Managing Complexity

Mitesh Parekh - Diploma 4

Topic: Evolutionary Architecture/ Generative Architecture

Architecture is evolving every day; new styles and new ways of using materials are being developed. The use of the computer has become very important in the architectural field and new ways of design is at the front, generative based systems are giving architects and designer new approaches to develop ideas and results are being generated a lot quicker than standard means of design. Even though technology maybe new, architecture and evolutionary design is influenced from nature in terms of different forms and structures, and now the morphological processes which is becoming a major part of it. Nature is used as a source of inspiration where analogies and metaphors are taken. Architecture is a part of nature as the man-made environment is now a major part of the global environment. This brings the architectural concepts in a coded language to the genetic code script of nature. This can go back to the days of Frank Lloyd Wright, Louis Sullivan and Le Corbusier, as they all used analogies from nature. (Frazer, 1996)

"*The 20th century was the century of physics and the 21st century will be the century of biology." Freeman Dyson, 'Our Biotech Future' 2007.*

Architecture has always been known to have a relationship with physics but now there seems to be a shift towards biology, this has been outlined in Peter Trummer's article in the AD magazine. He outlines that nature's emergent process is being seen in architecture today. For example the Dutch coastline made major changes in their flood defence and to preserve the coastline. The Dutch started filling up the coastline with layers of sand to increase its strength. After time nature's morphological processes made new sandbanks emerge, so by providing physical protection new landscapes are generated. Another example of nature's morphological process is the Rhinoceros Animaris by Theo Jansen, the Animaris is a walking skeleton and is made out of yellow electricity tubes, this skeleton only moves because of its relationship with the Dutch coastline, the skeleton is wind powered and their structure create a walking behaviour in response to the specific ground conditions. (Trummer, 2008)

Rhinoceros Animaris

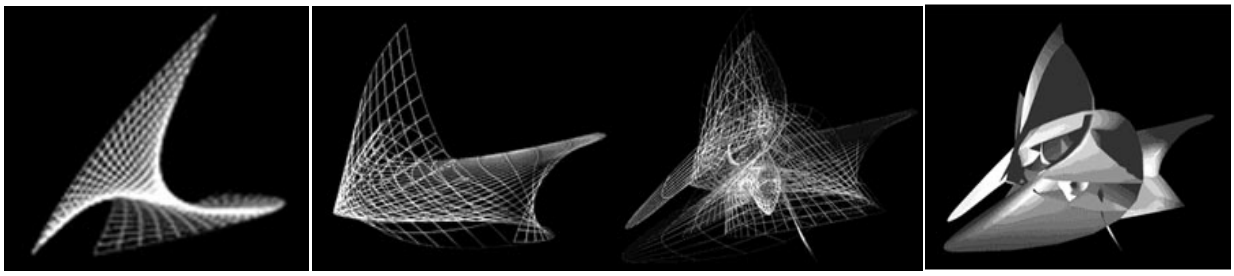
In nature it is only the genetically coded information of form which evolves, but selection is based on the expression of an organism, the codes are manufacturing instructions. Artificial life considers coded instructions which are environmentally dependent but as in the real world model, it is only the code-script that evolves (Hemberg et al, 2003).

Alan Turing was interested in morphology and simulation of morphological process by computer based mathematical models. In 1935 he had the idea of the universal computing machine, the Turing Machine,

which could duplicate the functions of a mathematical machine and functions of nature. (en.wikipedia.org) He used an endless paper tape and a head which could move backwards and forwards along the tape, reading, writing or erasing symbols. The idea of this was that the machine could perform any computable process given to it by a set of logical instructions on the tape. (J Frazer, 1998) The Von Neumann Machine was a follow off from the Turing machine as John Von Neumann developed the basis of the serial computer defining the 3 basic elements of central processor, memory and control unit. This was developed and it formed America's first computer.

An evolutionary model is integrated into the real world, it requires an architectural concept to describe in the form of genetic code; the code is mutated and developed by computer program into various models in response to the physical generative environment. This is evaluated in the environment and the models that are successful are used to repeat the steps until a stage of development is selected for prototyping in the real world. (Frazer, 1996)

An example of evolutionary system created as an adaption of the Turing Machine, is the well known experiment using generative architecture, the Evolutionary Architecture Exhibition by John Frazer at the Architectural Association (AA) in January 1995. At the centre of the exhibition was the Interactivator, which was an evolving environment which responded to interaction from the visitors of the exhibition and the atmosphere around the exhibition space. The Interactivator would evolve the model by using the information gathered by the visitors interacting with it. Temperature, humidity, noise, smoke and many natural aspects made the model evolve with the data collected by the sensors around the exhibition space. Internet cooperation was also integrated into the evolution of the model by allowing virtual visitors to input genetic information. Others ways to make the interactivator evolve was for it to be downloaded to remote sites to replicate itself and each replication will take its own evolutionary path and its results feed back to the main model. The final way that the Interactivator could evolve was by allowing access to the exhibition through a normal website for the visitors to understand the context of the experiment and see observe the stages of the evolving model (Frazer, 2002).



Evolving Model of the Interactivator

The generative system I will be speaking about will be the surface based design tool a plug-in for Maya designed by Martin Hemberg, Genr8.

Critical Analysis Text:

'Exploring generative growth and evolutionary computation in architectural design'
Martin Hemberg, Una – May O'Reilly, Achim Menges, Katrin Jonas, Michel da Costa Gonçalves and Steve R Fuchs, 2003

My critical analysis will be on the Genr8 design tool. Genr8 is a surface based design tool developed to integrate evolutionary computation, generative computation and creating a physical environment modelling technique; it was developed by Martin Hemberg and his advisors Una – May O'Reilly and Peter Testa, it is a part of the work carried out by Emergent Design Group at MIT. Emergent Design Group was founded by MIT in 1997 at the School of Architecture & Planning, to research new approaches to design at the intersection of architecture, engineering, artificial intelligence, and material science. Focusing on emergent design the Emergent Design Group develops generative simulations, tools like Genr8, prototype designs and building systems on the emergent properties of materials. Projects combine developments in modelling theory, intelligent systems, organizational theory to find new forms of architecture and a scientific way to design space in computation whether it may be contemporary or however technical. (projects.csail.mit.edu)

Genr8 was developed to help design in a generative process using a generative design tool; it genetically modifies the design using an encoding algorithm and creating different outcomes that interacts with its environment to show different results.

Martin Hemberg, Una – May O'Reilly and Peter Testa's work combines evolutionary computation, generative computation and physical environment modelling techniques in the tool (Hemberg, Integrate) The main goal of the Genr8 design tool was to integrate the natural processes of evolution and growth and model the major features of emergence and combine these within a computational framework. It is to apply the tool as a generative design tool that will produce complex and adaptable architectural forms (O'Reilly, AD 2003).

The tool is plug-in for Alias Waterfronts 3D modelling software Maya and can be used via the Genr8 user interface or through Maya's built in a scripting language. The tool is based on the Lindenmayer system (L-system)(Testa et al 2001) which is a re - writing system that are a set of rules and symbols commonly used to model the growth in plants and measure the morphology of various organisms, it was first introduced by biologist Aristid Lindenmayer (Hemberg, 2001). In the 1960's Lindenmayer proposed a string re-writing algorithm based on formal grammar theory which can model plants and their growth process. L- Systems can be perceived in 2 parts; firstly the generative process is a string re-write system where new generations are being created by the letters that are on the initial string and are replaced in parallel by other letters according to the set rules. The next part is the interpretation process which is the letters of the string from one or more generations that are interpreted, string interpretation can be used for visualisation (www.mh-portfolio.com). The interpretation system used in Genr8 is the turtle interpretation.

Genr8's L-system was developed by Martin Hemberg and named Hemberg Extended Map L-systems (HEMLS) in order to create surfaces in 3D that have been evolved in the physical environment. The extended system of this makes the genr8 work in a three dimensional format to make the string surfaces. This is the basis of the Genr8 growth model that l-systems are needed for, the tool used the evolutionary algorithm to find grammars and the type of evolutionary algorithm being used is the grammatical evolution (Hemberg, 2001). The evolutionary algorithm is a generic population based the optimisation algorithm it is using organisms influenced by evolution in biology such as reproduction, recombination, mutation, selection and so on. The most well known type of the Evolutionary Algorithm is the Genetic Algorithm that tries to find the solution of the problem in the form of strings of number and applying operating systems such as recombination and mutation. Other types of Evolutionary Algorithm's are Genetic Programming, Evolutionary Programming and Evolution Strategy (Eiben, 2003). Grammatical Evolution combines the strengths of Genetic Algorithms and Genetic Programming. Genetic Programming is the solutions made

in computer programming that fixes the program so that the parameters are allowed to evolve in the physical environment (Testa, AD 2002).

One of the main issues with this evolutionary algorithm is its fitness function is a criteria set by the user that can define certain aspects at the same time which are size, smoothness, soft boundaries, subdivisions and symmetry. A few generations can be created and a change to surface maybe needed and can be defined in the fitness criteria (Hemberg, et al, Genr8). The fitness function is the type of function that uses the chromosome in genetic algorithms so the particular chromosome can be ranked at a certain level according to its fitness like in biological terms for example when a group of athletes compete to find out who is the fittest and the winner of the competition is the fittest. The better the fitness value the better the solution in evolutionary algorithm (Eiben, 2003) In Genr8 the fitness function is literally a controller that guides the user through the evolutionary search.

The evolutionary algorithm works with the Backus - Naur Form (BNF). BNF is a method for specifying grammars in computing. Genr8 has two types of mapping steps one of which maps a genome to a grammar and next interprets the grammar and therefore constructing the surface which is the phenotype in this tool. The mapping rules are determined by the genome in Genr8 (Hemberg, 2001). A genotype of the organism is inherited instructions it carries within it genetic code and its rules of a cell, organism or individual as the case in the Genr8 design tool (Testa, 2002 AD). The genome in biology of an organism is its hereditary information encoded in DNA. In computing the genome of an organism refers to the full set of chromosomes or genes of that specific organism (en.wikipedia.org). The phenotype is the observable characteristic of an organism such as morphology development biochemical or physiological properties or behaviour.

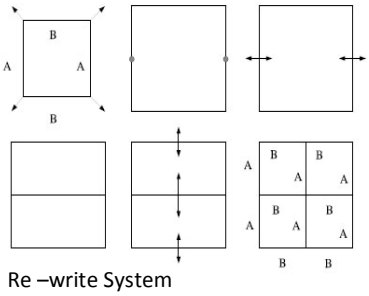
Genr8's re write systems is structured like a tree and they are later grown in the three dimensional environment. Genr8 is a reactive growth model that will react with its environment to evolve, this L-system is an interpretation process and the graphical system used in Genr8 is the turtle system so the string can be formed into surfaces. The turtle moves around in three dimensional spaces and draws lines according to the set of turtle rules. Spatial coordinates x, y and z defines the condition of the turtle and this is also dependent on its orientation, the orientation is represented as 3 vectors H for the turtles heading, L for turning left and U for turning up. The turtles are controlled by commands and each command has a specific symbol, which allows branches to be drawn from the main line using the commands and equations (Hemberg, et al, Genr8). This can be identified as form of emergence, which is when certain things happen that we are not sure of the outcome from various means of testing. Emergent Design is the process that uses techniques and approaches from the disciplines in not only Architecture but also of Computer Science and Artificial Intelligence. The process focuses on morphology, making the most of the emergent reaction and adaptive properties of architectural form and complex organizations. Emergent Design uses software tools that allow the exploration of locally defined, bottom-up, emergent spatial systems. (Testa et al, 2001)

Genr8 is a plug - in for Maya the scripting language is written in C++ and this is used by Maya's Application Programmer Interface, but Genr8 does not use any Maya representation it has its own surface model. The Genr8 environment models 3 forces, attractors, repellors and gravity working like magnets and can influence which direction the surface grows. The environment within Genr8 is powerful, once a string is drawn the model evolves with the environment and gives an impact to the surfaces development. There are 3 main control points in the interaction between the Genr8 tool and the architect, firstly by setting up the digital physical environment, secondly supplying the growth instructions and finally by interactively guiding the evolutionary algorithm using the design tool. (Hemberg et al, 2003)

Hemberg's goal is to create a surface based design tool that interacts and reacts to its environment. Genr8 gives architects and designer's new ways of experimenting with form and various types of outcomes where thousands of generations can be created that may not be possible to do by other means of design.

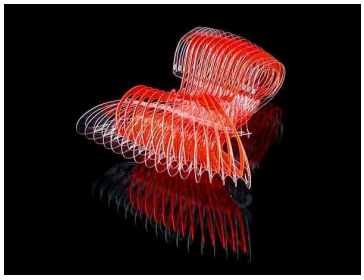
"*The aim of an evolutionary architecture is achieved in the built environment the symbolic behaviour and metabolic balance that are characteristic of the natural environment." J Frazer, An Evolutionary Architecture* 1996

Genr8 has been used in many student projects at the Emergent Design and Technology program at the Architectural Association such as, Steven Fuchs's Butterfly Machine, Achim Menges – Pneumatic Strawberry Bar, Sectional Surfaces, Fibrous Surfaces, Katrin Jonas's Surface Envelopes and Manuel da Costa' Nested Cubes. (Hemberg et al, 2003)

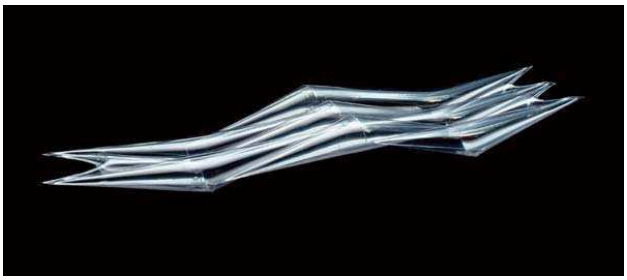


Re –write System

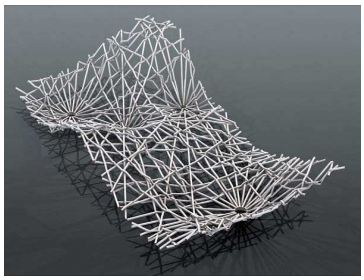
Butterfly Machine



Sectional Surfaces



Strawberry Bar



Surface Envelopes

The Project I will be studying that used the Genr8 design tool is the Strawberry Bar by Achim Menges. Menges wanted to use Genr8 to show the possibilities of how the form can be generated and evolved using a computational tool. The pneumatic strawberry bar was a design for a bar at the Architectural Association's end of year party in 2003; the design consisted of using recombination, reproduction, mutation, competition and selection to adapt in an evolutionary form to use as a design strategy (Hemberg et al 2003).

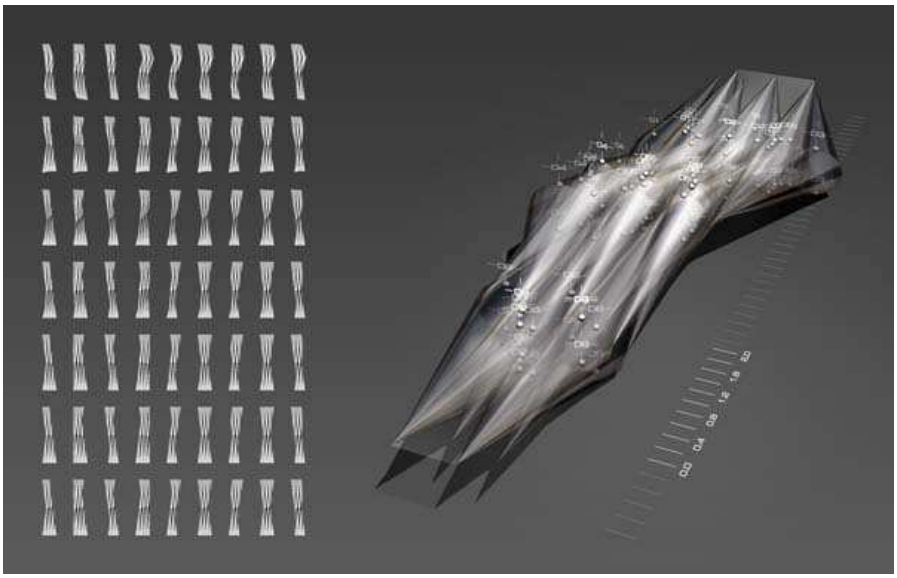
From initial studies in this project the various options were explored and limitations from generation to fabrication were found by pushing the experiment towards pattern making. These patterns will evolve as different species across each generation but will keep their structural capacity and characteristics. (O'Reilly, AD 2003)

Firstly Menges started by using the Genr8 in a simple form, a pneumatic component defined by cut pattern using geometric constraints of 2 trapezium from like surfaces that were aligned at the plane of the connecting seams. By defining the different lengths of the surfaces at the defining points the component becomes a 3 dimensional form once inflating (Hemberg, et al 2003). This provides a basis to start an evolutionary process. Menges bred more than just one surface, he breeds three sub – populations and these are co evolved in the project. Two sub populations were evolved using the definition points of the shorter and longer surfaces and one defined the special position. According to the base, the specific fitness criteria for each subpopulation of each distinct surface were created (www.achimmenges.net).

Two interrelated curved surfaces that bred in an environment are defined by attracting and repelling forces, and the evolved surfaces could be analysed in other software, part of this analysis was done in an engineering software called Easy. This resulted in parameters being modified on Genr8 from the data taken from the structural analysis in Easy. Emergent geometric patterns informed and changed the fitness criteria accordingly. Menges formulated a number of fitness criteria that had to be realized through Genr8's fitness function. (Testa, AD 2002) Geometric features such as regional change in curvature and the direction of surface normal defines the position and number of construction planes, as well as depth of sections, across many populations. A feedback loop was created to the most recently evolved surface, by doing this it maintains the logic of the pneumatic component in a larger evolutionary system but dissolves the distinction between the environmental constraints and the individual response. (Hemberg et al 2003)

Menges was also able to make good use of the environmental features in Genr8 as he used a successive amount of surfaces as bounding boxes to help realise the constraints. The result of this experiment shows the level of complexity and consistency performed by Achim Menges that is very difficult to achieve in conventional design approaches. (O'Reilly, AD 2003)

Menges ran Genr8 over 600 generations and 144 species were identified and catalogued according to patterns of relevant geometric features in his study using the Genr8 design tool. Considering the interrelated evolution of the defining surfaces the criteria for evaluation was the relative fitness amongst the emergent species created rather then the total fitness ranking of the individual organisms. (Hemberg Integrating) Structurally the behaviour of the pneumatic system relied on specific geometric relations like alignment and distances of the main defining points and the selected individual organisms were the ones that shared the geometric features. The individual of the chosen species that grew in the most developed generation was picked. The genotype of this incorporated the genomes of three geometric defined surfaces finding a degree of phenotypic plasticity that allows the pneumatic system to adjust to the constraints of a digital cutting pattern and computer aided manufacturing process. (Testa, AD 2002)



Strawberry Bar with evolutions

In Genr8 a number of geometric constraints are found, including curvature in relation to total surface geometry or the density of the construction planes needed based on the degree of curvature. As well as the fitness ranking system this process turns the fitness criteria into an evaluation tool that evolves within the feedback loop of form generation and external analysis

The architects use a process of design that brings out emergence. In Genr8 the aspects of an architectural brief are studied and addressed with a bottom up system. This explores different types of processes such as morphology, material, structure, program etc, and is integrated and combined to form the architectural experience and the three dimensional tools that tackle this design brief. (Hemberg, GENR8)

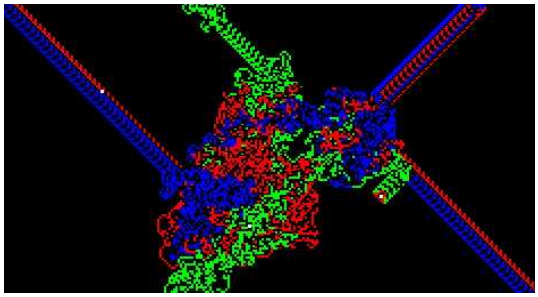
A bottom-up approach is the linking of base elements which are sub – elements of the system which are first to the systems specified in great detail. These sub – systems expand and are then linked together with the larger sub – systems, this process continues growing like a tree with many branches until top-level system is formed. It is a structure that will start from the bottom and will work its way up to the top until it find its complete form (en.wikipedia.org). We can compare this system to a seed where at the beginning, it starts off really small but then grows into a complex form; this is defined as complexity in the Genr8 tool. In computation the complexity theory are the amount of resources required using genetic algorithms, it questions as the algorithm increases, how and what the requirements will be for that change and what memory or size of the resources will need to be, it finds the scale of the resources to the algorithm. (wikipedia.org)

Complexity can be best defined by a quote given by P. Cilliers *"Complexity is the interaction of constituents of the system and its environment, it is of such a nature that the system as a whole cannot be fully understood simply by analysing its components"*

Optimization is the system that is modified to make that system more efficient or by using fewer resources, a computer program may work faster or how much memory it will need to work better so to find this outcome it is optimized, to work out the best available values of the system and how it will be used.

Artificial Life is based on processes, and its evolution through simulations using computer models, robotics, and biochemistry. There are three main kinds of Artificial life and they are soft hard and wet, and come from software, hardware and from biochemistry (wikipedia.org). Artificial life takes influences from

traditional biology by trying to create the biological process in computers. An example of Artificial Life is Chris Langton's Ant; here squares are coloured on a plane in either black or white. The square is known as the ant. The ant can travel in four, up down left and right at each step it takes. Langton's ant is the best example of cellular automaton. Another example of emergent cellular automaton is James Conway's game of life. Cellular automaton is a collection of cells on a grid of a shape that evolves through time steps according to a set of rules based on its neighbouring cells (Tierney, 2007). The rules are then continuously repeated in as many steps as you may want. Von Neumann was one of the first people to consider such a model, and incorporated a cellular model into his "universal constructor". (Frazer, 1996)



Chris Langtons Ant

In Genr8 creativity plays an important role in the process of form making. The tool helps and influences their creativity and overall help the architects design in a creative process. A tool such as Genr8 and many other tools similar to it are based on nature and the process that shows how form evolves. (Hemberg, Extending) This shows how an evolutionary computational tool can be integrated into architecture to help with process of design and this is what Menges has shown in his strawberry bar project. Menges shows the form of the can be integrated into architecture and Genr8 is another tool that has helped generative design stamp its influence on architecture. Hemberg has helped architects understand that generative architecture can help in the design field. Genr8 is still used as research tool at the University of Dublin where students are experimenting with the tool.

These types of morphological experiment shows the way that he used Genr8 in evolutionary computation as a design tool that can generate intricate surface variations and can work within the logic of geometry of the relevant material and structural system. This was one of the key steps to the rise of evolutionary architecture with genetic and generative algorithms and has formed a stepping stone for further tools to be developed (Hemberg, et al 2003). Complex modelling and evaluation techniques shows Genr8 has taken the process of evolutionary tools to another level and shows that analysis and dynamics can be merged with evolutionary computation so that the ranging level of design complexity, integrated design and manufacturing can work together. This suggests a new parametric framework that shows us the design is not only a finished product of operative patterns, the performance of the species and the rise of the emergence within it creates an evolutionary generative process. Like other 3D modelling tools Genr8 allows us to glimpse into the future of evolutionary architecture. (O'Reilly, 2002 AD)

"As for Its contributions to generative design, I think of it as a successful proof-of-concept, demonstrating that ideas from ALife and EC can be applied to architecture. We were not the first group to demonstrate this." (Hemberg, 2009)

There have been many other tool that have been created since Genr8, Yaniv Junno Ophir was one of the last people to interact with Genr8 and feels it is an important starting point for generative design tools. *"GENR8 was conceived at a time when architecture was beginning to discover the world of computation and they ways in which that world has been affected by metaphors from various domains like biology"* (Ophir, 2009)

GENR8 contributed a great deal to the creation of a new design methodology. Ophir states *"I would call this methodology "environmental design" not in the sustainable sense of course but rather from the perspective of how a design comes to life. In GENR8 you create an environment and the rules that govern that environment; the building that's created is then a response to that environment."* (Ophir, 2009)

One design group that has been influenced by the Genr8 tool is the GROImp where they developed a tool called Relational Growth Grammars. Growth grammars are a rule-based approach to the modeling of dynamic systems, they are a form of L-systems and Relational growth grammars that are based on the concept of graph rewriting. The group has also created the sensitive growth grammars which forms an extended variant of L-systems. GROImp use the language XL as their relational growth grammars, XL is built on top of the Java language so that it can combine rule based model with the strength of Java (www.grogra.de). This group has led off from the Genr8 design and further develops generative tools in architecture, Ophir states, "GENR8 is Jimi Hendrix and GROImp is Eric Clapton, Jimi came first but died young, leaving behind a legacy for Clapton to follow." (Ophir, 2009)

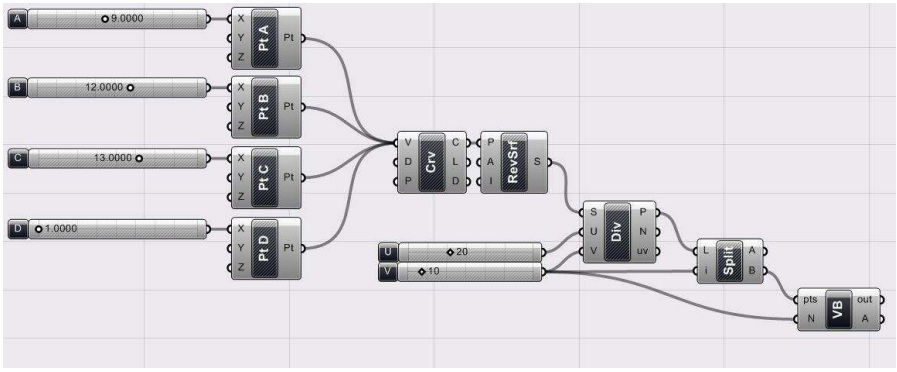
There are many other types of generative design tools developed by the Emergent Design Group at MIT, such as the Morphogenic Surface Structures (MoSS), it is a similar plug-in to Genr8 designed by Markus Kangas, it is a research plug - in that also uses Lindenmayer systems to generatively model or grow surface structures within the three-dimensional computer environment. The environment gives a controlled flexibility to the system which can give you the real world constraints including material properties and dynamic loads. MoSS allows the user to specify a base grammar and guide growth through the application of boundary and field conditions. (Testa, AD 2002)

Another is Weaver which is also a plug-in for Alias Maya and was designed by Simon Greenwold. It is a design tool that is capable generating woven strands and explaining the characteristics of the strands, Weaver applies the pattern to a defined surface. The resulting weaves can be complex and depend both on the description of the weave pattern and the form of the surface at which the weave will be placed. Weaver was influenced by exploring forms of industrial braiding and weaving *(*web.mit.edu/arch/edg).

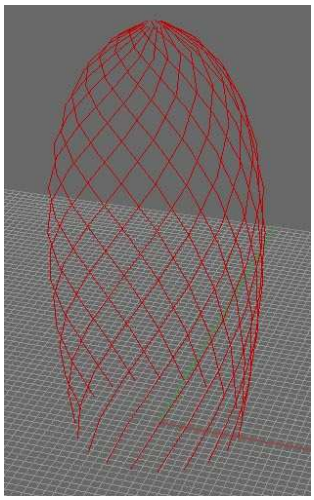
Agency is another emergent design tool developed by Simon Greenwold which involves 3 components; one is a component of methodology and then researching evolutionary programming techniques and a design component that applies to emergent technologies to develop the distributed systems. The software is for agent-based evaluation of fitness and allows the direct user interruption and reintegrating the phenotypically modified individuals. Agency is another Alias Maya plug-in *(*web.mit.edu/arch/edg).

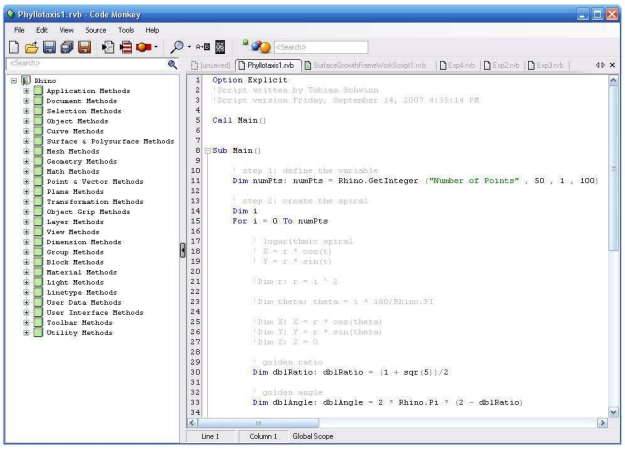
GERMZ (Genetically Recombinant Model) is a computational design that is another plug-in Wavefront designed by Brian Clarkson and Hyung-Jin Kim which is an innovative design tool and uses the application of Genetic Programming (GP) to the generation of three-dimensional form, and in its intelligent interaction with the user. GERMZ also supports the nonlinear design process like Genr8 by always forwarding multiple solutions for review *(*web.mit.edu/arch/edg).

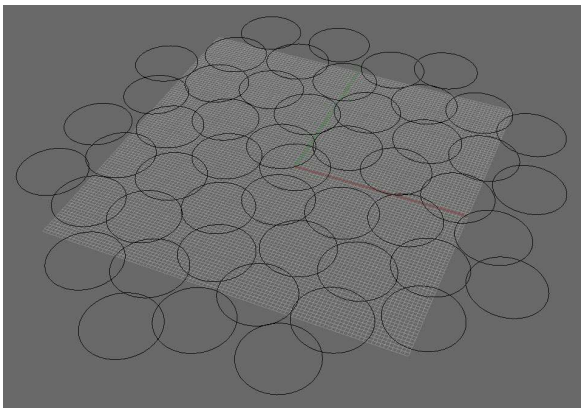
There are many generative design tools that are in use today, the like of AutoCAD and Microstation have integrated design tool to help build the generative process. Monkey & Grasshopper (visual scripting) are another type of scripting tool which is plug - ins for the 3D modelling software Rhinoceros. Biology is a major part of architectural design and Genr8 is an important generative design tool that has helped in the creation of other tool to integrate with architectural design. Evolutionary computation is an ever growing environment, it has given new ways of generating creative architecture and has changed the way we perceive the design process. Many architects today are turning to generative design components to further develop their design process and it has become a very important part in architecture.



Grasshopper Visual Scripting Tool







Monkey Scripting Tool

References

Books

Burke A, Tierney T, Network Practices – New Practices in Architecture and Design
Princeton Architectural Press (2007)

Bentley, P, Evolutionary Design By Computers
Morgan Kaufmann (1999)

Frazer, J, An Evolutionary Architecture
Themes VII (1996)

Eiben A.E, Smith J.E, Introduction to Evolutionary Computing
Springer (2003)

Papers

Bentley P, Aspects of Evolutionary Design by Computers, (1999)

Frazer, J et al, Generative and Evolutionary Techniques for Building Envelope Design. (2002).

Hemberg, M. et al. Exploring Generative Growth and Evolutionary Computation in Architectural design. (2003)

Hemberg M & O'Reilly U, Integrating Generative Growth and Evolutionary Computation for Form Exploration.

Hemberg M & O'Reilly U, Extending Grammatical Evolution to Evolve Digital Surfaces with Genr8

Hemberg M & O'Reilly U, Geometry as a Substitute for Structural Analysis in Generative Design Tools

Hemberg M, O'Reilly U & Nordin P, GENR8 – A Design Tool for Surface Generation

Hemberg M, GENR8 – A Design Tool for Surface Generation (2001)

Peter Testa et al, Emergent Design: A crosscutting research program and design curriculum integrating architecture and artificial intelligence. (2001)

Articles

O'Reilly U, AD Magazine Emergence: Morphological Design Strategies, Evolutionary Computation and Artificial Life in Architecture, 2003

Testa P, AD Magazine Contemporary Techniques In Architecture, Emergent Structural Morphology Vol. 72(1), Jan 2002

Trummer P, AD Magazine Versatility and Vicissitude, Engineering Ecologies, Vol. 78(2), 2008

Websites

projects.csail.mit.edu

en.wikipedia.org

http://mit.edu/edgsrc

www.mh-portfolio.com

www.grogra.de

web.mit.edu/arch/edg

Personal Communication

Martin Hemberg, Jan 2009

Una – May O'Reilly, Jan 2009

Yaniv Junno Ophir, Jan 2009