is clearly related to the menger sponge, which like all fractals has the curious property of having finite volume but a surface area tending towards the infinite.

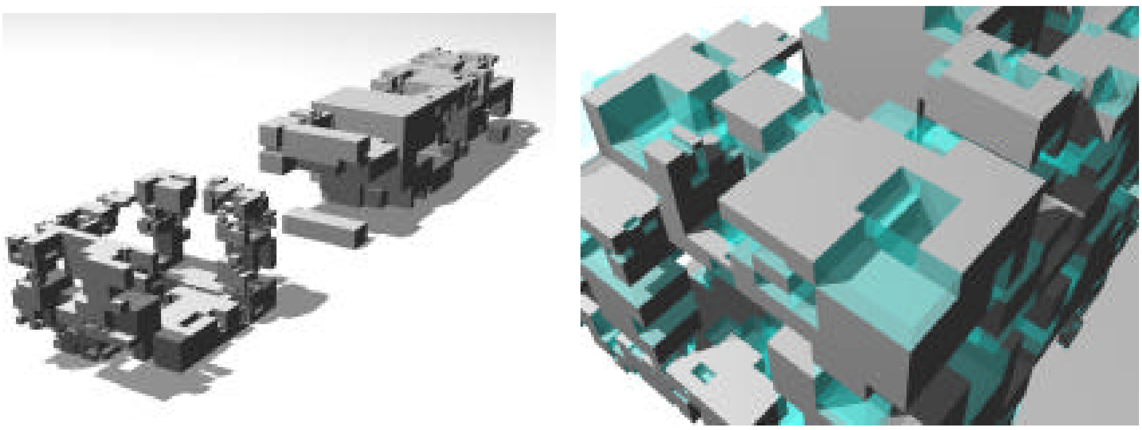


Fig 6 block and cube experiments (with delete replaced by transparency)

The pure recursive system was further elaborated by setting up different values for amount of slicing, proportional system and keep/delete ratios for each level of recursion (there were usually only 3 levels, to correspond to VDLaan's three orders of size) This allows fine tuning of the outcome, (i.e. keeping only few blocks at the first recursion leads to a spread out pavilion like morphology, while the reverse leads to denser more detailed single masses - the villa or palace perhaps.)

PLATES

The following project explores a way of developing form as the emergent property of the interaction between a form making process (Lindenmayer systems (Lindenmeyer & Prusinkiewicz. 88 90) and an automatic reading of the dynamics of occupation using swarming agents. Rather than form as an end in itself, it is the by-product of the structural coupling between two open systems: the evolving L-system and the swarms of interacting virtual agents. (See appendix 2 for a technical presentation of the ideas about autopoesis and structural coupling)
Using L-systems with GP has been an on going experiment at CECA, with a variety of approaches to form generation ranging from the "balls in space" approach where the production system determines the position of points in space (represented as spheres in the isospatial system) (Coates 95) through simple insertion of cylinders as in the 3D branching structures, to more complex edge / node rewriting systems for inserting different 3d objects with a series of production rules. (Coates 1999) In general such systems rely on evolving the production system at the heart of the L-system; i.e. the genome is the right hand side of the production system, written in l-system symbols. Since the symbol string is represented in normal lisp format as a succession of atoms and lists, it can be used as an s-expression and the normal operators of crossover and mutation can be done a la Koza. (Koza 92) and Jacob (Jacob 94)

In Corinna Simon's experiments the l-system was initially defined as an edge rewriting system with two left-hand sides and two right hand sides, whose most simple expression was a branching sequence of hexagonal plates.

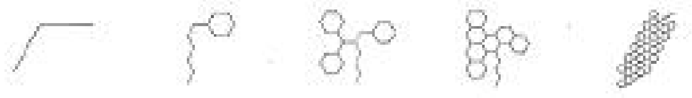


Fig 7 edge rewriting line system for generating hexagonal arrays

A > (B y+ F y- A)

B >(y- F y+ F y+ F y+ F y+ F y+ F y- F y+ F B)

The symbols are :

F draw a line

Y yaw (+ or -)

P pitch (+ or -)

R roll (+ or -)

Where the angles for the rotations are 120 degrees

Which allows the production of lines in 3D space.

Subsequent experiments lead to adopting a simpler node rewriting system where the draw function was reduced to inserting a hexagonal plate.

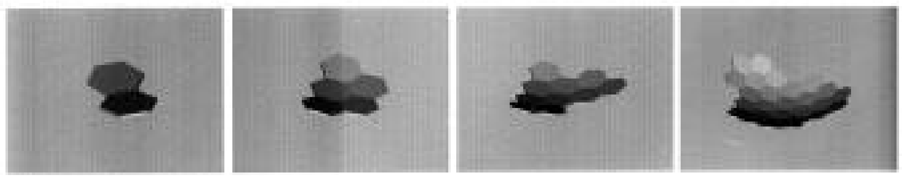


Fig 8 1 2 3 & 4 recursions of hexagonal plate L-System

F > (F y- y- (y- y- F) r+ y- y- (y+ y+ F))

In this case the yaw angle is 120 degrees and the roll and pitch angles are 10 degrees.

This was chosen because the task of the system was not to build a skeletal structure (the familiar branch/leaves scenario of plant models cf. Lindenmeyer A Prusinkiewicz. P 88 90) but to develop an areal surface structure as explored by Kaandoorp (Kaandoorp94) in his work on sponges. A sponge develops in a milieu of water born particles and its shape is the result of the attempts by the sponge to absorb the maximum amount of particles of food floating by in the current. In these experiments the l system was evolving in an environment of swarming perceptive agents whose behaviour was initially independent of the plate structure (as in the food particles) but where a feedback loop was implicated in coupling the evolution of the l-system with the developing swarm environment.

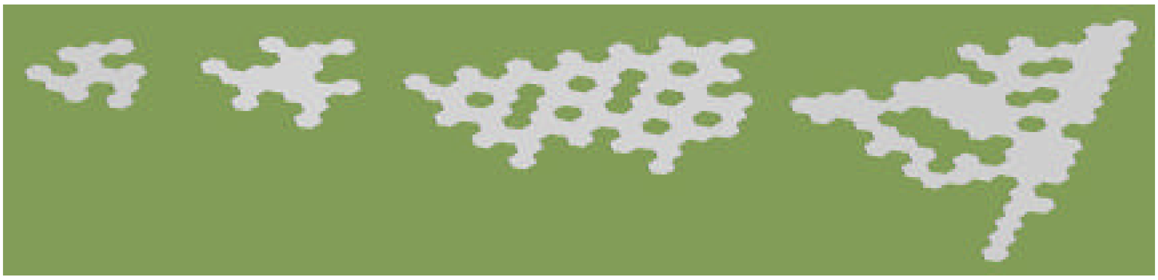


Fig 9 branching structures evolved using the plates L-System

The definition of a fitness function based on the swarm allows natural selection amongst the l-systems, rather than relying on the eyeball test, and provides a closed loop which automatically evolves towards a result where the swarming agents and the plate system are in balance.

Fig 10 Some multi-layered structures

The figures illustrate the range of morphologies the L-System can adopt with flat or curved plates and single or multiple layers, and figure 11 shows that the evolutionary system has to not only develop a good spread or cover over the swarm, but also has to avoid inefficient duplication of plates.

Fig 11 Inefficient and efficient growth

The project is very abstract and must be seen as part of a long-term debate about the possibilities of exploring urban dynamics. However, it is based on a very particular observation of land use in Kings Cross railway lands in London, which is modelled by swarms. (Langton 92) CECA has been exploring swarming behaviour for some time as another way of exploring emergent forms of spatial occupation. (Coates 99)

The swarms (which are essentially 2d walkers) represent the idea that in certain situations (in derelict or underused land) land use can change by opportunistic occupation of land with a series of complementary activities, which encourage further infection (as it were) eventually leading to a new set of uses and with them urban fabric and infrastructure.

In this abstract model, the swarming agents represent these activities, and the l-system the infrastructure, which tries to evolve to cover the most activities, represented by markers dropped by the agents when complementary activities are recognised. These markers represent the food for the l-system , more markers found = greater fitness in an individual l-system.

The feedback between the swarming agents is the standard one of each agent moving towards the nearest other agents of the same type. There are five types of agent representing the five activities found on the site. When agents of different types meet, they can optionally drop a marker (if the agents are complementary). Since the different agent types swarm individually, a meeting of two different types typically also means that two swarms have met, leading to many markers being dropped.

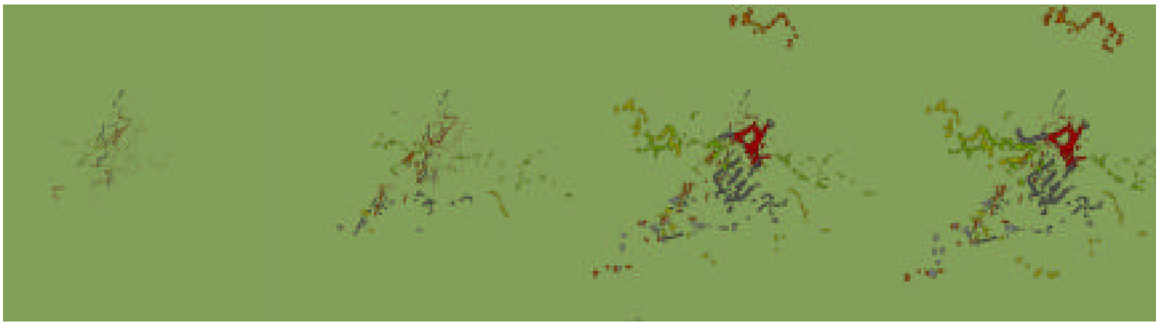


Fig 12 The evolution of the swarms

The feedback between the growing/evolving L-System and the agents is that when the L-System "covers" a marker, it is recognised and labelled (turned red). This feeds back to the swarm mechanism, since the agents are encouraged to drop new markers in the neighbourhood of a red

marker. Thus, the two systems are coupled, with the agents initially seeding the site, and the GP l-system attempting to evolve an efficient infrastructure whose fitness function is:
Number of markers covered - number of hexagonal plates used in the construction

In this way the two systems (the swarm and the GP) are coupled together, with the agents initiating spatial occupation, the GP / marker/swarm system gradually herding the emergent occupation into spatially coherent areas in order to maintain its own organisational integrity (maximum food per unit of structure in the terminology of the sponge model)

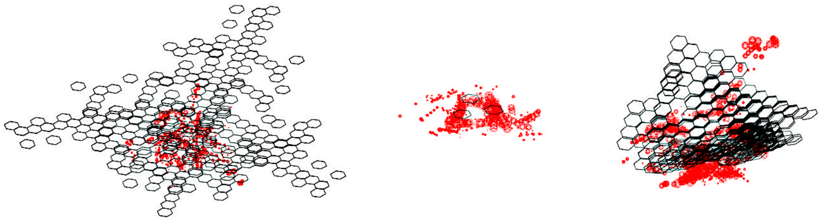


Fig 12 Some final results of coupled systems

The end result of this coupling is an emergent occupation which provides optimal local correlation between uses (as defined by the agent correspondences set as part of the swarm system) and an optimal global relationship between these uses and the infrastructure needed to service them.

BLOBS

Traditionally space is regarded as leftover from human interventions, delineating shells or objects. Space could only change if men chose to manipulate the built environment, making space a dependent static entity [Derix and Thum, 2000]. This perception rests within our nature as living systems; we are embedded in the biophysical world where our primary senses as vision or touch perceive physical entities (high quantities or clusters of atoms or molecules) over non-physical [Miller and Lenneberg, 1978]. The non-physical represents our blind spot. Thus, we create in our psychic and communication system thought constructs and semantics that are based on physical experience. Although Luhmann gives the communication its autonomy, its elements are essentially embedded via the psychic system in the neuro-physiological and organic system.

Architectural theorists like Bill Hillier [1996] and Christopher Alexander [1965] have generated an understanding of a systemic structure of space or rather the city and of networks of relations within those structures. This project goes a step further and proposes space as an autopoietic system that produces its elements and relations through operational closure by itself [Derix and Thum, 2000]. Further, if space was to be assumed an autopoietic system, then it will be capable of structural coupling with other autopoietic systems, like actions of people that belong to the social system, or others. (see appendix 2)

Additionally, according to Luhmann all autopoietic systems are capable of observation [Kneer and Nassehi, 1993]. The operation of observation can take its own observations and actions as reference leading to self-observation. Re-computations of descriptions of itself generate the possibility of self-differentiation giving rise to the opportunity of spatial sub-systems. These spatial sub-systems generate their options for adaptation to contextual perturbations. The architect knows neither the functionally differentiated sub-systems nor their options for structural change. The speculation arises, that spaces can differentiate into sub-systems where the human psychic or communication can't observe and describe any differences [Derix and Thum, 2000]. In other words people might be occupying spaces and spaces might be occupying social fields with reciprocal ignorance. The neuro-physiological and organic system might be able though, to enter structural coupling with those undetected sub-spaces and generate options for mutual adjustments within a consensual domain. That could be a reason why one can see spaces being differently used than the planner had in mind and couldn't predict, especially salient as an example is Brasilia.

AN ARTIFICIAL NEURAL NETWORKS MODEL

Understanding that space as we can't see and describe it is a dynamic system, which through its operational closure generates its own elements and relations that it self-organises through second order observation, the epistemological approach to space formation and interpretation must shift.

The systemic structuring of space hides on the side of the distinction that we cannot describe - the non-physical - our blind spot. Since we can't linearly cause change in spatial systems, designers should try to broaden their design approaches via new analytical tools of spatial relations [Derix and Thum, 2000].

An artificial neural network (ANN) based on the Kohonen self-organizing feature map (SOM) shows close affinities to the conditions of complex and self-organizing systems qualifying itself as a good basis for an abstracted autopoietic spatial network [Cilliers, 1998].

The SOM developed by Teuvo Kohonen [1995] is one of the few unsupervised network types bearing close relations to the mechanical processes of the human cortex.

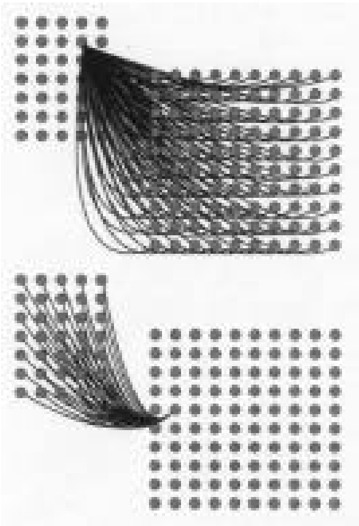


Fig 13 Kohonen SOM Input-Output

SETUP & SPATIAL DETERMINANTS

Kohonen's algorithm had to be modified from a two dimension to a three dimensional matrix where vectors could change their position and length in three-dimensional space.

As a ‘proof of concept exercise’, inputs the self-organizing space (SOS) 'perceives' are three-dimensional points from a virtual model of the area north of King's Cross Station in London serving as a test site. The points are generally corner points of volumes, but the SOS can also interpolate points along edges between two existing points. This type of environmental input doesn't describe any volumes, planes or edges, in other words points are the smallest geometrical and morphological entity one can perceive without inferring a semantic object that is part of a human communicative consensual domain.

The SOS' matrix of neurons consists of 3D points as well. Each neuron establishes after each generation of adaptation a perceptive space within which it can 'perceive' points from the virtual model. This perceptive space is calculated by comparison of the distances (relations/ connections/ weights) of each neuron to all its neighbouring neurons in the matrix. Initially, the shortest connection determines the radius of a sphere that prescribes a sphere-external cubic perceptive space. After several tests, the cube seemed more suitable than the sphere, because it increases competition between neurons over input since perceptive spaces are more likely to overlap. Over time, each neuron's perceptive space radius might non-linearly change due to functions that memorise each neuron's position and input perception over a certain number of generations.

These functions compute a local as well as global dynamism value, which when referenced to each neuron can modify the perceptive space of each single neuron separately. But each neuron can also modify its perceptive space by computation of its dynamism and previous perception. The SOS can therefore compute its previous perception, describe its own observations, and internally perturb its structure in order to maintain its homeostasis, aiding the continuation of perception. Generally ANNs adjust their structures only within one adaptive generation. S.A. Kauffman [1991] recommended 'networks can be made more complex by imposing certain *biases* on the nodes.' The bias imposed on the neurons of the SOS is the perceptive space based on distances to neighbours.

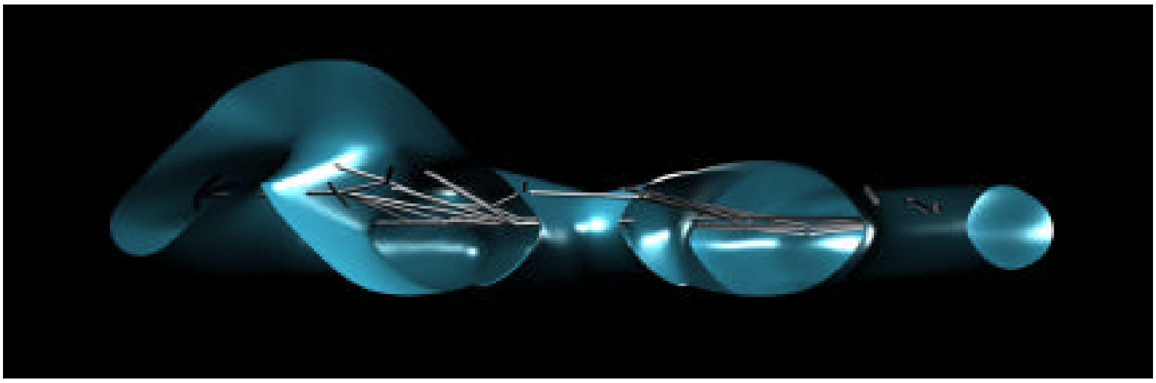


Fig 14 Prototypical section

When the perceptive spaces of the neurons have been established, each neuron compares at the beginning of each adaptive generation its Euclidean distance to all points of the virtual model stored in an array. Points inside the perceptive space will be considered as input for the neurons. But since several neurons might 'find' common points, competition over these points begins, resulting in the establishment of the winners as the neurons that have the closest position in space to the input points. Based on this competitive procedure, a multitude of points are selected from the virtual model, which form a space representing the contextual perturbation perceived.

SELF-ORGANISATION PRINCIPLES

After the space perturbing the SOS has been selected, the self-organisation of the network starts. As a basis for the learning Hebb's learning rule was used, which itself was first verbalised by Freud at the end of the 19^{th} century in his work 'Project for a scientific Psychology' [Cilliers, 1998]. During each step of an adaptive generation, one winner of the SOS will be assimilated over repetitive cycles to the perceived input point until it is marginally close to the spatial position of that point. The winner establishes at the beginning of its assimilation process a monotonously decreasing neighbourhood around itself within which the contained neurons will also be assimilated to the input point, though to a lesser degree. All neurons outside that neighbourhood are dissimilated. This recursive feedback either excites neurons or inhibits them [Spitzer, 2000]. The competitive learning rule generates for each input one topological cluster, whereas the representation of the input itself is distributed over

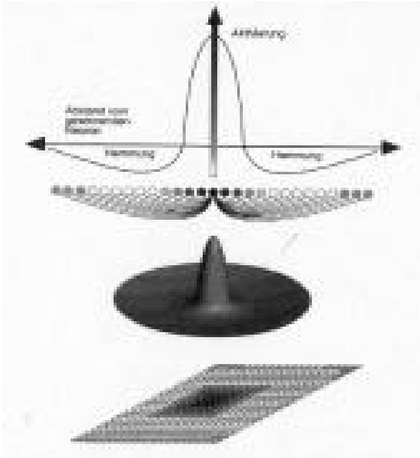


Fig 15 Perceptive Topologies

the whole network. The differences between neuronal_topological configurations contain *a* 'meaning' for the inputs perceived. Yet, since each winner will re-organise the structure of the SOS within one adaptive generation, the 'meaning' for each input is continuously referred as long as the SOS perceives new input spaces relating to Derrida's concept of *différance*. Theoretically, at the end of each adaptive generation a *Gestalt* is generated by the structure of the network that is isomorphic to the perceived space. Since on the other hand the structures at the beginning of each adaptive generation determine the present perception of the network, the evolution of the SOS heavily influences the present *Gestalt*. Thus, a perceived space will not be able to linear-causally generate a discrete isomorphic structure.

As mentioned above, an autopoietic system needs to be open in order to exchange energetic resources with its environment to retain its operational closure. The SOS takes points from its context, describing spaces. If on the other hand, the SOS can't perceive more than three points (a space), the system disintegrates, for it cannot maintain its internal processes that make adaptation possible. That condition of the presence of a contextual threshold at which the dynamism and the processes of the SOS cease to exist points towards an important characteristic of autopoietic systems: the necessity of embeddedness into an environment without which it can neither learn, evolve nor adapt [Steve Grand, 2000]. Just like artificial life, the SOS is context-dependent and as such makes it more coherent with complex system theory than other artificial parallel-processing complex models that are context independent in order to maintain their processes.

Hebb's competitive learning rule is also termed the 'use-principle'. Input spaces that occur more frequently reinforce connections between a similar group of neurons facilitating the reading and classification of that input into topological clusters [Cilliers, 1998]. The frequency strengthening

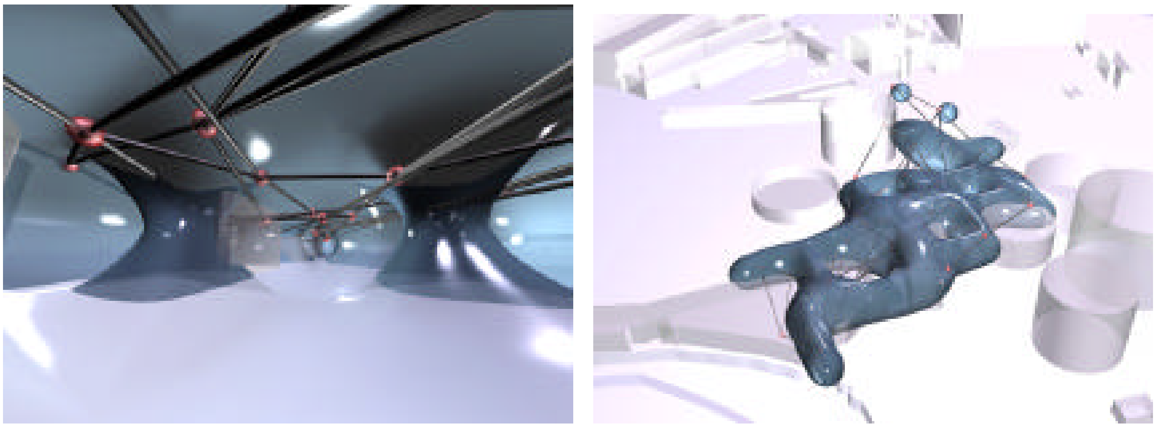


Fig 16 Single SOS adaptation inside and general view

the connections between neurons of a certain topological cluster are also less likely to immediately perceive completely unrelated input since their perceptive spaces are much smaller due to the bias imposed on the neurons. Thus, similar input will be perceived within the same group of neurons, allowing for a generalised learning of affinities between features of input [Spitzer, 2000]. A sort of memory has been created.

If on the other hand an input is rarely perceived, strong connections cannot be formed and the organisation of that input in the network quickly re-structured. Thus, the input will be 'forgotten' again.

Cilliers describes Hebb's rule as a mnemonic function as following: '"Memory" refers here to the physical condition of the brain: which pathways are breached (facilitated) and which are not. Memory is not a cognitive function performed by a conscious subject, but an unconscious characteristic of the brain.' [Cilliers, 1998]

To visualise the structural space and morphologies the SOS generates, an algorithm that generates implicit surfaces enveloping densities of in this case points, which represent the neurons was applied. The algorithm used for the SOS is called 'marching cube algorithm' Bloomenthal, 1988]. With the help of implicit surfaces a distinction between the systemic internal body or form from its environment is possible that enables the analysis of neuro-spatial typologies about which will be talked further down.

EMERGENT PHENOMENA

Autopoietic systems are rooted with their smallest decomposable elements within the environment that defines those units [Miller and Lenneberg, 1978]. So that the human being, although composed of four autonomous systems, can be traced to its organic biological context the cells are embedded in. One binary code of distinction for visual and haptic sensing is physical/ non-physical, as discussed above. For an attempt at an autopoietic spatial system like the SOS the smallest element is a space made of at least four points. The problem arises that it is unknown what code of distinction the SOS or space in general is based on. Not being able to grasp its code of distinction, it seems impossible for now to investigate into possible communicative consensual domains space might develop. Therefore, space as it is based on a very different type of perception will generate its own type of 'reality', making it very difficult to evaluate, as of at this point in time, the *Gestalten* and morphologies that the SOS brings forth.

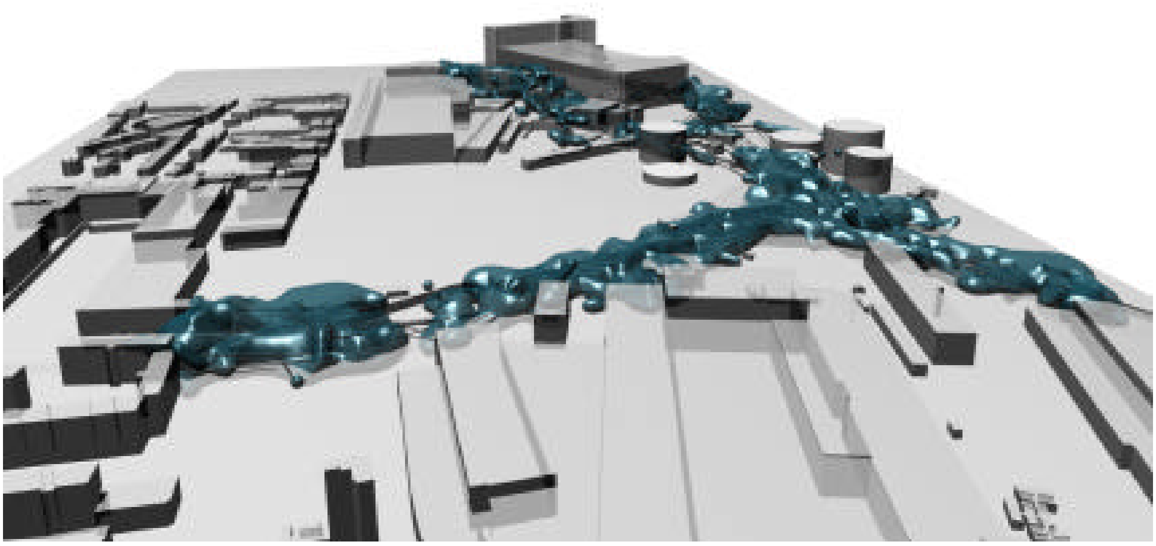


Fig 17 perspective of tracked morphology

Whilst investigating a large number of footage of animations taken from the network, a repetitive feature appeared to be discernible that could be associated to a phenomenon present in our human communicative consensual domain. It is a kind of behaviour and decision making process that the SOS expresses through a topological sequence of *Gestalten*. Towards the end of an adaptive generation the structure and therefore shape of the SOS comes to momentary stable states when the input space has been sufficiently adapted to. In those phases toward the end of one generation and at the beginning of another, some neurons, possibly those that have been inhibited throughout the generation, will generally be isolated outside the topological clusters of neurons. Those neurons will probably have a greater perceptive space and function as a type of dominant sensor, or *feeler*, which explores the future options of perception. Metaphorically speaking, it behaves like a snail that feels the environment and takes decisions for the network of how interesting a certain direction seems. The consequence is either that the main cluster of the network will follow into the direction of the *feeler*, the *feeler* withdraws and re-integrates with the main cluster, or the network fragments into clusters. Such a repetitive phenomenon

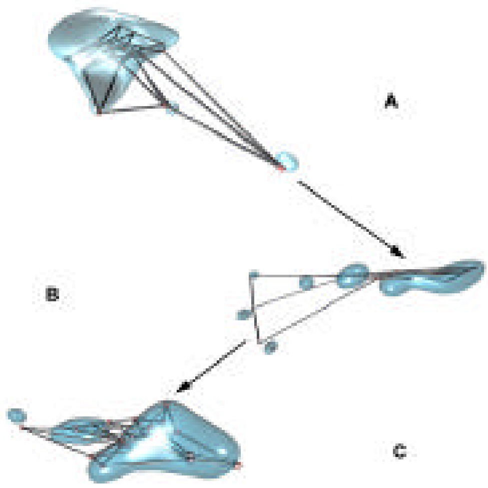


fig 18 haptic feelers

like the above described *quasi-haptic* sensory perception of the SOS is described by Cilliers as a pattern of entrainment. He states that ' when patterns will catch others in their wake in the sense that they will start appearing in concert. This process increases the order in a system and facilitates the formation of associations through resonance' [Cilliers, 1998]. Kauffman also puts forward some arguments for the emergence of features in self-organizing systems: 'He demonstrated the formation of order through "cores" of stability that form in a network. This stability "percolates" through the network as adjacent nodes are drawn into stability by the already stable group. The result is that the network is "partitioned into an unchanging frozen core and islands of changing elements". Fluctuating groups are thus isolated, and order is imposed upon the network [Kauffman, 1991].'

CONCLUSION

The current self-organizing spatial neural network can merely be regarded as a morphogenetical tool that incorporates salient characteristics of complex as well as autopoietic systems at a low level of complexity. The virtual model of the site under investigation to test the analytical and syntactical skills of the neural network is also of much reduced complexity. Further, it would be desirable to introduce additional input variables that the SOS could perceive and adapt to. However, the resulting Gestalten and the adaptational structures of the network suggest some *real* complexities resulting from its interactions through perception and their organisations.
To be able to literally make more sense of the networks' *Gestalten* within our semantics of our communicative consensual domain, one must apply other levels of reading to the resulting structures. The SOS can only be the very first step in the analysis of complex systems, such as the urban tissue. New ways of classifying and describing the results must be added on via maybe other neural networks or genetic algorithms that can develop 'fitness functions' for generated morphologies. Even then the development of a 'fitness function' will be difficult to justify unless it would be generated by a complex system itself:

'Since the self-organizing process is not guided or determined by specific goals, it is often difficult to talk about the *function* of such a system. As soon as we introduce the notion of function, we run the risk either of anthropomorphizing, or of introducing an external reason for the structure of the system, exactly those aspects we are trying to avoid. When a system is described within the context of a larger system, it is possible to talk of a function of the sub-system *only within that context*. […] The notion of function is intimately linked to our *descriptions* of complex systems. The process of self-organisation cannot be driven by the attempt to perform a function; it is rather the result of an evolutive process whereby a system will simply not survive if it cannot adapt to more complex circumstances.' [Cilliers, 1998]

Appendix 1

The form bank was defined as a set of lists which represented (as numbers) the sub sets of proportions that define the form bank. To create a particular instance random picks were made in the lists to select 3 particular postions along the lists, the proportion from which width breadth and length can be calculated. The only way that evolution can work is for the genes passed on to descendants to specify as accurately as possible their phenotypic expression. Then the fitness score can be reliably associated with particular genes. If part of the genotype > phenotype expression allows for random generation of morphological parameters (size of a block for instance) it is useless to pick a winner as its descendants will be just as likely to generate unfit morphologies. The solution is to write a function is initially parameterisable (to cover the widest range of legal shapes) but once evaluated always returns the same result.

Appendix 2

Maturana Foerster, Luhmann

'Some systems have a very large number of components and perform sophisticated tasks, but in a way that can be analysed (in the full sense of the word) accurately. Such a system is complicated.'[Cilliers,1998]

A consequence of complicated systems is their linear-mechanical functioning, which prohibits adaptation to changes in the tasks or the contextual parameters prescribed. The car as a machine for example is as whole causally defined by he parts in a summative manner.

In a similar fashion modern and contemporary architects synthesise their buildings or in fact entire city quarters. Master plans are self-contained systems that generally neglect their environment. Building and urban planning degenerate into reductive experiments *in vitro*. The second law of thermodynamics proved *in vitro* experiments to be alienated from the 'real world' and its dynamics [Tor Norretranders, 1991].

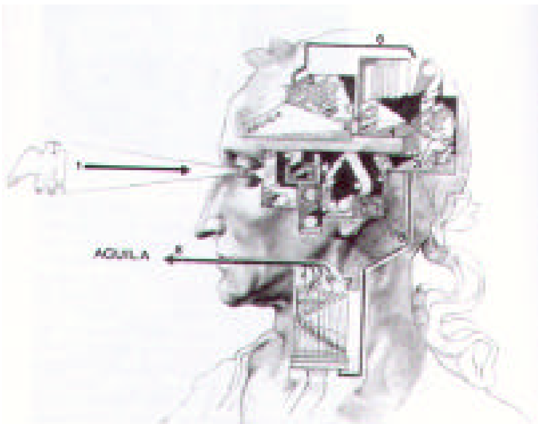
Open systems on the other hand are dynamic. The ability of simultaneous feedback at local scale enables the systems to respond to context generating the global form. The global form determines the organisation that is functionally differentiated from its environment via the adaptation of its parts. Thus, contextual openness demands organisational closure [Maturana and Varela, 1987].

Subsequently, an environmental stimulus will be distributed over the whole system. The representation of whatever has been perceived is not locally stored and indefinitely fixed, but relies on ephemeral configurations between the system's elements.

This notion of dynamic distribution is found most clearly in the French philosopher's, Jacques Derrida's language theory. Derrida's key-concept is found in his term *différance*, which combines the concepts of difference with deferment. Meaning lies within the dynamic distributed relationships of the system's elements -here signs. The input of a new communication and the following changes of the system's structure are self-referential processes, which ensure each other's existence - neither the sign nor the language is dominant [Cilliers, 1998].

Autonomy (openness via closure), non-linearity, distributedness, self-reference and self-propagation, are all included as principles in Maturana's, a Chilean neuroscientists, theory of autopoiesis [Maturana and Varela, 1987].

Autopoietic systems are as an emerging organisation defined by their smallest units. In the case of living systems, these units are biological cells. Consequently, any meta-level of organisation emerging from the interaction of the cells, as consciousness, is however embedded within the physical world. The cybernetician Heinz von Foerster described cognition as a process of computations of computations [von Foerster, 1984]. Not the quality, but the quantity of *a* reality is perceived. Contextual stimulations do not linearly provoke a certain neuronal configuration or description, but the computation of neurons in an early instance referenced to previous neuronal computations generates optional descriptions.



Foerster's example leads to another aspect of autopoietic systems. The history of all structural adjustments of a system is called its ontogeny. During the ontogeny certain stimuli return more frequently than others. High frequency enforces the formulation of more elaborate structural configurations, which assures an automated preparedness for recurring situations. Living systems are structurally determined through their ontogeny [Maturana and Varela, 1987].

The phenomenon of two autopoietic systems recurrently perturbing each other is called *structural coupling*. Via *structural coupling* modi of behaviour are automatized and intentions created. The meta-spaces that contain those coupled structures Maturana describes as *consensual domains*. A system's ontogeny **<u>Fig A1 Traditional Cognition</u>**

determines if a system is fit to participate in a *consensual domain*. Maturana's concept of cognition rests within *structural coupling*. Perceptions, and meanings within a consensual domain, are generated through perturbations from the environment - interactions between systems and with their context. He calls it *Enaction*. Similarly, Piaget pointed out, that 'The "intuition" of space is not a reading or apprehension of the properties of objects, but from the very beginning, an action performed on them [Piaget and Inhelder, 1956].'

The German sociologist Luhmann expands Maturana's definition of the human being as one autopoietic system by dividing it into four autonomous systems: the organic, the neuro-physiologic, the psychic and the communicative [Kneer and Nassehi, 1993].

The smallest unit of the communication system is a synthetic communication, which is composed of two processes, observation and description. The distinction for an observation is based on binary codes. At any one time a communication can only observe and describe one side of an argument. The unseen side of an observation can be compared to the 'blind spot' of our eye.

Luhmann attributes the process of observation to all autopoietic systems. Since autopoietic systems produce their elements and their relations themselves, also the processes of observation and description are system internal operations [Kneer and Nassehi, 1993]. Thus, observations are also structure determined based on the system's ontogeny. Through the self-referential interactions of the communication system and its operational closure, communications can either communicate *about* something - an external reference - or describe its own observations and take itself as reference. Autopoietic systems have the ability of self-observation or second order observation, reminding of course of von Foerster's example of *a* reality or the act of cognition and perception being computations of previous computations.

Luhmann substitutes Maturana's consensual domains through sub-systems. Sub-systems emerge from highly complex systems, such as quarters within cities. If via second order observation the perspectives of an observation or the complexity of the code of distinction increase, the structures of a system differentiate themselves to an ever-higher number of specific systems internal as well as external (contextual) perturbations. To deal with such complexity, the system modulates itself into sub-systems with their own code of distinctions, i.e. architecture into surveyor, builder, designer (who's field is differentiated into model maker, cad-specialist, 3D modeller, draftsmen, etc). Each subsystem generates through self-observation new sets of perception/ perspectives and systemic structures that increase the adaptational options when perturbed. Thus, the system as a whole possesses an excess of options for adjustment to contextual and internal perturbations, which assures survival chances. Sub-systems perceive *a reality* according to their own codes of distinction.

References

Alexander, Christopher 'A City is not a Tree', Architectural forum, 122, no. 1, 4/1965

Alexander Christiopher, 'Notes on the Synthesis of Form', Harvard University Press, 1974

Anderson S "Problem-Solving and Problem-Worrying" Architectural Association 1966 (private communication)

Bertalanffy, Ludwig von "General System Theory. Foundations, Development, Applications", George Braziller, New York, 1968

Bentley, Peter J., Evolutionary Design by Computers, Morgan Kaufmann Publishers; 1999

Bloomenthal, Jules 'Implicit Surfaces', Unchained Geometry, Seattle, 1988

Bonabeau, Eric , Dorigo, Marco and Theraulaz , Guy 'Swarm Intelligence. From Natural to Artificial Systems' Oxford University Press, 1999.

Broughton, T.A.Tan, ., P.S. Coates, . "The Use of Genetic Programming in Exploring 3d Design Worlds." CAAD Futures 1997, R. Junge (ed), Kluwer Academic Publishers ,1997

N. Chomsky, 'Syntactic Structures', The Hague: Mouton, 1957

Cilliers,Paul . 'Complexity and Postmodernism. Understanding complex systems'
Routledge, London, 1998.

Coates P.S.& Makris D. "Genetic programming & Spatial morphogenisis" AISB '99 symposium on creative evolutionary systems Published by the Society for the study of artificial intelligence and simulation of behaviour Sussex University dept of Cognitive science. Edinburgh1999

Coates Paul S. AA Dipl & Hazarika Luit MSc B.Arch "The use of Genetic Programming for applications in the field of spatial composition" GA 1999 Milan

Coates P.S. H.Jackson 'Evolving spatial configurations' Eurographics 98 ICST.London
1998

Coates Jackson& Broughton *Chapter 14* in : Ed P.Bentley "Evolutionary design by computers". Morgan Kaufmann 1999

Derrida, Jacques "Margins of Philosophy", Brighton, Harvester Press, 1982

Derix C. and Thum, R.'soS: self-organizing Space', essay for Generative Art 2000 Conference, Milan, 2000

Gips J, Stiny G, 1980, "Production systems and grammars: a uniform characterization", Environment and Planning B 7 399-408

Goldberg, David, E., Genetic Algorithms in Search Optimization and Machine Learning,
Addison-Wesley 1989

Steve Grand, 'Creation - Life and how to make It', Weidenfeld and Nicoloson, London, 2000

Heinz von Foerster, "On Constructing a Reality", Lesson on Constructivism & 2nd Order Cybernetics, published in 'Observing Systems', Intersystems Publications, Blackburn, Virginia, 1984

Hermann Haken & Robert Graham, 'Synergetics - The theory of Cooperation', Umschau 6 (eds), 1971

Bill Hillier, 'Space is the machine', Cambridge University Press, Cambridge, 1996

Jacob C *Genetic L-System Programming* in Davidor Schwefel & Reinhard "Parallel problem solving from nature III" Springer Verlag.

Jacobs, J.'The Death and Life of Great American Cities', Vintage Books, New York, 1961

Jeffrey M.L., Generating Fractal Architecture, 1998, University of East London, Msc Thesis, Computing and Design

Koza. J. R Genetic Programming: On the programming of computers by means of natural selection. Harvard University Press,Cambridge MA,1992

Koza. J. R Genetic Programming II. Automatic Discovery of Reusable Programs.Harvard University Press,Cambridge MA,1994

Kaandoorp J.A. Fractal modelling Growth and form in biologySpringer Verlag Berlin 1994

Kruijtzer G., Ruimte en Getal, het plastische getal en het gulden snede getal, 1998, Architectura & Natura Press, Amsterdam

Kauffman, S.A. 'Antichaos and Adaptation.', Scientific American, pp. 64-70, August, 1991

Kojin Karatami, 'Architecture as Metaphor', MIT, Cambridge (USA), 1995

Kneer/Nassehi, 'Niklas Luhmanns Theorie sozialer Systeme', Wilhelm Finkel Verlag, Munich, 1993

W Koehler, 'The Place of Value in a World of Facts', Liveright, New York, 1938

Teuvo Kohonen, 'Self-Organizing Maps', Springer, Heidelberg, 1995

Luchins, A S 'Max Wertheimer', in D.L.Sills(Ed), vol. 16, 1968

Laan D.H. van der, Architectonic Space, 1983, Koninklijke Brill, Leiden

Laan D.H. van der, De Architectonische Ruimte , 1997, Koninklijke Brill, Leiden

LeCorbusier, The Modulor I & II, 1948 - 1955, Birkhauser, Basel

Langton C. G. (ed.) *Artificial Life II*. Proceedings of the workshop on Artificial Life. Santa Fe. Feb (Addison-Wesley. 1990).

Lindenmeyer A Prusinkiewicz. P the algorithmic beauty of plants springer verlag 1990

Lindenmeyer A Prusinkiewicz. P Developmental models of herbaceous plants SIGGRAPH V 22 N0 4 august 1988

Luhmann, N. 'The Autopoiesis of Social Systems', published in: F. Geyer and J. van der Zouwen (eds.), 'Sociocybernetic Paradoxes', Sage, London, 1972

Maturana H. and F. Varela, 'The Tree of Knowledge', Goldmann, Munich, 1987

Maturana H, 'Metadesign - Human beings versus machines, of machines as instruments of human designs?', essay, August, 1997

Maturana H, 'Biology of Language: The Epistemology of Reality' in:

Millonas Mark M.'Swarms, Phase Transitions, and Collective Intelligence' in Artificial Live III Ed. Christopher G. Langton, SFI Studies in the Sciences of Complexity, Proc Vol XVII, Addison-Wesley 1994.

Miller and Lenneberg, 'Psychology and Biology of Language and Thought: Essays in Honor of Eric Lenneberg', Academic Press, New York, 1978

Norberg-Schulz, C. 'Intentions in Architecture', MIT Press, Cambridge, 1965

Norretranders, Tor "Feel the World", Gyldendal, Copenhagen, 1991

Piaget J. & B. Inhelder, 'The Child's Conception of Space', London, 1956

Reynolds, C.W. Flocks, herds and schools: a distributed behavioural model. Computer Graphics, 21(4).

Saussure Ferdinand de, "Course in General Linguistics", London, Fontana, 1974

Spitzer, M. 'Geist im Netz. Modelle fuer Lernen, Denken und Handeln.', Spektrum Verlag, 2000

Valery, Paul "Reflections of Art", New York, Pantheon, 1964

brief introduction on neural networks taken from:

Froehlich, J. 'Neural Networks with Java: Neural Network Overview', 1997,

http://rfhs8012.fh regensburg.de/~saj39122/jfroehl/diplom/e-11-text.html

Marching Cube algorithm taken from Paul Bourke: http://www.mhri.edu.au/-pdb/modelling/polygonise/