AFTER ARCHITECTURE ...CHARTING A NEW COURSE

by
Girish Ramachandran

Bachelor of Architecture
University of Madras
Regional Engineering College
Tiruchirapalli, India , June 1986

Master of Landscape Architecture
The Ohio State University
Columbus, Ohio, March 1990

Master of Design Studies
Harvard University
Graduate School of Design
Cambridge, MA, June 1994

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF **MASTER OF ARCHITECTURE** AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY. FEBRURARY 1998

Author:

Girish Ramachandran
Department of Architecture, January 16, 1998

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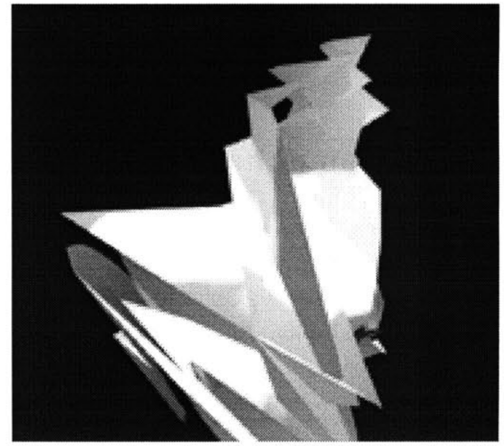
Thesis Co-Advisor

Accepted by :

Roy Strickland
Chairman, Department Committee on Graduate Studies

AFTER ARCHITECTURE ... ...CHARTING A NEW COURSE

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF **MASTER OF ARCHITECTURE** AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.
FEBRURARY 1998



A Synthesis of Science Computation

by
Girish Ramachandran

After Architecture ... ... Charting a New Course

Reader: **Una-May O'Reilly**
Post-doctral associate
The Artificial Intelligence Lab, M.I.T.

ACKNOWLEDGMENT

I greatly appreciate the support and dedication I received from my thesis committee. Working with you was an intellectual experience. You greatly challenged my capacity to think and explore. Peter Testa, Mark Jarzombek and Una-May O' Reilly made a great team of thinkers and visonaries to work with. Thanks for your confidence in me and for keeping me on track. You helped me formulate a new process for architectural design exploration.

To Peter Testa and Mark Jarzombek for your inspiration, critical insights into architecture and its relevance to nature and society today.

To Dean, William Mitchell, for your inspiration, valuable feed backs and confidence in my abilities.

To Ms. Una-May O' Reilly of the Artificial Intelligence Lab at MIT for collaborating with me on this project, for being patient and supportive of my ideas, for the support in software engineering without which this could not have been accomplished in such a short period of time.

To my wife Jaya for the care of our new born daughter Brinda, for bearing my absence from home, for the sacrifices she made, encouragement and support she provided me in the 10 years of our married life which enabled me to attend Harvard, GSD and MIT. To my parents whose encouragement, sacrifices and dedication has enabled me to pursue my academic interests. To parents-in-law who were very kind enough to come and help us during this period to take care of little Brinda.

AFTER ARCHITECTURE ...CHARTING A NEW COURSE

by
Girish Ramachandran

Submitted to the Department of Architecture on January 16, 1998 in Partial Fulfillment of the Requirements for the Degree of **Master of Architecture** at the Massachusetts Institute of Technology.

ABSTRACT

The thesis is a synthesis of technology, art, science, computation and philosophy in charting a new course for architecture. It attempts to address the questions : Can architecture model natural phenomena's or nonlinear processes ? Can we have a theory for the generation of architectural forms ? The site becomes an impetus for wider search which parallels emerging scientific & nonlinear paradigms, resulting in a nonlinear thesis the final product of which is not inevitable.

The site becomes the model of thinking and testing. The thesis addresses the importance for architecture to recognize the convergence of two most powerful disciplines i.e. Biology and Information technology, that would have a major impact on humanity and bio-sphere in the next millennium. It is an attempt to find new forms of inspiration from nature, to find a theory of generation of forms at a period when as a result of the technological advancements in genetic engineering, biotechnology, computation, information technology and molecular engineering (nanotechnology), the relationship between man and nature is getting blurred. Ideas and concepts of artificial life, genetics and biological analogies are proving to be very valuable in the advancement of computational techniques (genetic algorithms, genetic programs) and material sciences (bio-materials, nano-technology, memory shaped alloys).

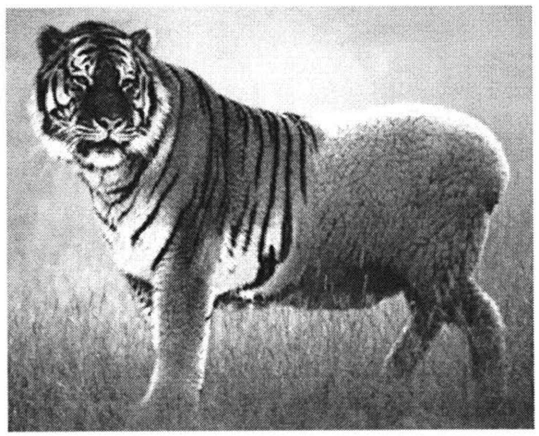
This thesis explores the potentiality for architecture to engage and embrace the emerging paradigms shifts in science and interpret them architecturally and to find ways in which architecture could interface at this convergence of Biology and Information technology. This challenge demands creative exploration at the levels of architectural theory, design strategy or concepts, methods and realization. The final product is a process that is based on biological analogies and genetics, coupled with emerging computational techniques of genetic programming as a generating force for architecture. The primary inspiration comes from the fundamental basis of genetics and evolution and the information systems of nature. A prototype system built as part of this thesis integrates evolution, both as a metaphor and an active generative modeling tool, with the interpretive aspects of the design process.

The architect is firmly in control but the evolution module aids him or her by providing the unexpected 3-D spatial and volumetric configurations which would be impossible to conceive otherwise and suggesting novel combinations or adaptations of forms currently under consideration. This evolutionary modeling tool keeps the clay wet for the architect to interact, interpret and translate these complex 3-D forms and spaces to architecture at any given time. It also provides the capability to track ancestral history of forms and to use genetic properties of any particular generation in the evolution process. The thesis thus sets the framework for future exploration based on artificial life, a new form of designed artifact interacting and evolving in harmony with natural forces.

Thesis Supervisor : Peter A. Testa   Title: Associate Professor of Architecture

Philosophy Art
Technology

Figure 1.0. *Thesis Presentation*



Study the field as a living organism, it has no form but it has structure.
Find its structure and form will come.

---John Habraken

CONTENTS

Collaborators : Girish Ramachandran & Una-May O'Reilly

Girish Ramachandran

EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT), CAMBRIDGE, MA
Master of Architecture (**M. Arch**) 3 1/2 Yr. program, Concentration: Architectural Design, December 1997

HARVARD GRADUATE SCHOOL OF DESIGN, CAMBRIDGE, MA
Master of Design Studies (**MDesS**), Concentration: Architectural Technology & CAD/CAM, 1994

THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO
Master of Landscape Architecture (**M.L.A**) 3Yr. Program, Concentration: landscape architecture, planning and GIS, 1990

UNIVERSITY OF MADRAS, INDIA
Bachelor of Architecture (**B.Arch**) 5Yr. Program, Major: Architectural Design & engineering, 1986

SELECTED SKILLS

Architectural & Landscape architectural design, Land planning, Site planning, Urban planning, drafting, Model making.
Knowledge of various graphics, CAD, 3-D modeling and Visual Simulation, GIS, construction management and structural design software including, AutoCad, Form-Z, Hyperspace, 3-D studio, Lightscape, PolyTrims, Photoshop, Arc/Info, ArcView, Imagine, ArcCad, Walkthru, MacProject, Multiframe3D, MathCad. Programming in AutoLisp and other languages.
Teaching, Marketing, Self initiation, professional management & team work, ability to enjoy working with responsibility even under severe stress and pressure, in team and under different working environments. Ability to meet deadlines and to work with budget limitations

PROFESSIONAL EXPERIENCE

ICON Architecture, Inc., BOSTON, MA
Consultant - Planner/Landscape Architect, Summer 1997

HOSKINS, SCOTT & PARTNERS, BOSTON, MA
Architectural Intern, Winter 1996-97

DR. KEN YEANG, ARCHITECT, KUALA LUMPUR - MALAYSIA.
T.R. HAMZAH & YEANG SDN.BHD. Architectural Intern, Summer 1996
Worked on exploratory projects with an architect known worldwide for Bio-Climatic Skyscrapers.

WALLACE, FLOYD, ASSOCIATES INC., BOSTON, MA
Architectural Intern, Winter 1995-96

R S P ARCHITECTS PLANNERS & ENGINEERS LTD., SINGAPORE.
Architectural Intern, Summer 1995
Worked with the design team of one of the largest A/E firm in S.E. Asia in the preliminary design stage of "Taman Suria", a high density, mixed-use urban development project in Johor Bahru, Malaysia.

Collaborators : Girish Ramachandran & Una-May O'Reilly

Girish Ramachandran

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI), REDLANDS, CALIFORNIA
GIS Benchmarks & Applications Prototype Specialist, Dec. 1991 - Sept. 1994
GIS Applications Programmer, Feb. 1990 - Dec. 1991

- Provided technical marketing support to the President and Marketing Director of ESRI, one of the leading Geographic Information Systems (GIS) software development and consulting company in the world. The GIS software Arc/Info, ArcView and ArcCad are the main products of ESRI.
- Designed, programmed and tested GIS software functional and performance tasks as per benchmark specifications and demonstrated it during various large-scale Federal government and International GIS benchmark tests. Contributed to ESRI' s success of winning all the major National and International GIS benchmarks, resulting in procurement of ESRI' s software and services worth millions of dollars by leading U.S and International government agencies .
- Researched and analyzed various spatially based decision making processes for potential GIS market. Prototyped and recommended GIS applications. Contributed to the marketability of the software in emerging markets. Demonstrated software capabilities in various domestic and international trade shows. Customized the software for demo, benchmarks, training and marketing.
- Programmed and customized large turnkey Arc/Info applications development projects for domestic as well as international clients. Provided on-site consulting and programming help for clients.

KIRLOSKAR CONSULTANTS LTD., INDIA
Person-In-Charge, *World Bank assisted Traffic and Transportation study, Tiruchirapalli, India* Jan.1986 - Jun.1986
Coordinated with city agencies, scheduling, budgeting, preparing of reports, briefing senior executives on project status.

Selected Professional GIS Work

South Australian Engineering and Water Supply benchmark of Digitized Facilities Information System. 1993
US Forest Service benchmark & Prototype development. 1992
Epidemiology and Preventive Medical Services. Prototype development of GIS applications. 1992
Bureau of Land Management (**BLM**) benchmark & prototype development of the **ALMRS** system, 1992
Republic of Cyprus Geographical/Spatial Enquiry and Analysis System benchmark and prototype development. 1992
Republic of Cyprus request for tender. Proposal and cost estimate for Applications Development. 1991
State of California Department of Health Services (DHS-HWDC). MEDIMAP applications development. 1991
National Weather Service, prototype development of Advanced Weather Interactive Processing System (**AWIPS-90**).
Pennsylvania Electric PENSITES Site location System. Applications development. 1991
State of Ohio, Ohio Data Center, Columbus. Prototype development of Emergency Management System. 1990
Kawauchi Heights, Japan. Development of 3-D real-time Visual Simulation model of the landuse development proposal.
HongKong Land Information System and Cadastral Information System. Applications programming. 1990

RELATED RESEARCH

Exploration and realization of architectural form using CAD/CAM based rapid prototyping techniques, 1994
Published in the second edition of the book - *"Digital Design Media " by William J. Mitchell and Malcolm McCullough.*
Generated digital vocabulary of complex 3-D architectural forms derived from fruits, explored design concepts through CAD modeling, developed and programmed in Autolisp, a prototype framework of CAD/CAM **unfolding** process for the fabrication patterning of exterior cladding panels of this 3D curvilinear form. Advisors: *Dean. William J. Mitchell, Mr. James Glymph , Principal Frank O Gehry & Assoc.*

3-D real-time construction simulation using project management and scheduling information, 1994
A self-initiated prototype application development using "Walkthru " software by Bechtel Corp. and "Construction Simulation tool kit (CST)" by Jacobus Technology. Advisors: *Prof. Spiro N. Pollalis,(Harvard GSD), Prof. Gehard Schmitt (ETH, Zurich)*

An experiment in integrating real-time 3-D modeling and visual simulation techniques with GIS, 1989-90. M.L.A Thesis , In collaboration with The Ohio State University, Department of Landscape Architecture and Center for Landscape Research, University of Toronto, Canada. Advisors: *Prof. Douglas S. Way, Prof. Dana Tomlin, Prof. John W. Danahy (University of Toronto)*

ACADEMIC EXPERIENCE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT), CAMBRIDGE, MA
Research Assistant - **Graham Foundation Grant study** on Architecture-Landscape Pact at MIT. 1997
Teaching Assistant - Computer Resources, Department of Architecture, MIT.
Teaching Assistant to **Prof. William J. Mitchell** for Geometric Modeling. Sept. 1994.

HARVARD GRADUATE SCHOOL OF DESIGN, CAMBRIDGE, MA
Teaching Assistant to **Prof. Ian McHarg** for Landscape Planning Studio, Jan. 1994
Work published in Ian McHarg's autobiography "A Quest for Life" 1996.
Teaching Assistant to **Prof. Carl Steinitz** for Landscape Planning Studio, Sept. 1993
GIS Applications Assistant, Graduate School of Design, Sept. 1993 - Jun. 1994
Assisted faculty and students in the use of computer aided Visual simulation tools and GIS for landscape & Urban planning.

UNIVERSITY ARCHITECTS OFFICE, THE OHIO STATE UNIVERSITY, COLUMBUS, OHIO
Graduate Administrative Associate, Apr. 1987 - Dec. 1989.
- Designed and produced drawings for project captains and assisted them in gathering related information.
- Conceptualized and developed the integration of GIS with real-time 3-D modeling & visual simulation as a decision support system for the development of a Master Plan for The Ohio State University campus.

HONORS

Development of Rapid-Prototyping techniques in Architecture, "*Unfolding Process* ". Published in the second edition of the book "Digital design Media - by *William J. Mitchell and Malcolm McCullough* "
Letter of Appreciation from Vice President of **PRC. Inc.** and President of **ESRI** Jack Dangermond, for "excellent work in prototyping the Advanced Weather Interactive Processing System **(AWIPS 90)** for the **National Weather Service.**"
GIS-CAD integration work appeared as the cover page of **ACSM Bulletin**
Graduate tuition award, M.I.T 1994-97; Graduate Associate Award, The Ohio State University, July 1987- Dec. 1989.

Collaborators : Girish Ramachandran & Una-May O'Reilly

Una-May O'Reilly

Employment History

Present:	Post Doctoral Associate Artificial Intelligence Laboratory Massachusetts Institute of Technology, Cambridge, MA.
1993 - 1995	Graduate Fellow Adaptive Computation Program Santa Fe Institute, Santa Fe, NM.
1988 - 1995	Graduate Student and Doctoral Candidate School of Computer Science Carleton University, Ottawa, Canada.
1985 - 1988	Software Engineer Networking and Local/Toll Services Bell Northern Research, Canada, Ltd.

Education

1995	Ph.D. (Computer Science), Carleton University Thesis: An Analysis of Genetic Programming Advisor: Franz Oppacher
1990	M.C.S. (with distinction), Carleton University Thesis: Extending Case Based Reasoning for Knowledge Based Assistance
1985	B.Sc. (with distinction) , University of Calgary

Teaching

1993 Lecturer, Carleton U.: Introduction to Computers for the Social Sciences. A freshman level course for novice computer users which provided an introduction to word processing and spreadsheets and taught the rudiments of programming with PASCAL.

1989 Lecturer, Carleton U.: Computer Principles and Applications. A freshman level course for core C.S. students which covered principles of data structures and algorithm design.

1988 - 1993 Teaching Assistant: Distributed Algorithms, Artificial Intelligence, Software Engineering, Computer Architecture

Honors

1995 - 1997 Natural Sciences and Engineering Research Council (NSERC) Post-doctoral fellowship

1993 - 1995 Ontario graduate scholarship

1991 - 1993 NSERC Post-graduate award

1988 - 1992 Bell Northern Research Post-graduate award

1980, '83, '84 University undergraduate academic awards

Research Area

Artificial Intelligence: program discovery, genetic algorithms

Publications: Refereed Conference Papers

U.M. O'Reilly and F. Oppacher. *Learning New Features and Heuristics for Matching and Using Cases*, in Proceedings of Florida AI Research Symposium (FLAIRS), M. B. Fishman, Ed., 1991.

U.M. O'Reilly and F. Oppacher, *Design Assistance by Extending Case-Based Reasoning* in Proceedings of Fourth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems (AIE/EIA), 1991.

S. Matwin, U.M. O'Reilly, F. Oppacher and B. Pelletier, *Unsupervised Learning of Design Rules Aided By System Derived Heuristics*, in Proceedings of Artificial Intelligence in Design, J.S. Gero, Ed., Butterworth Heineman, 1991.

U.M. O'Reilly and N. Santoro, *The Expressiveness of Silence: Optimal Algorithms for Synchronous Communication of Information*, Graph Theoretic Aspects of Computer Science, Proceedings of 1992 Workshop on Graphs, E.W. Mayr, Ed., L.N.C.S. No. 657, Springer Verlag 1993.

U.M. O'Reilly and F. Oppacher, *An Experimental Perspective on Genetic Programming,* in Proceedings of Parallel Problem Solving From Nature, 2. B. Manderick, R. Manner, Eds., Elsevier, 1992.

U.M. O'Reilly and F. Oppacher, *Program Search with a Hierarchical Variable Length Representation: Genetic Programming, Simulated Annealing and Hill Climbing*, in Proceedings of Parallel Problem Solving From Nature, 3. Y. Davidor, H.P. Schwefel, R. Manner, Eds., L.N.C.S. No. 866, Springer Verlag 1994.

U.M. O'Reilly and F. Oppacher, *Hybridized Crossover Based Search Techniques for Program Discovery,* Proceedings of 1995 IEEE International Conference on Evolutionary Computing, D. B. Fogel, Ed., 1995.

U.M. O'Reilly, *Investigating the Generality of Automatically Defined Functions*, Proceedings of the First Annual Conference on Genetic Programming, J. Koza, D. Goldberg, D. Fogel, R. Riolo, Eds., MIT Press, 1996.

Publications: Refereed, Journal Length Publications

U.M. O'Reilly and F. Oppacher. *The Troubling Aspects of a Building Block Hypothesis for Genetic Programming*, Foundations of Genetic Algorithms, D. Whitley, M. Vose, Eds., Morgan Kauffman, 1994.

U.M. O'Reilly and F. Oppacher. *A Comparative Analysis of Genetic Programming.* Advances in Genetic Programming 2, Ch. 2, P. J. Angeline and K. Kinnear, Eds., MIT Press, 1996.

U.M. O'Reilly. *Why and When Does Genetic Programming Succeed?* in preparation, to be submitted to Journal of Evolutionary Computation

U.M. O'Reilly. *Evolving Vision-Based Functions for Cog*. in preparation, to be submitted to special issue of Artificial Life on Evolutionary Robotics.

Publications: Book Reviews

Genetic Programming II by John R. Koza, in Artificial Life Journal, 1995.

Technical reports, non-refereed publications

U.M. O'Reilly. *Knowledge Acquisition by Machine Learning*, Invited paper in proceedings of Canadian Information Processing Society (CIPS) Congress, 1990.

U.M. O'Reilly and F. Oppacher. *Using the Expert as an Oracle for Knowledge Acquisition in Case-Based Reasoning Systems*, in Proceedings of AAAI-'90 Workshop on Knowledge Acquisition: Practical Tools and Techniques, 1990.

O'Reilly and W. Mendell. *An International Lunar Farside Observatory and Space Station*: From the 1993 International Space University Design Project, The 4th International Conference and Exposition on Engineering, Construction, and Operations in Space, 1993.

U.M. O'Reilly and F. Oppacher. *Using Building Block Functions to Investigate a Building Block Hypothesis for Genetic Programming,* Santa Fe Institute Technical Report No. 94-04-020, 1994.

Invited Talks

"Machine Learning for Knowledge Acquisition", Canadian Information Processing Society Congress 90, Oct 1990.

"Genetic Algorithms and Genetic Programming", Ottawa-Carleton Joint Institute of Computer Science Lecture Series, Sept, 1992.

"Comparative Approaches to Program Discovery",
- Technical University of Zurich, Switzerland, Spring, 1995.
- Artificial Life Colloquia, Iowa State University, Fall, 1995.
- MIT Artificial Life seminar, Fall, 1995.
- University of Wisconson, Madison, Chaos, Complex Systems seminar, Fall, 1995.

Reviewer

International Conference on Genetic Algorithms (1993, 1995)
Parallel Problem Solving from Nature (1992)
Journal of Evolutionary Computation
AAAI (1995, 1996)

Program Committee

International Conference on Genetic Algorithms (1997)
International Conference on Genetic Programming (1996, 1997)

Guest Editor

Special Issue of the Journal of Evolutionary Computation on "Evolutionary Approaches to Program Induction", to appear in 1997.

Professional Service

Organizing Committee Member

International Joint Conference on Artificial Intelligence Workshop on Evolution and Chaos in Cognitive Processing, Sydney, Australia, 1991.

Workshop on Evolutionary and Computational Landscapes, Santa Fe Institute, July-Aug. 1995.

Community Service

Technology and Academics: Bell Northern Research University Liason to McGill University Dept. of Systems and Electrical Engineering, 1987.

Pathmakers: Women in the Sciences High School Liason Organization, 1992.

Role Models for Young Women, Santa Fe Middle School Liason Organization, 1994.

Academic Development

International Summer School on Comparative Approaches to Cognitive Science,
Aix En Provence, France, Summer, 1992.

International Summer School on Logic Programming, Acireale, Sicily. 1992.

NATO Adanced Study Institute: The Biology and Technology of Intelligent Autonomous Agents, March, 1993.

As a member of the Canadian delegation: International Space University, Space Sciences Program, June-August, 1993.

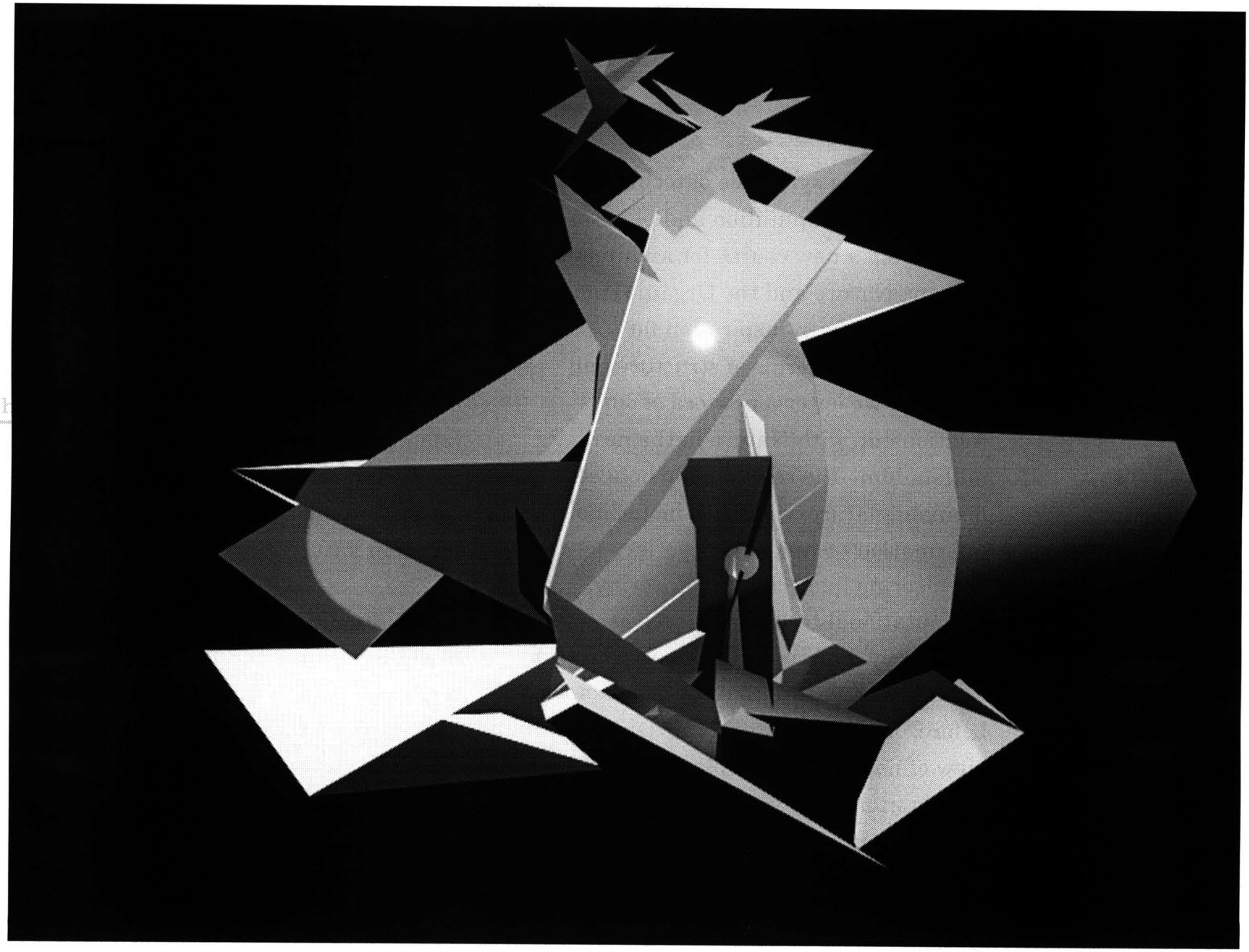
Creative Thought must always contain a random component. The exploratory process –the endless trial and error of mental progress—can achieve the new only by embarking upon pathways randomly presented, some of which when tried are somehow selected for something like survival.

--Gregory Bateson

Science is still searching for a theory of explanation, architecture for a theory of generation.

--John Frazer

Figure 2.0. Opposite Page.
Example of a model evolved by mutations and croassover



1.0 INTRODUCTION

The thesis is a synthesis of technology, art, science, computation and philosophy in charting a new course for architecture. Biology, Nature and the Organic tradition have always been inspiration for architecture in terms of structure and form. As we enter a new era of our relationship with Nature in the next millennium –the relationship between man and nature, will, with biotechnology, information technology, genetic engineering, molecular engineering, computational technology, become completely blurred. It will lead us into a new form of Nature that we have not seen before. We are constantly revising our view of nature and our place in it and now we can literally say that architecture is part of nature in the sense that man-made environment is now a major part of the global eco-system.

It is at this point that I begin to contemplate about broader issues such as: the relevance architecture should have to nature in the future, the inspirations we can draw from the second nature (artificially constructed nature). Can architecture be a medium to explore and exemplify morphogensis in the natural world. ? Can architecture spatially construct and provide opportunities for imagination and revelation of the biological, nonlinear processes, or natural forces that shape our landscapes and forms in nature ?

In an attempt to address some of these broad issues, the thesis begins in a traditional manner to find an architectural interface for a devastated landscape where various forms of natural as well as man-made forces (visible, invisible, silent and violent) interact on the site. It departs from a traditional design approach in that the selected site becomes an impetus for wider search which parallels emerging scientific & nonlinear paradigms, resulting in a nonlinear thesis the final product of which is not inevitable.

From the analysis of the data gathered for the site, meandering through the possibilities and exploring through the threads of thought which generate new ideas, I realize that it is important for architecture to recognize the convergence of two most powerful disciplines i.e. Biology and Information technology that would have a major impact on humanity and bio-sphere in the next millennium.

Paradigm shifts in science, medicine, physics, information technology continue as we speak. Architecture like other forms of cultural expression is looking at ways to engage and interpret these paradigm shifts in science, and therefore it becomes important to understand their underlying concepts. As such ideas and concepts of artificial life, genetics and biological analogies are proving to be very valuable in the advancement of computational techniques (genetic algorithms, genetic programming) and material sciences (bio-materials, nano-technology, memory shaped alloys).

The final product is a process that is based on biological analogies and genetics, coupled with emerging computational techniques of genetic programming as a generating force for architecture. The primary inspiration comes from the fundamental basis of genetics and evolution and the information systems of nature.
A prototype system called Generative, Genetic Design Explorer (GGDE) built as part of this thesis integrates evolution, both as a metaphor and an active generative modeling tool, with the interpretive aspects of the design process.

The metaphor - replete with concepts such as genetic engineering, inheritance, sexual reproduction and random variation has proved valuable in providing a coherent, exploratory process. The thesis thus sets the framework for future exploration based on artificial life, a new form of designed artifact interacting and evolving in harmony with natural forces.

2.0 INSPIRATION FOR EXPLORATION

FACTORS THAT MOTIVATED THE EXPLORATORY PATH.

2.01 Personal and Professional Experience

My academic training in architecture and landscape architecture were great asset in forging my career in computation and information technology, 8 years ago. Learning to design for human behavior in spaces were very useful in translating to virtual environments. The information synthesizing, breaking larger problems into smaller problems were all very useful in the design of algorithms for complicated tasks and for designing user interface in custom applications.

As a Benchmark and Prototype development specialist with Environmental Systems Research Institute (ESRI), one of the largest software companies in the world in the field of Geographic Information Systems (GIS), I had the opportunity to push the power of information technology to revolutionize decision making in previously unexplored territories. During this time I was directly involved in the benchmarks for various International and National level GIS systems. It was an experience and challenge for me to get insight to other disciplines such as, epidemiology , meteorology, geology, natural sciences, and find ways to bridge them using information technology. The projects which have some relevance to the thesis is the prototype for National Weather Service's coveted benchmark for Advanced Weather Interactive Processing System (AWIPS-90), U.S Bureau of Land Management (BLM) benchmark for The Automated Land Records and Minerals System (ALMRS), and other state-wide emergency management systems. The power of linking remote sensing satellite images with GIS has proven to be very valuable not only for defense agencies but also for various planners, environmentalists and policy makers in the decision making process.

2.02 Previous Academic Training & Research work.

My academic training in architecture, design and technology, landscape architecture, planning and landscape ecology enabled me to widen my search for design strategies. My association with design faculty at various universities and professionals in various disciplines ranging from designers, software engineers, ecologists, environmentalists, engineers, doctors and biotechnologist have all been source of inspiration.

My previous academic research work at Harvard University- GSD, MIT and The Ohio State University were also influencing factors in my approach. One such research project was done here at MIT as part of a design studio in 1994 with William Mitchell and James Gymph of Frank O Gehry & Associates. As part of design exploration for this CAD/CAM studio, I had unconsciously explored some of the principles and concepts of genetics, by mixing 3-D digitized models of two different kinds of fruits (mango & pear), to generate a complex form.

Some of my previous academic research projects are listed below:

Exploration and realization of architectural form using CAD/CAM based rapid prototyping techniques, 1994. Published in the second edition of the book - "Digital Design Media " by William J. Mitchell and Malcolm McCullough. Generated digital vocabulary of complex 3-D architectural forms derived from fruits, explored design concepts through CAD modeling, developed and programmed in Autolisp, a prototype framework of CAD/CAM unfolding process for the fabrication patterning of exterior cladding panels of this 3D curvilinear form.

3-D real-time construction simulation using project management and scheduling information, 1994. A self initiated research experiment at Harvard University, Graduate School of Design in bridging the disciplines of architecture and construction. The application was developed using "Walkthru " software by Bechtel Corp. and "Construction Simulation tool kit (CST)" by Jacobus Technology. Advisors: Prof. Spiro N. Pollalis,(Harvard GSD), Prof. Gehard Schmitt (ETH, Zurich)

An experiment in integrating real-time 3-D modeling and visual simulation techniques with Geographic Information Systems (GIS), 1989-90. M.L.A Thesis , In collaboration with The Ohio State University, Department of Landscape Architecture and Center for Landscape Research, University of Toronto, Canada. Advisors: Prof. Douglas S. Way, Prof. Dana Tomlin, Prof. John W. Danahy (University of Toronto).

A non-funded collaborative project which integrated two most powerful computational modeling and analysis tool available for landscape architects and planners at that time i.e. Arc/Info GIS system by ESRI, Redlands, CA and PolyTrims by CLR University of Toronto. The integration enabled one to design in a 3-D virtual environment and to quickly simulate 'walk-thrus' and various "What if" scenarios of large scale urban and landscape models. It also provided full capability to design with planning controls and to perform real-time 3-D simulation of models as large as the City of Toronto. This project continued and, after I joined ESRI, I was able to secure funding for University of Toronto through ESRI for further development of this research initiative.

2.03 Personal Interests to Explore New Design Strategies and Processes.

My previous academic and professional backgrounds in –architecture, landscape architecture, information technology and computational techniques and, my inquisitiveness to explore new territories, prepared me to take an exploratory path for my thesis. Complexity and obscurity surround the concepts of design and creativity, architectural relevance as a reflection of our society and culture's achievement becomes questionable. The rapid advancements in science and technology and the paradigm shifts in sciences inspired me to raise questions about the future relationship of architecture to nature. I decided to take this opportunity to explore and formulate some alternative design processes and strategies that responds to the emerging artificial environments that architects would have to deal with in the future.

To explore and address some the broader questions raised earlier, the selection of the site that poses such new conditions was crucial. A site that would serve as radical platform to develop and test alternative design strategies and demand new technology becomes imperative. Experience and interests in bridging disciplines with aid of computational and information technology was another factor which motivated me to look at alternative approach and the need for inter-disciplinary exchange.

2.04 Site as an inspiration and motivational factor:

With the advancement of technology today, man has been able to manufacture a new breed of "devastated" landscapes in the form of landfills for human habitation. These forms of landscape disasters are growing in unprecedented rate all across the country. It is these kinds of unsuccessful interface with nature that human beings create which pose environmental threats and sometimes resulting in disasters.

One such form of devastated landscapes are the wetlands. Wetlands have often been regarded as wastelands – sources of mosquitoes, flies, unpleasant odors, and disease. People thought of wetlands as places to avoid or, better yet, eliminate. Largely because of this negative view, more than half of America's original wetlands have been destroyed—drained and converted to farmland, filled for housing developments and industrial facilities, or used to dispose of household and industrial waste. The site which I have chosen for my thesis is a large urban landfill in a coastal wetland located, close to the city of Boston, Massachusetts.

3.0 THE SITE

3.01 The Rumney Marsh — Area of Critical Environmental Concern

A 100 acre landfill in Rumney Marsh, Area of Critical Environmental concern, on the Saugus & Pines River estuary.

Coastal wetland North of Boston is the Rumney Marsh, a 1000 acre wetland located between the Town of Saugus , Lynn and Revere, MA. The RESCO landfill encompasses about 100 acres of ash dump, which was used previously as a municipal solid waste dump, within the Rumney Marsh Area of Critical Environmental Concern (ACEC). Adjacent to the RESCO landfill is a 12.6 acre GE landfill site used by GE's Aircraft Engine plant. The area is well served by State Highways and local roads. State Route 1A crosses the rivers mouth to the east and State Route 107 to the West. The nearest MBTA stop is 'Wonderland' on the Blue Line and the commuter train stop at Lynn. The site is bounded on the North by the Saugus river and 265 acres of upland and wetland owned by GE's Aircraft Engine Division. Bear Creek and Pines river forms the eastern edge of the site. The RESCO landfill abuts the site on the South side and the State Route 107 (Salem Turnpike) on the Westside.

Named the Rumney Marsh in early 1600's, Revere used the marshes for mining iron ore, haying, fishing and shellfishing. Its rocky outcrops became quarries for construction and its open spaces became housing developments, petroleum tank farms, and shopping centers. Revere's development has begun to creep into the last vestige of open space. In 1988, the Massachusetts secretary of Environmental affairs designated most of the Saugus and Pines River estuary and adjacent areas to be an "Area of Critical Environmental Concern".

Figure 3.0. *Digital Orthophoto of the landfill site.*

Many types of activities are specifically excluded from the ACEC such as improvement dredging, marina expansion. The site contains uplands, brackish wetlands, and is bordered by salt marsh.

City of Lynn plans to increase public access to water resources in the future, both the current use of bordering lands (Industrial) and physical and psychological limitations to access, have created barriers to this goal. In particular unattractiveness and distance from the residential area contributes to under utilization of the water resources. The river provides an important recreational boating harbor in an area experiencing an extreme shortage of recreational anchorage and mooring space. Lynn's major employer the GE, utilizes its only water front access, the Saugus river for fuel importation. General Electric Company in Lynn began using the river and improving the channel in the 1880's, receiving fuel and raw materials and shipping some electrical products. The MDC (Metropolitan District Commission) owns most of the Rumney Marsh ACEC area.

3.02 The Landfill

This active landfill, which has been active since 1938 is located in the Saugus and Pines river estuary. It has reached its maximum height limit of 50 feet. The landfill contains municipal solid waste and currently it is used for dumping ash from the RESCO incinerator plant on the site. Plans are underway for closure of the landfill and the RESCO landfill has been partly capped. Post closure uses for such landfill sites are mostly passive use facilities such as play fields, parks & recreation and in some instances shopping malls. This is mainly due to the cost of cleaning up landfill sites and infrastructure costs for capping and removing methane gas for active post closure uses.

In addition to other smaller landfills in this 1000 acre Rumney Marsh, there is an abandoned one mile stretch of I-90 highway to the West of State Highway 107, which was constructed in late 1960's. The mile long elevated I-90 in the middle of this wetland forms another form of landfill, filled with stone, gravel & sand. Thus the two disjointed and dissimilar landfills, RESCO-GE landfills in the east and the abandoned stretch of I-90 in the west, form a large scar in the landscape which is clearly visible from the satellite images. **See. Figure: 3.0**

3.03 Landfill Closure Plans

Plans have been approved to develop a nature trail and wildlife refuge as post closure use for both the GE and RESCO landfill sites. In conjunction with the RESCO habitat restoration, a network of nature trails is being developed around the capped 100 acre RESCO landfill. These nature trails will provide the public with open space recreational opportunities, and take advantage of the natural diversity and beauty of the Rumney Marshes that abuts both the GE and RESCO landfills. At the recommendation of the MDC, GE is proposing to coordinate with RESCO to develop a compatible landscape on the final cover of the landfill that compliments the habitat-related goals of the closure of both landfills. The RESCO landfill closure plan targets the breeding and wintering habitats of several bird species that are listed by the Natural Heritage and Endangered Species program (NHESP) as being threatened or endangered in the Commonwealth of Massachusetts. By providing habitats for these targeted species, the landscape will also provide feeding, breeding, wintering and migratory habitat for many other birds, small mammal, and reptile species in the area.

3.03 Characteristics of Estuaries

Estuaries are crucial transition zones between land and water that provide an environment for lessons in biology, geology, chemistry, physics, history and social issues. The Site selected for the thesis, located in the Saugus and Pines river estuary serves as a biologically significant site.

Human beings have always been attracted to estuaries. Commercially important fish and shellfish spawn, nurse, or feed in estuaries. Scientists and students, poets and painters, bird watchers and canoeists - all are inspired by the beauty and diversity found in an estuary. Estuaries tend to be highly productive areas, where the larvae of many fish species spend their first part of their life cycle. Furthermore, estuaries frequently have high concentrations of organisms that are utilized by fish for food, such as shrimp. Estuaries can also have numerous bottom-dwelling (or benthic) organisms such as oysters, crabs, clams, and scallops. These crustaceans and molluscs, many of which are called filter-feeders because they filter the water of the estuary to remove digestible particles. Thus, pollutants in the particles can be concentrated in their tissues. Because these organisms are frequently food for other marine organisms (or humans) pollutants in these sediments can be transferred up the food chain.

Estuaries are tidally-influenced ecological systems where rivers meet the sea and fresh water mixes with salt water. Estuaries provide habitat, nursery, productivity, water filtration, flood control. About 75% of commercial fish depend on the habitat of estuaries. It is here that the river meets the sea in shallow protected bays. Estuaries metamorphosize with tides, the incoming waters seemingly bringing back to life organisms that have sought shelter from their temporary exposure to the non-aquatic world. As the tides ebb, organisms return to their protective postures, receding into sediments and adjusting to changing temperatures and exposure to differing degrees of sunlight and different kinds of weather. At high tide, sea water changes estuaries, submerging the plants and flooding creeks, marshes, pannes, mudflats or mangroves, until what was once land is now water. The Indians called the estuary "Between-Land", not quite land and not quite water.

The landfill site located in a large coastal wetland and in a estuary, offers excellent opportunity to work on an urban wasteland close to a large metropolitan area and to explore various alternative solutions. The landfill could be understood as a floating object on the coastal wetland and as an interface of artificial and natural systems. Upon closure the landfills are capped to reduce the generation of landfill leachate by minimizing infiltration of storm water into landfill. Storm water gets directed off the cap to the adjacent wetlands and

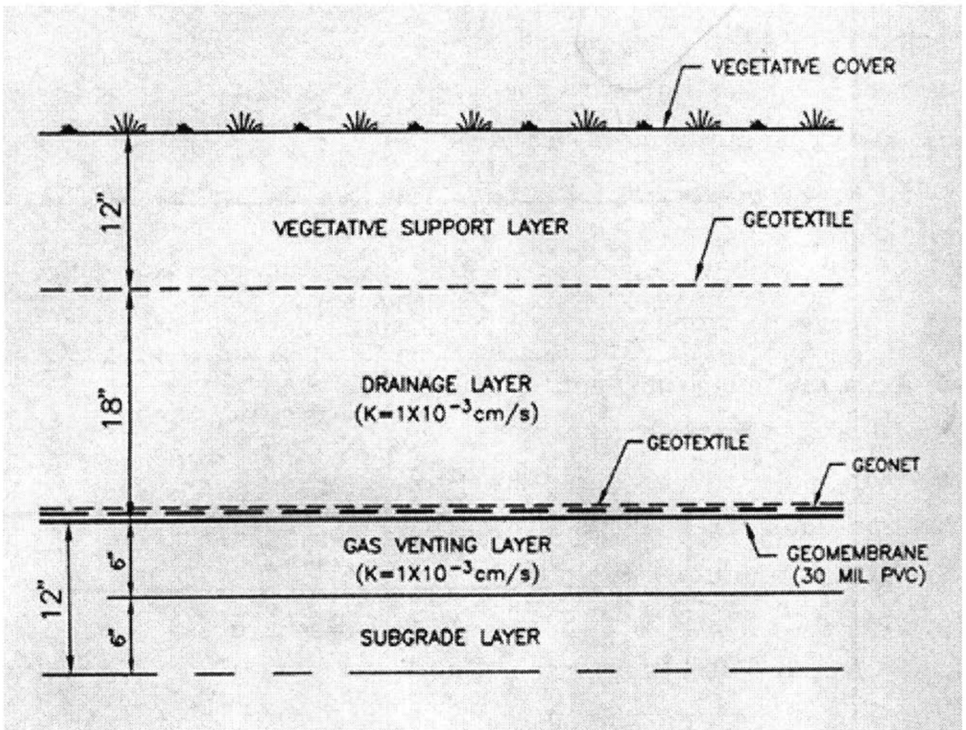


Figure 4.0. *Detail of landfill Cap*

minimizing contact with waste materials. The final cover systems consists of a multi-component cap. The layers of which consists of Subgrade layer, Gas venting layer, low permeability layer, drainage layer, Vegetative support layer and Vegetative cover. **See Figure**. 4.0

This junction between the natural systems/forces and technical systems has produced new site conditions which require special construction techniques and design strategies. The question we need to ask is how we are to find a meaningful approach to nature and technology in the future. The thesis sets out to explore alternative design strategies instead of the proposed nature trail and investigate ways in which architecture and landscape architecture should respond to this new man made interface with nature in the form of landfills.

The developments in biotechnology,

genetic engineering, biosciences has created an opportunity to enter into a dialogue with devastated landscapes for sustainable development, restoration and harnessing the resources.
Bioremediation, transgenic plants and crops, aqua culture, biotech products and biomaterials will soon be the agents to establish such dialog. Valuable environmental and marine microbial resources found in some of these polluted sites, salt marshes and wetlands are on the verge of transforming our landscapes and may provide alternative solutions for active post-closure use of the landfills.

4.0 POINTS OF DEPARTURE

4.01 General Discussions

Sifting through the electronic data, images and notes gathered regarding the site I begin to depart in the approach of my thesis. I realize that as we move towards the next millennium the two most important fields that would change our lives, the way we live and things around us are Biology and Information technology. Information technology in the form of –satellite images, digital orthophoto, ocean scanner images, GIS databases reveal natural and biological processes in a way that we have never understood before. DNA's remarkable information bearing ability and the recombinant DNA technology –ability to snip a piece of genetic information from one organism, transfer it to another, and get the host organism to "express" the new gene - that is carry out its instructions, are making major breakthroughs in science and medicine today.

It is important for us to recognize the potential impact of the convergence of these two disciplines of science - Biology and Information technology, the signs of which we are already witnessing.

Some of the federal government initiatives in this direction are: The Human-Genome Mapping project, Mapping of animal/plant/microbial genomes, the Natural Systems and Resource Mapping, the move to discourage human cloning efforts and funding for further research in biotechnology aimed at understanding the social, cultural, ethical, economic, and legal implications of biotechnology research and its applications.

Advancements in genetic engineering will alter not only human beings but also our eco-system. Transgenic plants and animals, genetically engineered foods, Philosophy

Technology

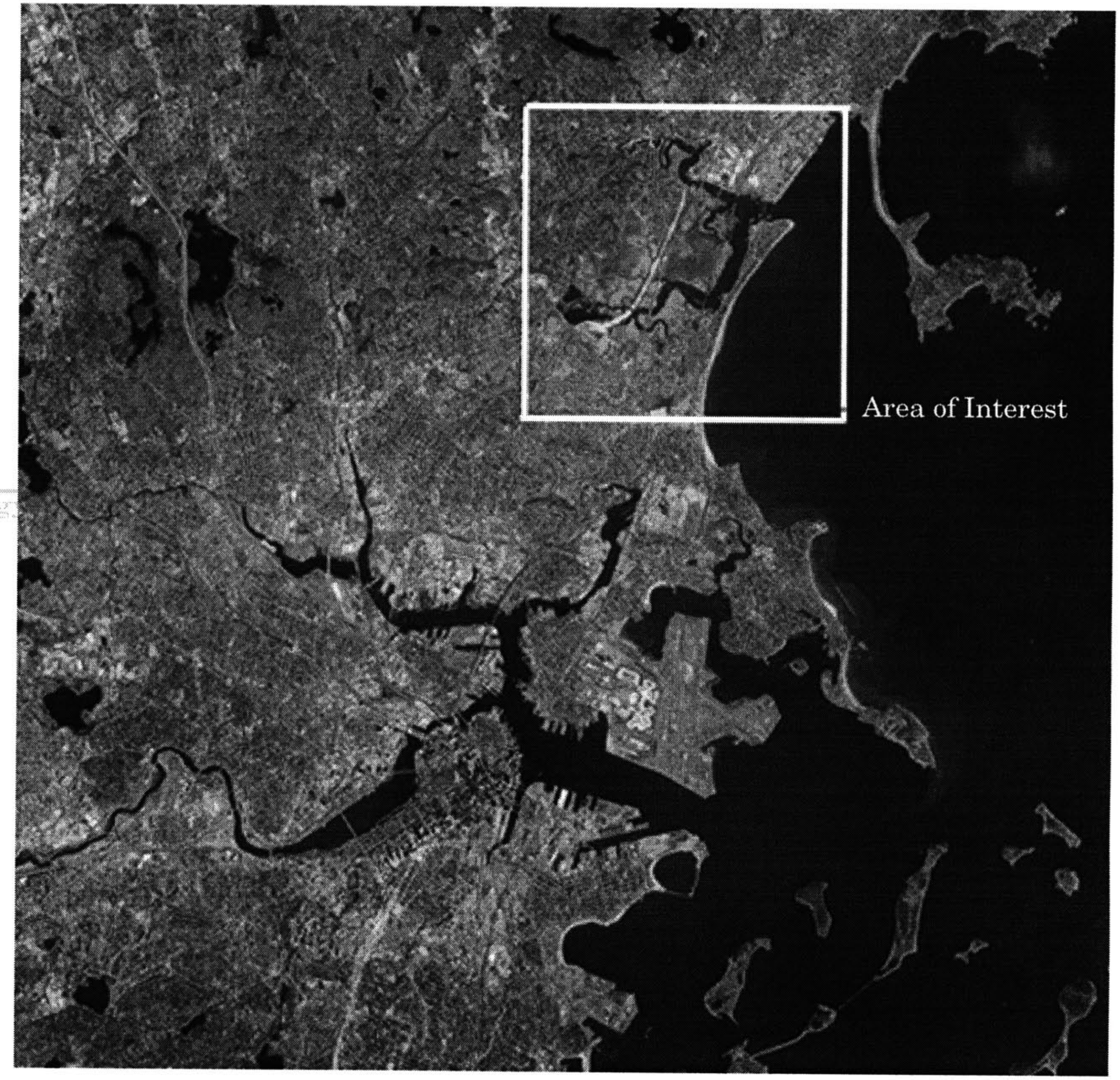


Figure 5.0. *Satellite image of Boston and the site.*

aqua-culture, marine biotechnology, bio-remediation techniques will alter the landscape and eco-systems. Through the use of advanced tools such as genetic engineering, biotechnology is expected to have a dramatic effect on World economy over the next decade.

4.02 Emergence of Artificial Organisms:

The pace of evolutionary change will be extremely rapid in the next millennium. The advancement of artificial life will be the most significant historical event since the emergence of human beings The impact on humanity and the biosphere could be enormous, larger than the industrial revolution. Information technology and biology are becoming the important economic resources of a country. Microbial resources and biological diversity are becoming hot trading commodities between nations and biotechnology companies. In an international level an emerging issue is that of conservation and protection of

Microbial-diversity of a Nation and various legislation in terms of Biopiracy and Bio-prospecting are being worked out. The first Bioprospecting agreement in the United States was signed by Diversa Corporation a San Diego, based Biotechnology firm, with the Yellow Stone National Park. The agreement authorizes Diversa, a world leader in the discovery and commercialization of biocatalysts (enzymes), to carry out research on microorganism from Yellowstone hot springs. Diversa has entered into similar 'bioprospecting' agreements in Costa Rica and Iceland.

The capacity to manipulate matter with the advancements in Molecular engineering called 'Nanotechnology' will utterly change with atomic precision, all the economic, ecological and cultural fabric of our lives.

I would like to discuss briefly some interesting developments in two areas which may have implications on our

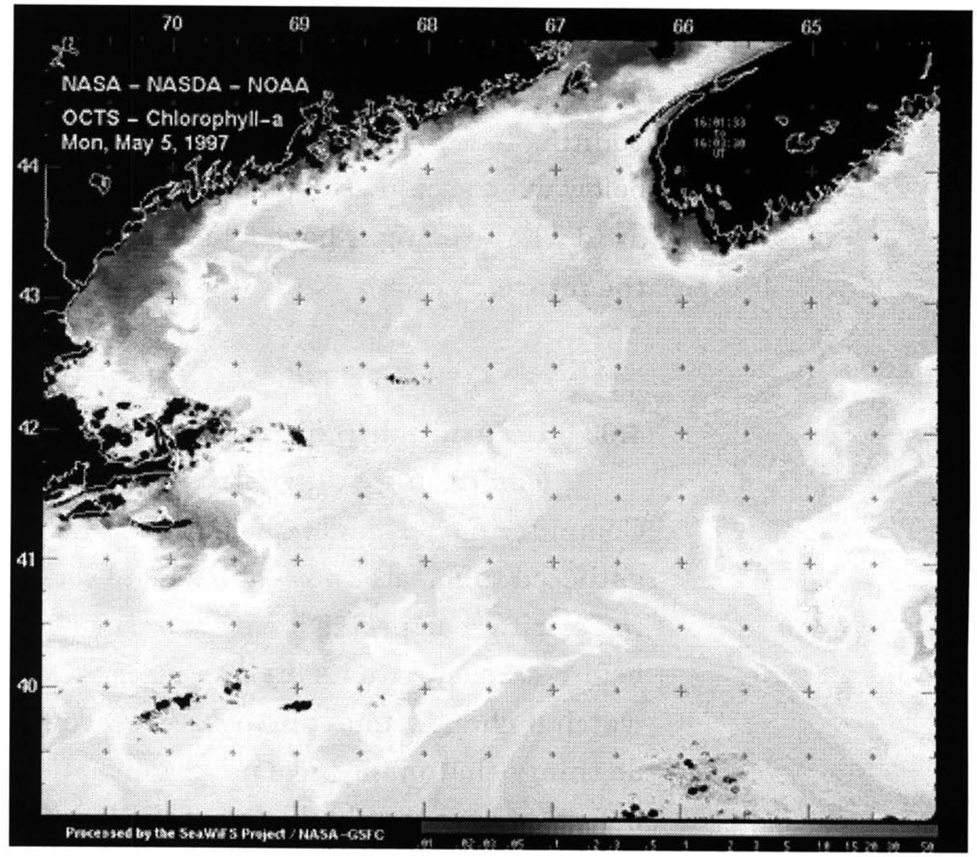


Figure 6.0. *Satellite Image showing the Chlorophyll content found in the coast of Mass.*

nature and the ecosystem and which are becoming news in our everyday life. It is impossible and beyond the scope here to discuss in detail these topics, hence I am pointing to few issues in each of the topics below which could stir some discussions as to what we might have to deal with in the future.

4.03 Relationship of Information Technology and Site processes

Computer models and information gathered from satellites enable us to see the territory as people have never seen before -to peek into its life processes, watch it change, imagine its future. They do things that maps have never done before -show not only the lay of the land, but things happening to it. The power of information and computational technology has enabled us to understand better weather phenomena's such as El Nino, monitor human devastation of the planet Earth such as the ozone hole. Powerful computing tools have enabled us to understand and explore nonlinear processes in a way that was previously impossible. Using information technology we are able to predict as well as observe natural phenomena's such as hurricanes, tornadoes, floods, snow and rain. Remote sensing satellite images provide us means to monitor, analyze, model and visualize biological activities (such as crop destruction, pollution, chlorophyll, type of vegetation and soil, moisture, energy) and natural processes (such as floods, tornadoes, hurricanes) for any part of the World.

The information systems are proving to be very valuable in the mapping of human systems and natural systems

From the various information gathered for the site, the most striking information which reveals the unconscious processes active on the site are the Ocean Color images and Sea surface temperature images.

Ocean color data provide an incomparable view of the changeable patterns of

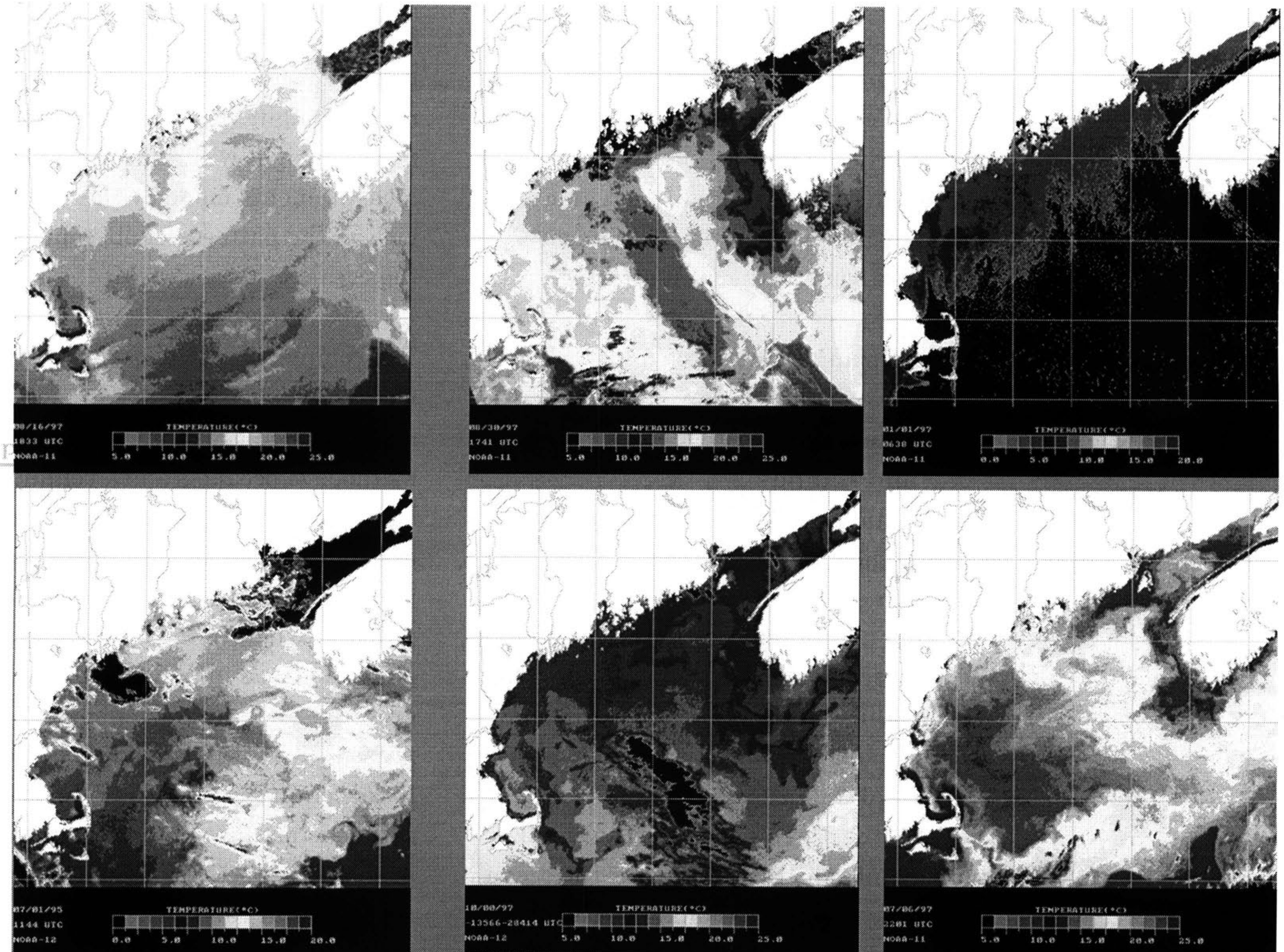


Figure 7.0. *Satellite Images of Sea Surface Temperature measured daily every few hours.*

biological activity in the marine realm. These data also indicate how, and where, physical processes interact with the biological communities of the ocean, particularly the minute plants (phytoplankton) that produce organic carbon by photosynthesis. The images shown are some of the most striking examples of ocean color data obtained by remote sensing from space.

4.04 Interactions of Ocean Currents and Biology

The Coastal Zone Color Scanner (CZCS) was designed to make precise measurements of the intensity of radiation in different portions (bands) of the color spectrum. These measurements indicated how much sunlight was being absorbed and how much was being reflected at (and from some depth beneath) the ocean's surface. The small living plant cells that exist near the ocean surface—called phytoplankton—contain chlorophyll, the pigment that allows them to convert sunlight and carbon dioxide into the organic matter of their cellular structure. The more chlorophyll that is present at the surface, the "greener" the reflected light will be. At the same time, more red light will be absorbed. Thus, the measurements made by the CZCS allow a view of the patterns of phytoplankton in the ocean.

The complexity of the patterns and the fact that they are always in motion makes it very difficult for the traditional methods of oceanography, conducted from a stationary ship, to make accurate estimates of the amount of phytoplankton in a given oceanic region. It is also difficult to determine how rapidly the phytoplankton in an entire region are growing. The process of photosynthesis in plants converts light and carbon dioxide to carbon in the cell. The rate at which carbon is produced by plants is called primary productivity, and it is one of the fundamental variables measured by biological oceanographers. It is only by

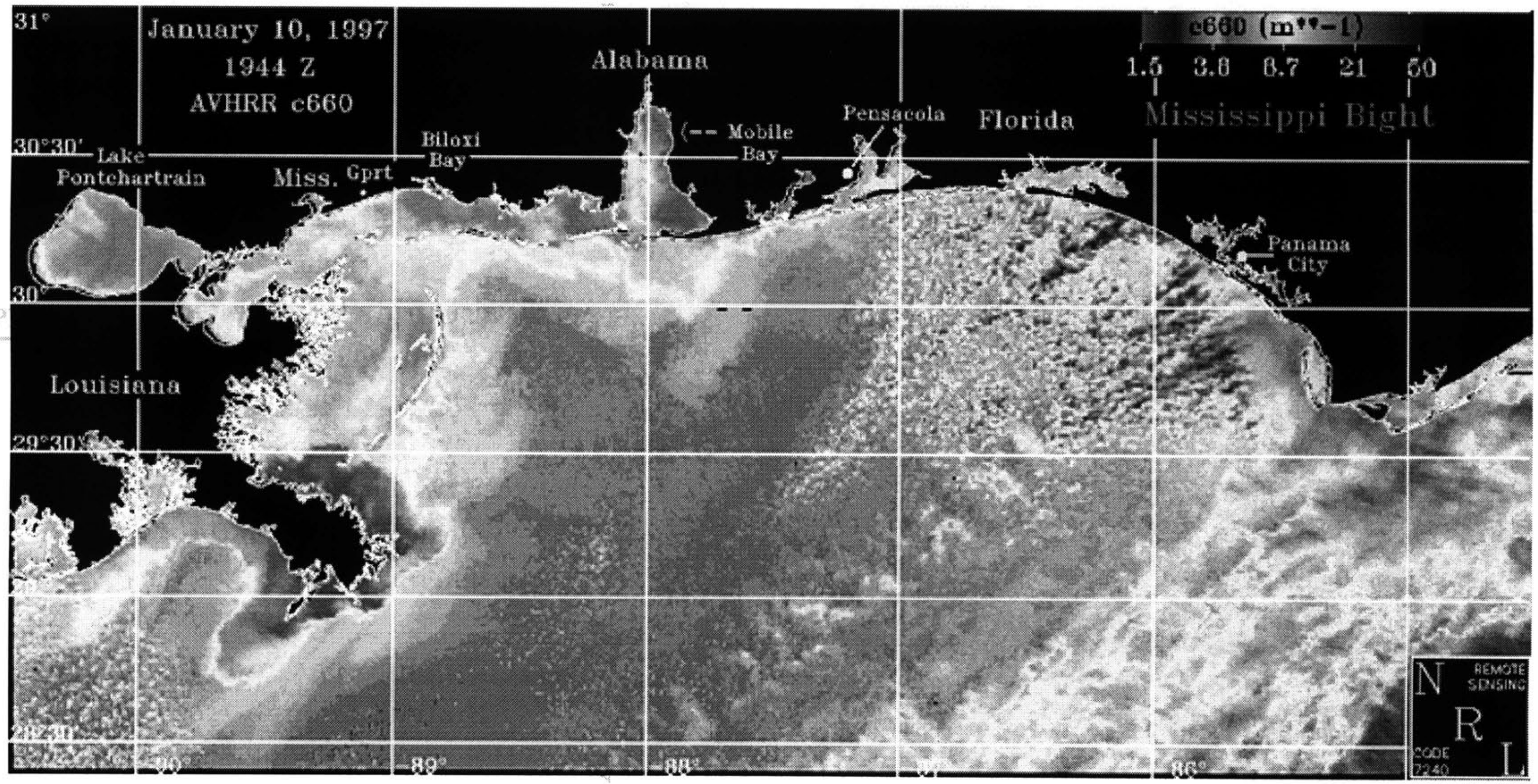


Figure 8.0. *Ocean Color Image revealing biological processes on*

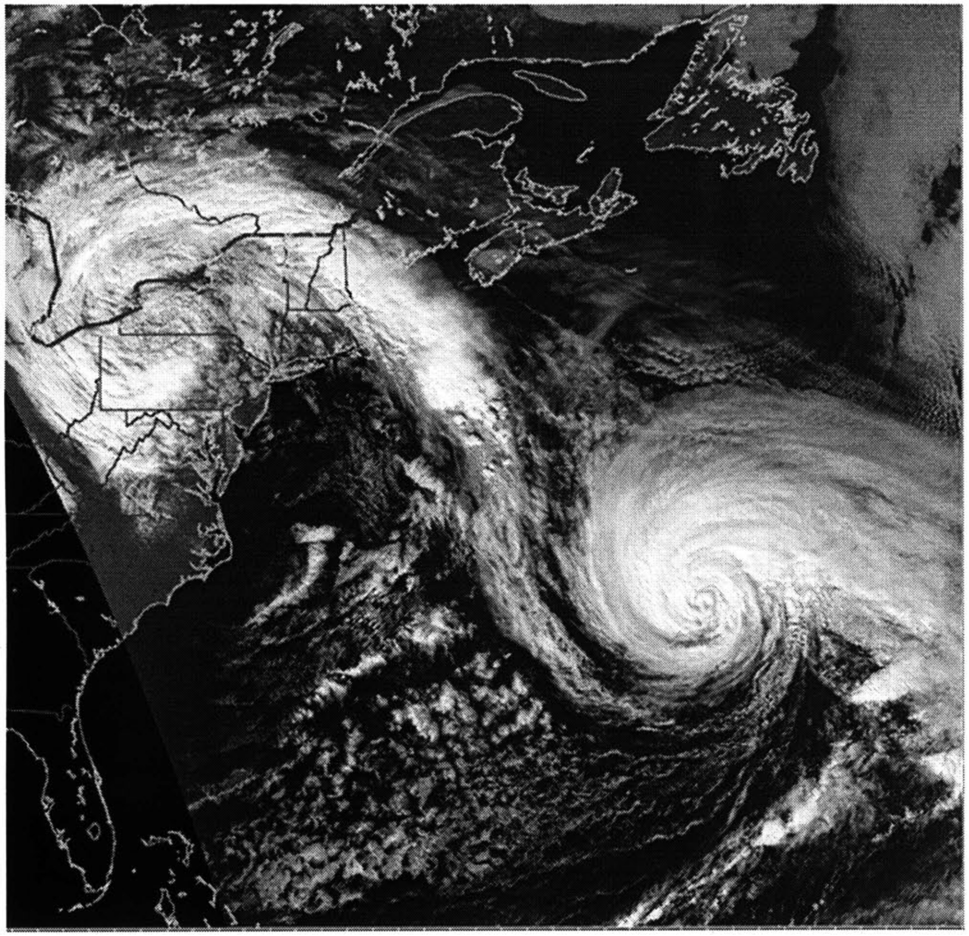


Figure 9.0. *Tracking hurricane 'Lilly'*

taking a view from space that the biological patterns in the whole region can be observed and measured, presumably allowing more accurate estimates of primary productivity. There are many different processes that influence the growth and movement of phytoplankton in the ocean.

The ocean color maps offer new possibilities in terms of layer, depth, edge and concentration. Shows various event patterns and biological forces occurring in nature- densities and magnitudes of events, they reveal the interaction between two different field conditions - the "Biological field" and the "Atmospheric field".

4.05 On Microbes and Microbial Biotechnology

The U.S. Fish and Wildlife Service characterizes the designated area as "one of the most biologically significant estuaries in Massachusetts north of Boston." Majority of this Rumney Marsh wetland system are Salt marshes. Salt marshes are extremely productive communities, however they are not very diverse.

Most people understand biodiversity in terms of plants, animals, and may be insects. New research in microbial ecology and molecular biology points out that the real diversity lies in millions of single celled microbes. Edward DeLong, a microbiologist at the University of California, Santa Barbara (UCSB) points out that the evolutionary reason for this diversity is the microhabitats in soil.

Mitchell L. Sogin, a molecular evolutionist at Woods Hole Marine Biological laboratory in Massachusetts commenting on the U.S National Science Foundation (NSF) special competition for research funding on 'Life in Extreme Environments' points out that extreme environments include not only natural but unnatural ones, and wants to see what may be flourishing in industrial waste pools or mine tailings. Many microbes that thrive in polluted environments such as landfills or industrial waste dumps, are becoming hot commodities for the biotechnology industry.

The BIOTECH program proposal summary by the European Union states that Extremophilic archaea abd bacteria have tremendous potential in biotechnology because of their ability to grow under extreme conditions and to produce stable products with high technological value.

Among the extremophiles now under increasing scrutiny are those that prefer highly acidic or basic conditions (acidophiles and alkaliphiles). Acidophiles thrive in rare habitats having pH below five and alkaliphiles favor habitats with a pH above nine. A remarkable group called "Halophiles" makes its home in intensely saline environments, especially natural salt lakes and solar salt evaporation ponds. Some saline environments are also extremely alkaline because weathering of sodium carbonate and certain other salts can release ions that produce alkalinity. "Alkalipiles" live in soild laden with carbonate and in so-called soda lakes. Whatever the reason for their greater activity in extreme conditions, enzymes derived from thermophilic microbes have begun to make inroads in industry.

Bio-remidiation is a biological process typically applied on contaminated sites for cleanup. Bacterial agents are injected on the soil or water to fight other unwanted bacterial growth. Biological agents are often used in cleaning up oil spills. The pollution caused as a result of the landfill leachate, the destruction of the wetland habitats all reflect the biological changes to the local eco-system.

According to Dorion Saga and Lynn Margulis, Microbial organisms are neither plant nor animals, are the dominant and oldest forms of life on Earth. Their continual growth, movement, chemical transformation, and death strongly affect human life. Our growing understanding of what life is, including the new techniques of genetic engineering, requires a familiarity with microbial world. The transfer of portions of DNA and RNA from one microbe to another for medicene, agriculture, and waste removal as well as industrial microbiology, has become a highly developed science with many ramifications.

Microbial biotechnology uses microbial genetics to address needs in clinical medicine, national security, and global ecology. Uses such as :
Species and sub-species identification using DNA and immunological-based

identifiers of environmentally or clinically relevant organisms.

Bioremediation and biodiversity

Bioprocess engineering, i.e. the application of microbial systems to problems in industrial ecology such as Biomining / biomachining / biocatalysis.

The Microbial Genome Initiative establsihed by the Department of Energy (DOE) to fund genomic sequencing and mapping of microorganisms –including Archaea also known as archaebacteria reflects the importance assigned to these microorganisms from the federal government.

Some biotechnology solutions for landfill and wetland restoration are:

- Bioremediation
- Bioprospecting of Microbial resources from saltwater and estuary
- Biotechnology based restoration of shell fish bed - aquaculture
- Transgenic plants

Processes active on site: Some of the processes active on the site are

- Bacterial growth in Leachate formed from the infiltration of storm water into the landfill.
- Biological agents for site remediation, genetic mutations, estuary, chlorophyll, plankton blooms,
- Destruction of Shellfish bed
- Microbial diversity.
- Mixing of fresh water and salt water.
- Infiltration of water and pollutants from the landfill.

4.06 Transgenic Plants:

Genetic engineering refers to sophisticated, artificial techniques capable of transferring genes from other organisms directly to recipient organisms. Genes determine specific traits, like color, height, or tolerance to frost, tolerance to salt, foliage. Genetic engineers can move genes from any biological source animals, plants, or bacteria into almost any crop.

Transgenic plants are crops that have been genetically engineered to contain traits from unrelated organisms. "Brain-shaped 'broccoflower' ! Tomatoes that look like giant marshmallows, tomatoes that are yellow and can stay fresh for a longer period. Beets that resemble red carrots, carrots that could be like orange golf balls. Plants that could have dense foliage with slender leaves. Genetically designed made to order plants are becoming reality. We have been successful in cloning animals and are not far from cloning human beings. Genetically eliminating diseases in humans, plants and animals are being tested as we speak. Now that genetically engineered foods and plants are becoming reality, the debate about such artificial environment is gathering momentum.

The benefits of transgenic plants and foods are many. Just to mention a few - transferring and eliminating unwanted genes. Example : transferring salt-tolerance gene from plants enable plants e.g. tomato, tobacco to grow with their roots exposed to salt. Many plants are very efficient sources of renewable organic materials. Potential use of starch from plants (e.g. corn starch) as a co-polymer in biodegradable plastics is another example. Through development of transgenic plants, the purity of many plant-derived chemicals can be enhanced and the range of chemicals expanded. Biotechnology offers the potential to change plant architecture precisely and optimize plant form. (e.g., tall or short plants,slender leaves). Changes in leaf form and/or number could maximize photosynthetic capacity and increase production, and changes in root architecture could facilitate and maximize water and mineral capture and uptake. Tools of biotechnology could be exploited to design plants that thrive in soils contaminated with heavy metals, such as cadmium or mercury, increasing resistance to disease.

Transgenic plants also pose a spectrum of ill effects on humans and animals to disruptions of wild ecosystems. Their new traits may cause any undesirable effect and alter our ecosystem. Soil insects and microorganisms, foraging and burrowing mammals, seed-eating birds, and a myriad of other non-target organisms will be exposed for the first time to vaccines, drugs, detergent enzymes, and other chemicals expressed in the engineered plants. Herbivores will consume the chemicals as they feed on plants. Soil microbes, insects and worms will be exposed as they degrade plant debris. Aquatic organisms will confront the drugs and chemicals washed into streams, lakes, and rivers from fields.

4.07 On CAD & Architectural Design

The term CAD is used for Computer Aided Design and design professionals have been using this term for the drafting and rendering services they provide to clients, claiming themselves as CAD designers. A more appropriate term to be used would be Computer Aided Drafting. Architects often misunderstand or misinterpret CAD for 2-D drafting and recently for 3-D modeling, walk-thru and rendering. In most cases CAD is used as a presentation medium, replacing the traditional medium of water, color, ink and expensive models. Hand drawn sketches are still the primary medium for design exploration and three-dimensional models are a start towards the use of computers in design exploration.

There is no question about the benefits of using computational medium for architectural production tasks, but I would argue that this does not give a legitimate reason to state that computational tools are used in design. In fact it is least used for the design process. Despite the availability of complex modeling tools, the use of computational power for design conceptualization, investigation of design strategies and alternatives is very limited. This I think, is due to the fact that the computational tools available today for architects do not generate forms to interact, analyze, interpret, examine, refine or dispose. Though the CAD programs available today for architects allow them to model complex surfaces and volumes, the use and generation of complex 3-D geometrical surfaces need proficiency in the use of these complex modeling functions and the ability in the part of the designer to conceive complex shapes and surfaces in order to model them. That is one of the reasons why these tools have not made any influence in the architectural vocabulary.

Architects seek inspiration for forms from various sources, often it is an interpretation of some sort and they do not model any processes. I strongly feel that in order for architects to use computational tools for design exploration, there is a need for generative modeling capability. Tools that would be able to generate suggestive, unexpected forms from a database of existing vocabulary, from various processes, a database of commonly used sources of inspiration, or a combination of any of these. These tools should be able to function in an integrated manner with other planning, modeling, analysis and visualization tools allowing the designer to interact with it and interpret them as and when necessary.

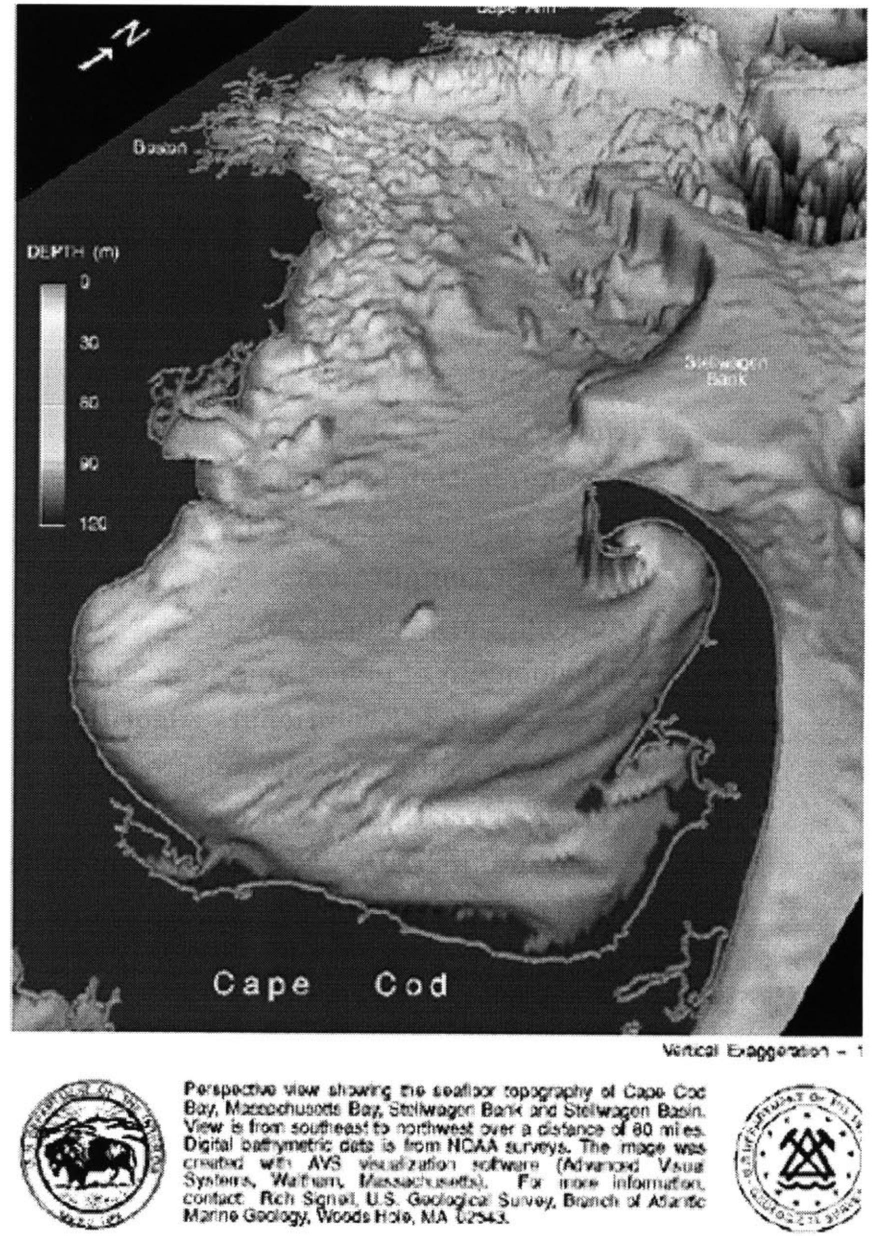


Figure 10.0. *A 3-D model of the Massachusetts Bay.*

5.0 ON GENETIC PARADIGM

5.01 Introduction

The computational Genetic Paradigm is bringing revolutionary changes in the understanding of human beings, animals and plants. Like Biotechnology, the convergence of Biology and information/ communication technology is the key factor in bringing about these changes. From the computational side, biological analogies are valuable in the development of algorithms. One such class is called "Evolutionary Algorithm", examples in the class are referred as genetic algorithm(GA) or evolutionary programming(EP). Genetic Programming (GP) is a sub class of genetic algorithms (GA).

The Genetic algorithm is an avenue for addressing problems in a wide range of disciplines, including, biology, economics, and perhaps architecture. The genetic paradigm with its unique mechanisms of population, inheritance, mutation, fitness and selection is a method distinctly different from traditional design and optimization methods.

The use of GAs as a model for investigating evolutionary behavior has its roots in the 1960's. It was John Holland in 1975 who presented the genetic algorithm (GA) model as a computational abstraction of the actual biological process. It has been summarized by Mitchell and Forrest:

> Holland's GA is a method for moving from one population of "chromosomes" (e.g., bit strings representing organisms or candidate solutions to a problem) to a new population, using selection together with genetic operators of crossover, mutation and inversion. Each chromosome consists of "genes" (e.g. bits) with each gene being an instance of a particular "allele" (e.g. 0 or 1). Selection chooses those chromosomes in the population that will be allowed to reproduce and decides how many offspring each is likely to have, with fitter chromosomes producing on an average more offspring that less fit ones. (Mitchell and Forrest 1994)

__ Mitchell, M., and S. Forrest. 1994. Genetic algorithms and artificial life. Langton, Christopher G., ed. Artificial Life 1, no. 3. Cambridge, Mass.: MIT Press.

Three genetic operators represent a highly effective way to provide the great number of potential offspring variations which facilitates the evolutionary process.

Mutation : The random change of a value at a single position or gene (alleles) in the chromosome. In another words changes in DNA or reshuffling of genes in sexual reproduction.

Crossover : Exchanges the locations of contiguous string of genes between two chromosomes – effectively, a sort of large-scale mutation.

Inversion: Retains the values of the alleles, but reverses their position on the chromosome.

The bitstrings representing the chromosomes are information which, when conveyed to a developmental process, will shape the physical characteristics of the offspring, the **phenotype**.

According to Stewart Wilson, in nature, the genotype contains (1) information that is descriptive, through the action of development and the environment, of a range of possible phenotypes, and (2) information encoding the development process itself, i.e. how to go about making a phenotype from a genotype. Both kinds of information are of course inherited and subject to variation and natural selection. (Stewart 1989)

In the genetic algorithm model, it is the interface between the genes and the physical development process which they regulate that is critical. It is through development of offspring that genotypical information used for transferal of attributes is transformed into phenotypical information used for evaluation of those attributes.

A critical part of the genetic algorithm is '**selection**'. The '**fitness function**' provides a metric for how fit the phenotype is. This value may be judged by how the phenotype adapts to its environment or it mat be artificially imposed for specific characters. Selection differs from the genetic model found in nature in that, in natural selection, the notion of a "fitness function" is largely irrelevant. Nature's selection does not depend on computing power and is based on the ability to reproduce. The "fitness function" in an algorithm could be a predefined set of preferred characteristic and each phenotype in the generated population could be ranked against them. It could also follow a biological model by creating an "environment" against which the fitness of each phenotype of the generation could be evaluated. The algorithm must posses the ability to evaluate the fitness of each member of the population of the current generation in order to determine the degree to which each genotype will be passed down the evolutionary path via inheritance.

John Koza points out in his book that, the environment in nature actually consists of both the physical environment as well as other independently acting biological populations of individuals which are simultaneously trying to adapt to "their" environment. The actions of each of these other independently acting biological populations (species) usually affects all the others. The environment of a given species includes all the other biological species that contemporaneously occupy the physical environment and which are simultaneously trying to survive. (koza 1992). Fitness thus could be considered as a relative measure of survivability in nature.

5.02 Genetic Programming (GP)

GP is a programming paradigm which extends the genetic algorithm to the domain of evolving computer programs. In GP, populations of programs are genetically bred to solve problems. The genes are program fragments which are joined in tree structures to form

A living organism does not possess its 'typical' form throughout its life; rather the form comes into being by a process of development. "So the living form may be called a 'genetic form' ... and therefore *morphogenesis* is the proper and adequate term for the science which deals with the laws or organic form in general". Thus, a scientific theory of form will be a theory of morphogenesis.

— Driesch, H. (1908)

programs. Through crossover, the structure of these programs is changed as in biological mutation, producing a large space of potential programs. The genetic programming paradigm represents a leap forward in the ability to optimize computer programs in a wide array of fields.

The genetic programming paradigm uses the genotype for fitness evaluation. In GP the program is both genotype and Phenotype because a program (is chromosome) is directly executed (as phenotype).

5.03 Applications of genetic algorithms:

Some of the applications of GA's are:

- Genetic programming of computers
- Study of ecological systems - Natural phenomena such as resource flows, flocking, and co-evolution
- Model of Economic systems and resource optimization.
- Optimization of mechanical design

Both biological and simulated evolution's involve the basic concepts of genotype and phenotype, and the process of expression, selection and reproduction with variation.

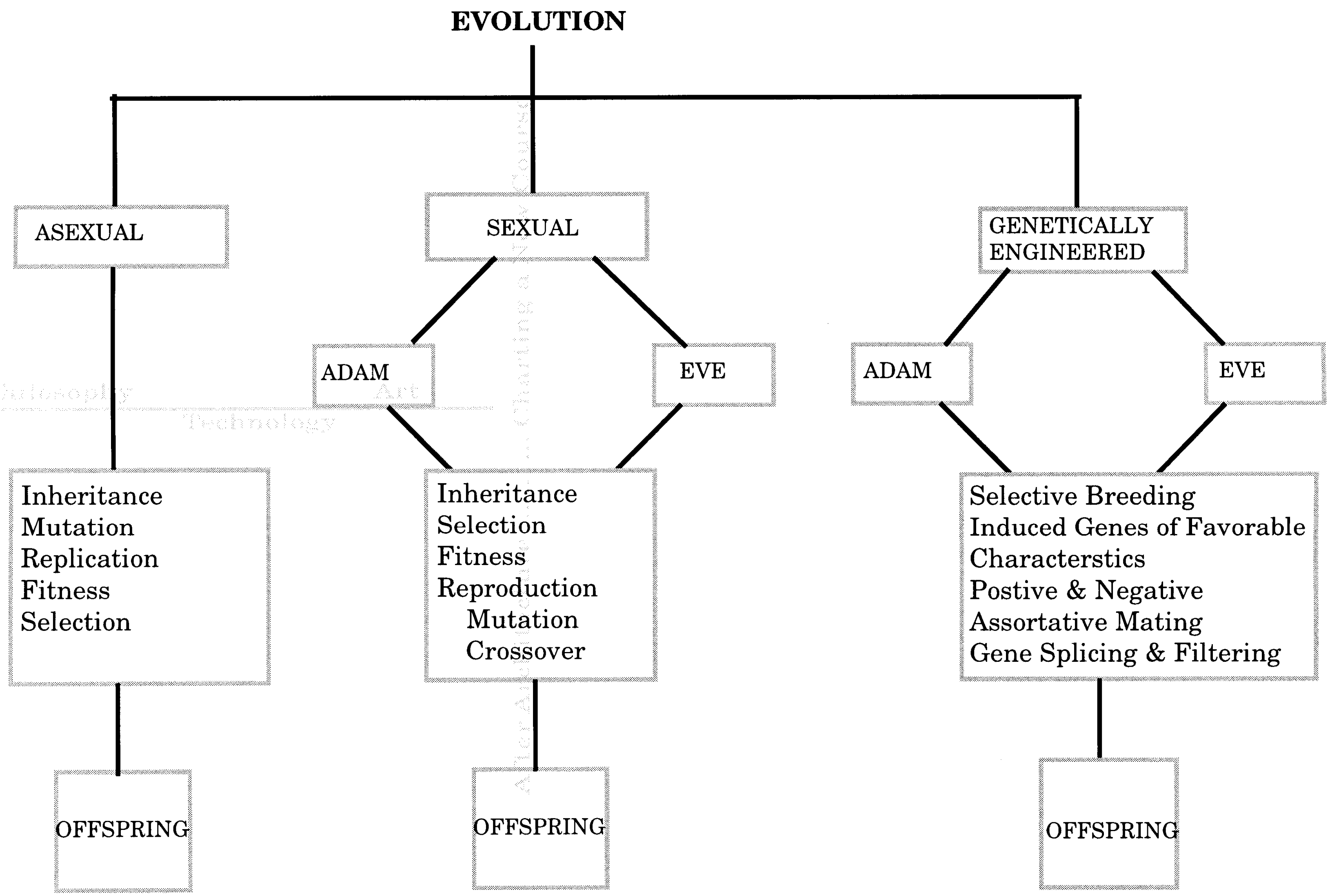


Figure 11.0. *Evolution Model*

Genetic Terms	Algorithmic Equivalent
Genotype: Genetic information that codes for the creation of an individual. Contains instructions for the development of an individual. (DNA). In humans, genotype is our sexual chromosomes.	Strings of Binary digits. GA -sets of procedural parameters. Hierarchical lisp expressions. In case of Genetic Programs (GP) the 'Genotype' is the program.
Phenotype: Individual itself. Phenotype is the form that results from the developmental rules of the "genotype". In humans, the Phenotype is the human being.	Set of procedural rules that use a set of genetic parameters (profile sets, programs). The form evolved by the program.
Selection/Fitness Function: Is a process by which the fitness of Phenotypes is determined. Selection operates on the Phenotype by favoring fitter ones for reproduction.	Calculate by explicitly defined fitness evaluation function or can be interactively selected by the designer.
Reproduction : Process by which new Genotypes are generated from an existing genotype or genotypes. Reproduction operates on the genotype.	A function from one lisp expression used to define one parent is chosen at random and replaced by another function chosen at random from the other parent.

6.0 ON GENETIC PARADIGM AND ARCHITECTURAL DESIGN

6.01 General Discussion

Gregory Bateson, in his book 'Mind and Nature', draws a comparison between the process of thought and the stochastic system of biological evolution. According to him, evolution is a stochastic process, the random component is the *genetic* change, either by mutation or by reshuffling of genes among members of a population.

The combination of phenotype and environment thus constitutes the random component of the stochastic system that *proposes* change; the genetic state *disposes*, permitting some changes and prohibiting others.

The parallelism between biological evolution and the process of thought is created not by postulating a Designer or

Artificer hiding in the machinery of evolutionary process but, conversely postulating that thought is stochastic.

The Genetic algorithm is a form of artificial evolution, and is a commonly used method for optimization. In other areas GA's are used as problem solvers. In architecture they must act generatively. GA's generate populations of individuals in the way that designers create a pool of ideas to draw from and operate on this population by recombining parts of different individuals or altering existing individuals through mutations. The ability to view and manipulate proposed solutions is essential to the decision making process. In addition it is essential that the designer be able to go back to any particular generation and manipulate any particular characteristic of that individual. The model itself, together with its evolutionary and descriptive processes, will result in a process driven architecture.

6.02 Site:

The Site, a junction of physical systems and natural systems serves as an ideal platform to explore the convergence of biology and information technology. This interface of artificial and natural systems and the unstable nature of the ground provides a radical platform to develop new strategies and alternative design solutions, material assemblies and tectonic systems. The landfill could be understood as a floating object on the coastal wetland. Though the genetic paradigm discussed above are applicable anywhere, this site seems to amplify (heightened awareness) man made conscious processes as well as unconscious, natural biological processes. The site thus becomes a source of inspiration and motivation to explore alternative design strategies using the computational genetic paradigm.

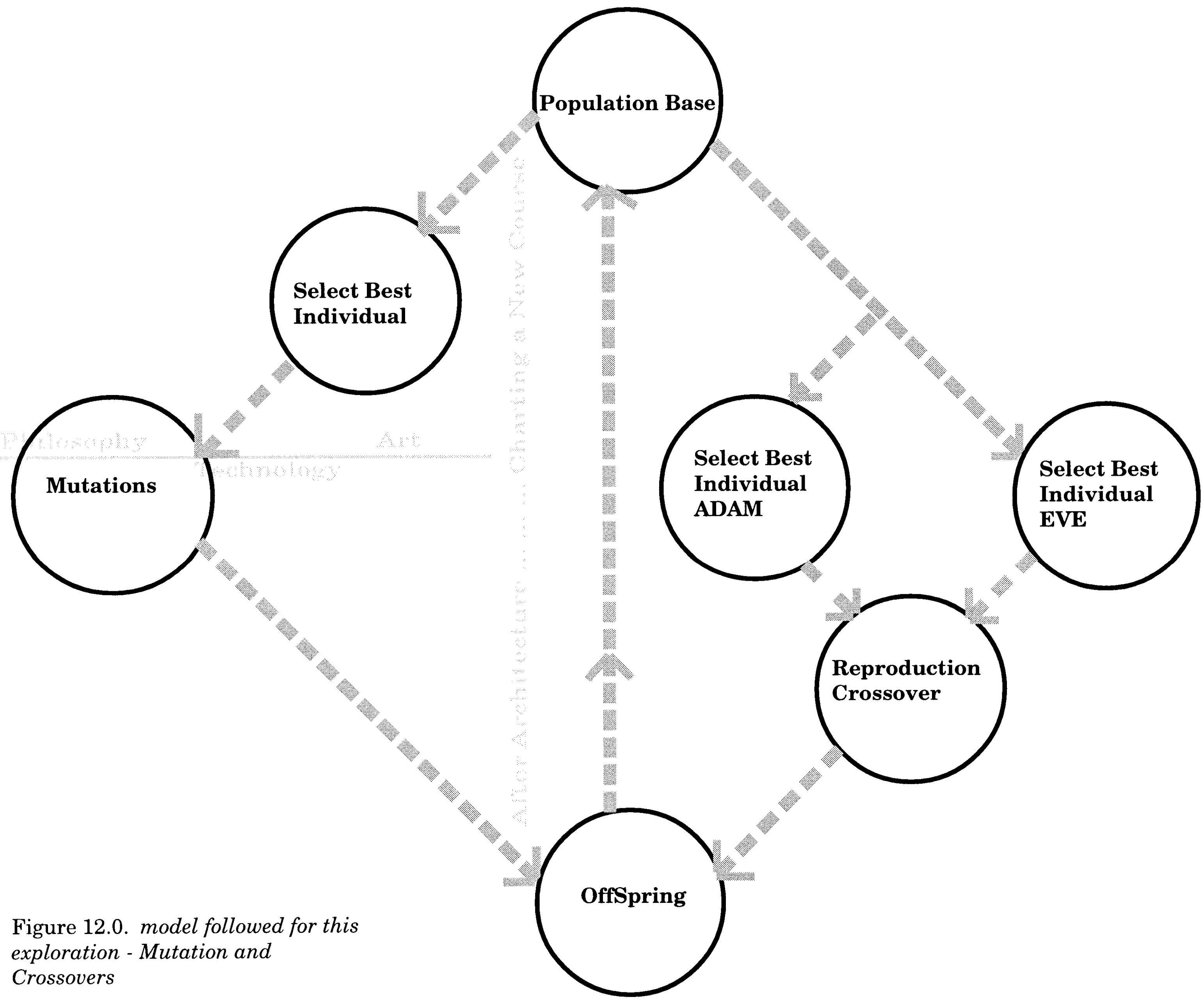


Figure 12.0. *model followed for this exploration - Mutation and Crossovers*

6.03 Disciplinary Need

The need to explore the genetic paradigm for architecture stems from within the discipline for the following reasons:

- The lack of theory for the generation of architectural forms.
- Architectural relevance to societal changes today. What architecture owes to science and society as a reflection of the achievements of mankind.
- In order to interpret and express architecturally our current understanding of, science, and the morphogenesis of forms in nature.
- A need to provide opportunities for imagination and revelation of natural processes through architecture
- Re-invigorate architectural thinking and to explore alternative design strategies for the future.
- To find ways in which architecture could engage in a dialog with emerging players in shaping our environment — biology, information technology, smart materials and artificial nature.
- Need for generative modeling tools to explore alternative design strategies.

6.04 Multidisciplinary Needs

Inadequacy within the discipline

Lack of interdisciplinary exchange in research for the fear of conceding architecture to other disciplines. Existing computational modeling tools serve very little in the initial design exploration process. Despite the availability of complex modeling tools, the use of computational power for design conceptualization, investigation of design strategies and alternatives is very limited.

Demand from the Genetic Algorithm (GA) community - graphic representation for evolutionary computation, lack of development in the GP applications for the generation of 3-D

graphics.
Genetic Algorithms was developed primarily for problem-solving and optimization in situations where it was possible to state clearly both the problems and the criteria to be fulfilled for their successful solution, this is not the case in architecture.

Common issues of interests within disciplines : the need to have interdisciplinary exchange without conceding architecture to other disciplines. Architecture is seeking algorithms and computational tools to model natural processes and for generative modeling. Interest expressed by faculty members at the school of Architecture at MIT and The Artificial Intelligence Lab to explore the possibilities of exchange in order to find applications for artificial intelligence, genetic algorithms in the design fields. The work of Karl Sims, previously with the Media Lab and Thinking Machines corporation, is the only known work at MIT in the application of genetic algorithms for 2-D as well as 3-D graphics.
Realizing the fact that today the success lies in having an interdisciplinary approach and collaborative strategies in research and business.

6.05 Personal:

Inspired by my background and with an understanding of the potential impacts of the convergence of the disciplines of Biology and Information technology, I begin to look for ways in which architecture could interface at this junction.

It becomes imperative for my thesis to explore the potentiality for architecture to engage and embrace the emerging paradigms and interpret them architecturally and to find ways in which architecture could interface at this convergence of Biology and Information technology. This challenge demands creative exploration at the levels of architectural theory, design strategy or concepts, methods and realization. Use architecture as a medium to interpret and celebrate these paradigm shifts and serve as prelude to future investigations in architecture.

Philosophy Art

Technology

7.0 PROTOTYPE Generative, Genetic Design Explorer

7.01 Introduction to the System

A prototype system called the "Generative, Genetic Design Explorer" , built as part of this thesis integrates evolution, both as a metaphor and an active generative modeling tool, with the interpretive aspects of the design process. The metaphor - replete with concepts such as genetic engineering, inheritance, sexual reproduction and random variation has proved valuable in providing a coherent, exploratory process.

Software used: Lucid-Lisp, AutoLisp, AutoCAD, 3-D Studio
Time constraints dictated that we do the genetic programming in Lucid-Lisp and then somewhat awkwardly interface it to our graphic engine of choice AutoCAD. 3-D studio was used for rendering the evolved models. The choice may be somewhat ad-hoc but they suited our level of experience and the investigative / exploratory nature of the project.

Hardware Used
Sun Sparc5 workstations, UNIX operating systems and PC's.

7.02 Data structure

The data structure are in three different levels. At the lowest level, i.e. at internal level or systems level the program operates on the vertices in the line segments defining the profile. At the display level or visual representation level, the program works in AutoCAD entity level called "Pface". At the interface level with architect, the program operates at levels of 'Frame' (profiles) and Surface (Skin or Planes). Our language for transformation has a visual vocabulary and the system takes action in terms of "Openings", "Fold", "Shift", "Delete", "Insert", "Lift", "Flip".

7.03 Goals

Though our desire was to develop an interactive genetic design exploration tool which in real-time, could simulate the entire evolutionary process, our immediate goals became —

> Demonstrate the proof of concept - on 'genetic architecture' - inspired from the basis of genetics and evolution and the information systems of nature.
>
> Establish a theoretical framework for exploration and interpretation of biological analogies in architecture.
>
> Stimulate interdisciplinary discussions in architecture.

For our convenience we decided to call this prototype as "Generative Genetic Design Explorer" or GGDE.

The simulation begins by first creating the population of genotypes. The seed used to create the population could be

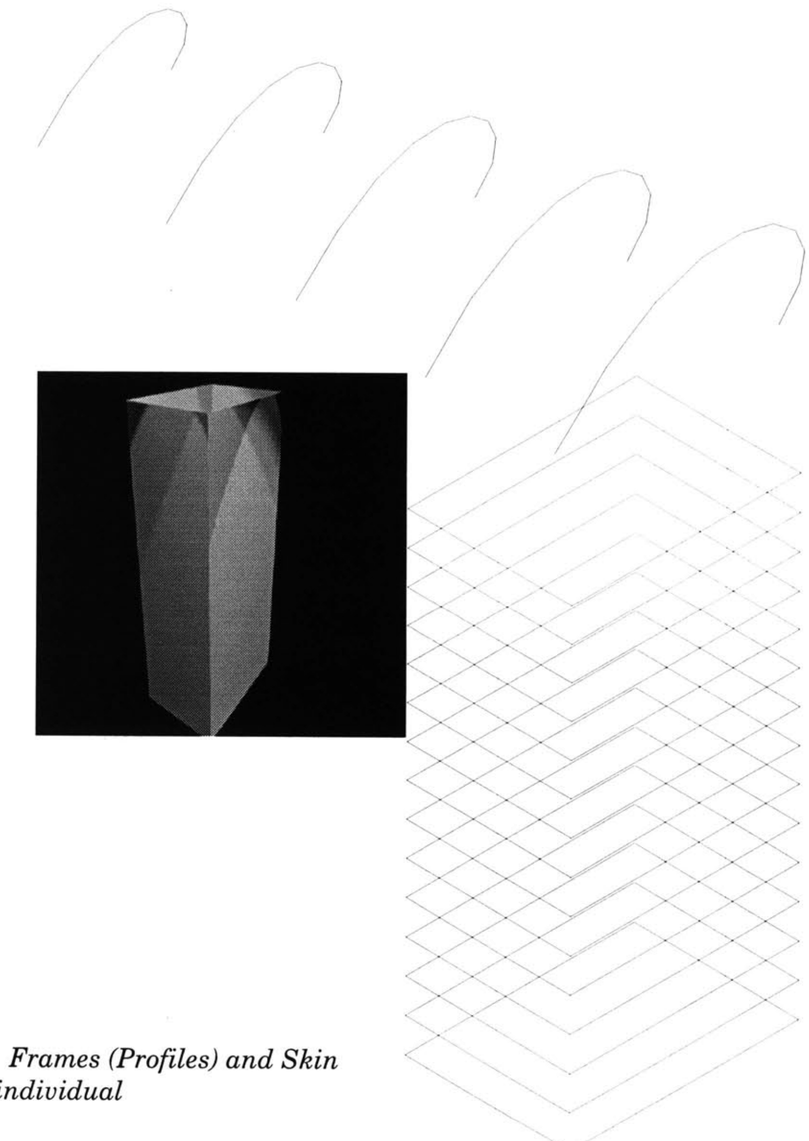


Figure 13.0. *Frames (Profiles) and Skin defining an individual*

Figure 14.0. *Frames (Profiles) and Skin defining an individual*

random or from an existing predefined set of species type.

7.04 Creation of initial Population database.

Each individual in the population consists of a series of profiles(skeleton) and a skin. A species may have at least two profiles which defines its shape and size. Profiles created are grouped selectively by the user to define the individual.

In generating the initial population an analogy of species type was used consisting of the skeletal framework and the skin which ultimately gives form and shape to living beings. This initial phase is in the hands of the architect who can define the kind of population he would like to work with. To begin with an individual could be extracted from a pre existing population database or can be created from scratch as in our case. In subsequent generations the individual could be selected from either of the above or from previous generation.

Species Types: To start, the architect builds some profiles which broadly fall within three different categories, which I would like to refer as species types - Vertical, curve, folded - representing different skeletal systems. Profiles created in AutoCAD are converted to lisp data set.

Example:

```
;; Generates a new profile set as a base to start
;; randomly selects profiles from profile database
and
;; makes a new set.

(setf *ps1* (make-random-pset 10))
(setf *pset* (engine-3 :lisp-profile-set *ps1*
          :transform-fn 'transforms-0
          :pface-filename "rand"
          :generation 0))

(write-profile-set-to-file "rand" *pset* 0)
```

7.05 Adding an individual to the database

This involves adding new individuals (profile sets) to the existing population base. All individuals, either created by the architect at the beginning or generated by evolution must be added to the population base in order to be accessible for selection. A new individual (profile set) can also be created by randomly selecting a specified number of profiles from the population base. This then means that the individual would have profiles from different species types.

7.06 Selection / fitness of the Individual for next generation

In any population a fitness or survivability has to be determined in order to process future generation. The fitness can be programmed or could be decided by the architect. Evaluation on objects can continue until an object with satisfactory characteristics has been evolved or until diversity within the system diminishes.

In our case, the selection of an individual from the population or from a particular generation for further evolution is done visually by the architect. Interactive selection based on visual perception of procedurally generated results, allows the designer to direct simulated evolution in preferred directions. It is often difficult to measure the aesthetic and visual success of simulated objects or images automatically, here the fitness is decided by the architect interactively.

7.07 Reproduction

Techniques for generating, mutating, and combining lisp expressions for evolution.

Mutations

Mutations and crossover in a GP is typically random. We mutate the programs in terms of choosing different arguments to transform. Mutation takes place at the level of nodes (vertices) of the individual. Nodes also mutate into different functions. Example (Sqrt X) can become (Square X) or (cosX) could become (sinX).

Though there can be any number of programs and arguments to programs, some of the programs implemented in our system for mutation are: Lift, Insert, Holes, Delete, Fold, Mix_XYZ, Flip_XYZ. If an argument is not provided, the program takes a random value where needed.

An example of arguments that can control the mutations using the program called "Fold" is as
follows:

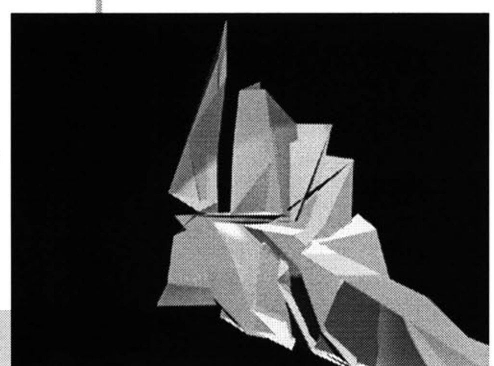
```
(defun fold (pset ;; a profile-set
&key (profile-names nil)  ;; which profiles to fold
(profile-quantity nil)  ;; how many profiles to fold
          (plane-list nil)  ;; which planes to do fold on
          (shift-list nil)  ;; angle of fold
          (fold-vertex nil)  ;; which vertex (position)
to fold, not zero!
          (vertex-quantity nil)  ;; how many vertices
to fold
          (rng *rng*)
)
```

CROSSOVER

```
;; crossover transformations
;;p2.engine-3.lisp
;; Generation "3" of p2.profiles
;; Lift transforms
(setf *pset*  (engine-3 :lisp-filename "p2.profiles-2"
          :transform-fn 'lift-transforms-p2
          :pface-filename "p2"
          :generation 3)
  ) ;; set
;; Delete a random profile
 (setf *pset* (random_delete *pset* 3))

;; FLIP
(setf *pset*  (engine-3 :lisp-profile-set *pset*
          :transform-fn 'flip_xyz
          :pface-filename "p2"
          :generation 3)
 )
```

```
 ;; vert.engine-3.lisp
 ;; Generation 3 of vert.profiles
 (setf *pset* (engine-3 :lisp-filename "vert.profiles-2"
          :transform-fn 'lift-transforms-1
          :pface-filename "vert"
          :generation 3)
 )
 ;; FLIP
 (setf *pset*  (engine-3 :lisp-profile-set *pset*
          :transform-fn 'flip_xyz
          :pface-filename "vert"
          :generation 3)
 )
 ;; MIX
 (setf *pset*  (engine-3 :lisp-profile-set *pset*
          :transform-fn 'mix_xyz
          :pface-filename "vert"
          :generation 3)
 )
```



```
;; Cross.engine-1.lisp
;; Cross of Generation 3 of "p2" and Generation 3 of "vert"
;; Run on host "Vert.profiles-3"
 ;; Lift transforms
(setf *pset*  (engine-3 :lisp-filename "vert.profiles-3"
          :transform-fn 'lift-transforms-p2
          :pface-filename "xo_p2_v"
          :generation 0)
  ) ;; set
;; MIX
(setf *pset*  (engine-3 :lisp-profile-set *pset*
          :transform-fn 'mix_xyz
          :pface-filename "xo_p2_v"
          :generation 0)
 )
;; Lift transforms
(setf *pset*  (engine-3 :lisp-profile-set *pset*
          :transform-fn 'lift-transforms-1
          :pface-filename "xo_p2_v"
          :generation 0)
 )
```

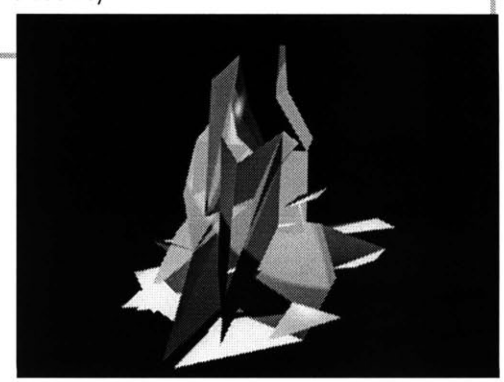


Figure 15.0. *Algorithmic concept of Genetic Crossover*

CROSSOVER

Mating expressions (crossover) - Genetic Programs can be reproduced with sexual combinations to allow characteristics from separately evolved individuals to be mixed into a single individual. A function from one lisp expression used to define one parent is chosen at random and replaced by another function chosen at random from the other parent. **See Figure:** 15.0

7.08 Development of the individual

To go from profile through the transformation to a visual representation with data structure which consists of a profile set and instructions to, generate the skin (pface) and to display the individual in AutoCAD.

7.09 Visual Representation, interaction

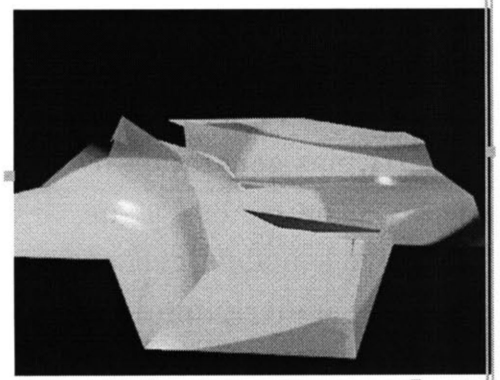
An auto-lisp file is written out by Lucid-Lisp which when loaded in AutoCAD generates a 3-D model immediately on the screen

7.10 Ancestral Tracking

It also provides the capability to track ancestral history of forms and to use genetic properties of any particular generation in the evolution process. The results of the various types of evolved models can be saved along with their underlying data structure (profile set), the program which generated it (engine) and the program which generates the model in AutoCAD. This forms a large population base of evolved forms which can then be used to contribute to further evolution's by mating them with other forms or further evolving them in new directions. **See Figure** : 16.0

DISPLAY / GENERATION INSTRUCTIONS

```
;; file ../p1-3-acad.lsp
;; created by umor & Girish
(command "pface"
"89.6643,0.0,16.26871"
"81.3082,0.0,19.26871"
"72.4605,0.0,19.26871"
... ... ... ...
... ... ... ...
""
 1 11 12 2 ""
 2 12 13 3 ""
 3 13 14 4 ""
... ... ... ...
"")
"27.213663293801375,34.274284784403726,260.25578712630005"
"45.42748020253862,75.04009622670782,278.6164779351896"
"45.42748020253862,70.91515568385948,222.30349650772476"
"41.42748020253862,65.32909445584835,147.32145017725694"
"")
```



STRUCTURE

#S(PROFILE-SET PROFILE-PAIRS (#S(PROFILE-PAIR A-NAME "p1.profiles-0" B-NAME "p1.profiles-1" TILING-PROPS #S(tiling-props :tiling-fn TILE-4 :hole-list NIL :patch-list NIL) FACE-HT NIL) #S(PROFILE-PAIR A-NAME "p1.profiles-1" B-NAME "p1.profiles-2" TILING-PROPS #S(tiling-props :tiling-fn TILE-4 :hole-list NIL :patch-list NIL) FACE-HT NIL) #S(PROFILE-PAIR A-NAME "p1.profiles-2" B-NAME "p1.profiles-3" TILING-PROPS #S(tiling-props :tiling-fn TILE-4 :hole-list NIL :patch-list NIL) FACE-HT NIL)

....

....

PROFILES (#S(profile :name P1.PROFILES-0 :vertices (#S(vertex :x 89.6643 :y 0.0 :z 16.26871) #S(vertex :x 81.3082 :y 0.0 :z 19.26871) #S(vertex :x 72.4605 :y 0.0 :z 19.26871) #S(vertex :x 63.1213 :y 0.0 :z 19.26871) #S(vertex :x 52.7991 :y 0.0 :z 22.26871) #S(vertex :x 45.5106 :y 0.0 :z 19.26871) #S(vertex :x 32.7307 :y 0.0 :z 19.26871) #S(vertex :x 22.2445 :y 0.0 :z 19.26871) #S(vertex :x 11.92224 :y 0.0 :z 19.26871) #S(vertex :x 5.859951 :y 0.0 :z 19.26871))) #S(profile :name P1.PROFILES-1 :vertices (#S(vertex :x 89.6643 :y 8.0 :z 16.26871) #S(vertex :x 81.3082 :y 8.0 :z 19.26871) #S(vertex :x 72.4605 :y 8.0 :z 19.26871) #S(vertex :x 63.1213 :y 8.0 :z 19.26871) #S(vertex :x 52.7991 :y 8.0 :z 28.26871) #S(vertex :x 57.5106 :y 8.0 :z 25.26871) #S(vertex :x 44.7307 :y 8.0 :z 25.26871) #S(vertex :x 34.2445 :y 8.0 :z


```
Engine for p1-3
;; Generation "3" of p1.profiles
;; Lift transforms
(setf *pset*  (engine-3 :lisp-filename "p1.profiles-2"
        :transform-fn 'lift-transforms-p1
        :pface-filename "p1"
        :generation 3)
  ) ;; set
;;
;; MIX XYZ
(setf *pset*  (engine-3 :lisp-profile-set *pset*
        :transform-fn 'mix_xyz
        :pface-filename "p1"
        :generation 3)
  ) ;; set
```

```
;; Insert a random profile
 (setf *pset* (random_insert *pset* "p1.profiles-1"))

 ;; Lift transforms
(setf *pset*  (engine-3 :lisp-filename "p1.profiles-2"
        :transform-fn 'lt_p1-3
        :pface-filename "p1"
        :generation 3)
  ) ;; set

(write-profile-set-to-file "p1.profiles" *pset* 3)
```

GENETIC INSTRUCTIONS

ANCESTRAL TRACKING

Figure 16.0. *Implemenation of Ancestral tracking (genealogy)*

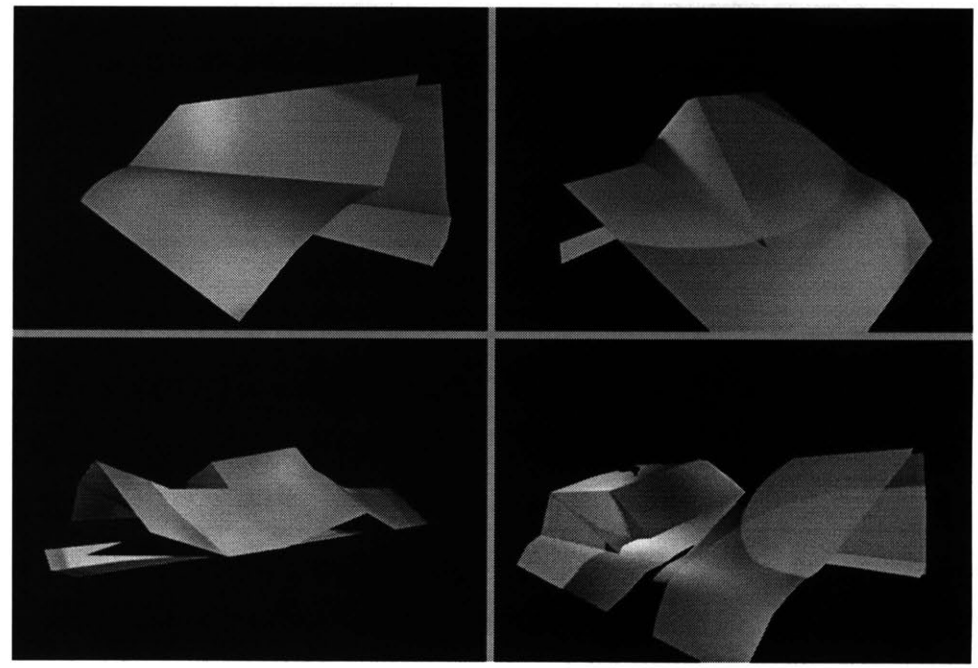


Figure 17.0. *Preliminary Models evolved from the genetic design explorer.*

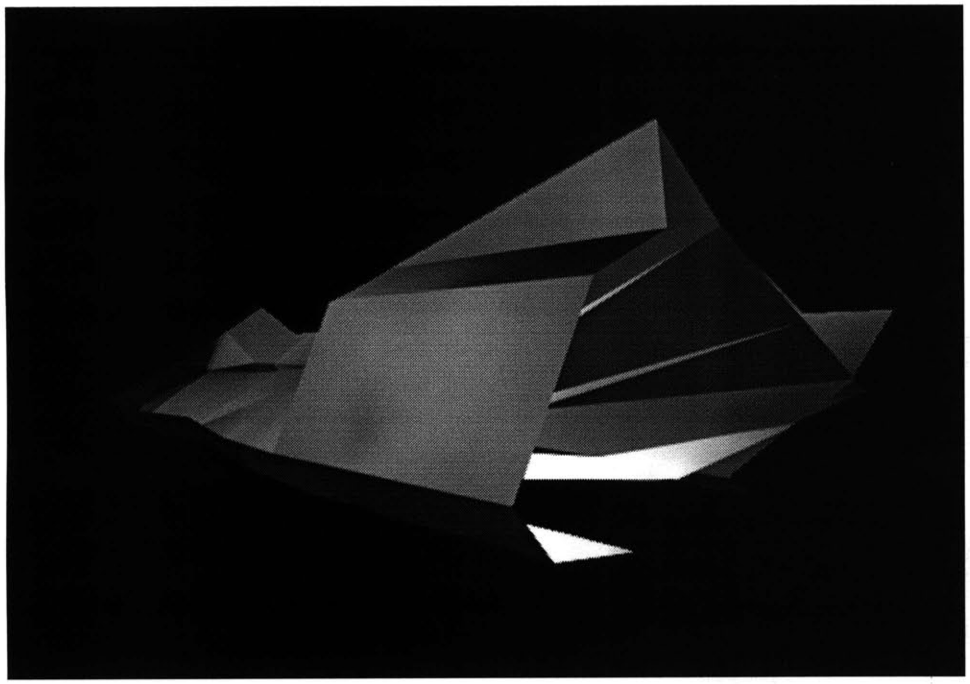


Figure 18.0. *Preliminary Model evolved from the genetic design explorer.*

8.0 RESULTS

The design of our Generative Genetic Design Explorer or GGDE implies a creative thinking process for the architect. This process is one of constant proposition and disposition of ideas. During the initial stages of design conceptualization, the designer iterates through a cycle involving interpretation of a concept, analysis, refinement, acceptance or rejection. The GGDE is intended to assist the designer in the early design conceptualization phase, and to provide the designer with provocative, stimulating, plausible directions to consider instead of a single solution. Simply having a complete solution may lead to design fixation where the presence of one idea may tend to block other ideas from being considered.

In the GGDE, evolution is guided through the interaction of the viewer. The

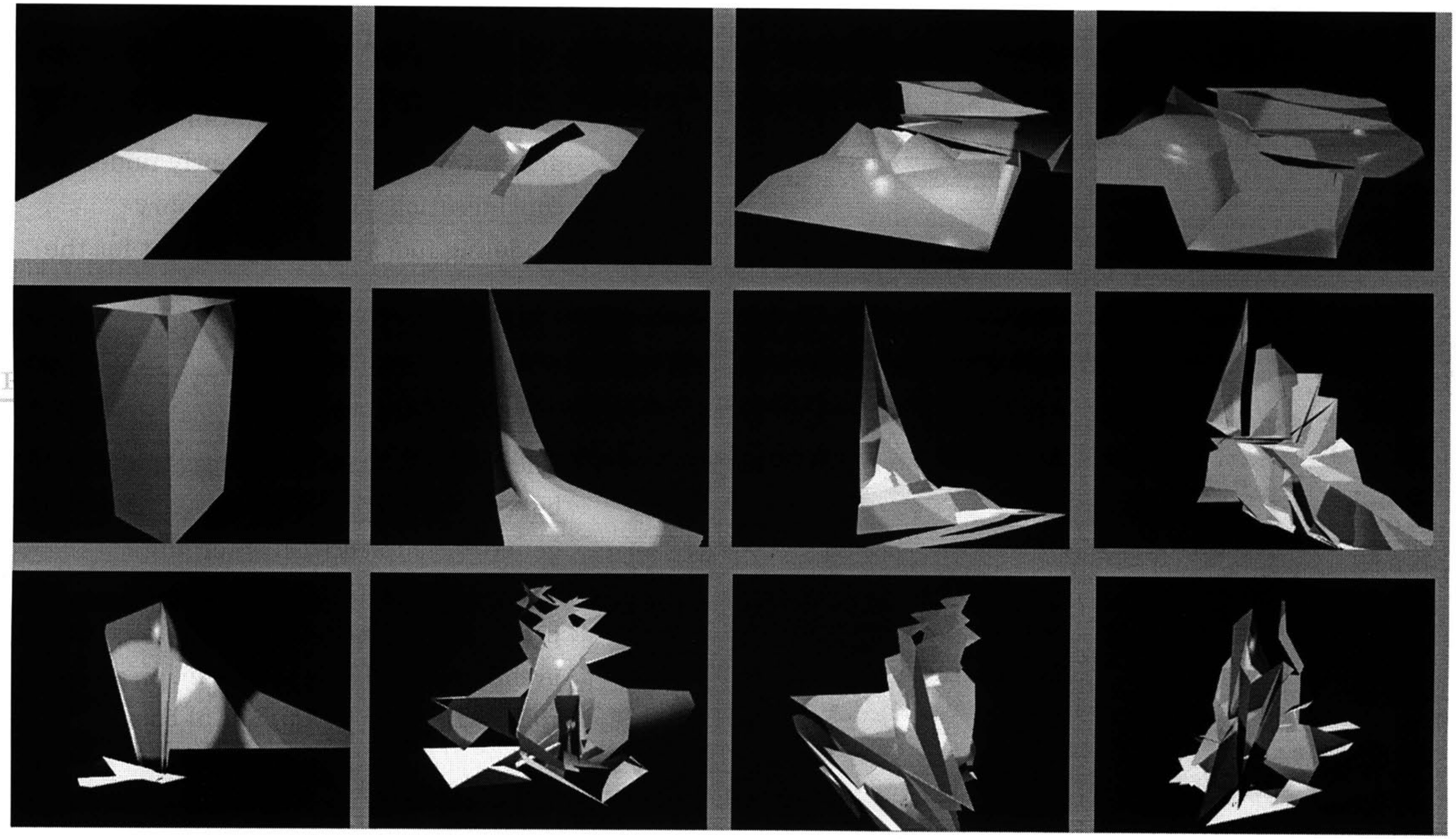


Figure 19.0. *Top two rows, moving L to R is the evolution. Bottom row, moving L-R are Crossovers. Outputs from the genetic design explorer.*

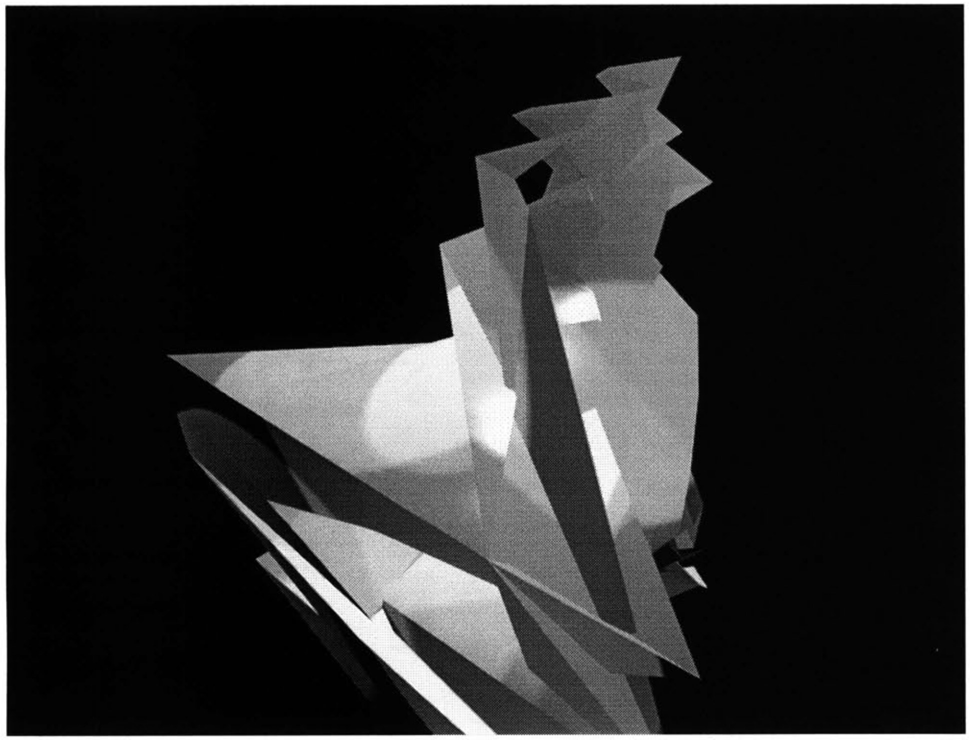


Figure 20.0. *Models evolved from the genetic design explorer.*

architect is firmly in control but the evolution module aids him or her by providing the unexpected 3-D spatial and volumetric configurations which would be impossible to conceive otherwise and suggesting novel combinations or adaptations of forms currently under consideration. This evolutionary modeling tool keeps the clay wet for the architect to interact, interpret and translate these complex 3-D forms and spaces to architecture at any given time.

The final product is a process that is based on biological analogies and genetics, coupled with emerging computational techniques of genetic programming as a generating force for architecture. The primary inspiration comes from the fundamental basis of genetics and evolution and the information systems of nature.
The thesis thus sets the framework for future exploration based on artificial life, a new form of designed artifact

interacting and evolving in harmony with natural forces.

This experiment differs from the more traditional GP methods in its fitness criteria, and the partial control yielded to the designer in guiding crossover and mutation of programs. GA's usually use an explicit analytic function to measure the fitness of phenotypes.

Fully automated genetic functions could not be implemented due to the limitations of time. But, despite their efficiency they don't always offer the best solution. In architecture it is often difficult to measure the aesthetic and visual success of simulated objects or images automatically, here the fitness is decided by the architect interactively. The objective or fitness criteria are determined or altered during the process by the designer. The designer has the ability to judge solutions based on various qualitative criteria based on concepts of aesthetics, practicality of construction,

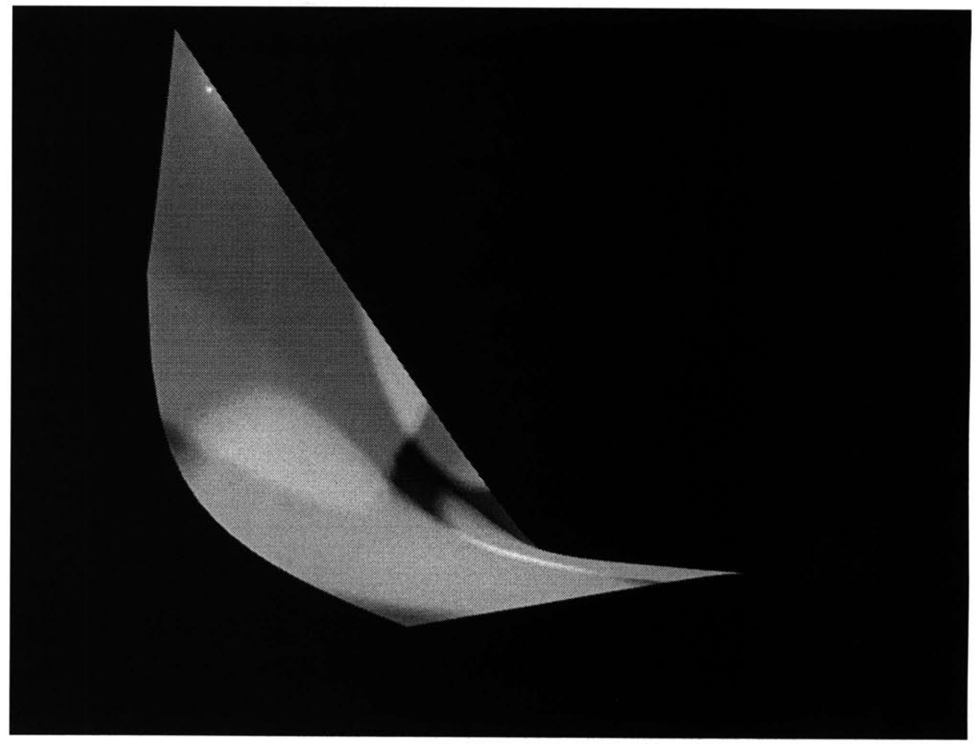


Figure 21.0 *Models evolved from the genetic design explorer.*

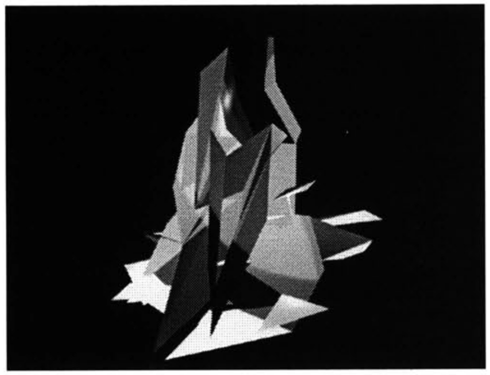


Figure 22.0. *Models evolved from the genetic design explorer.*

limits of time, space, materials, and so on. In the real world these criteria's are many and some which may overlap or conflict. It is not possible at this point to program all these criteria in the form of a computer code as it is difficult even for the designer to put it in words. Interactive evolution allows procedurally generated results to be explored by simply choosing those that are the most aesthetically desirable for each generation.

It is important to recognize that Site is the facilitator of this process, it nurtures the agent. It serves as a source of inspiration and motivation to explore alternative design strategies. Selection of the best individual in the case of architecture could be based on the adaptability to the environment — micro-climate, weather, soils, slope, hydrology, vegetation and so on. The individual can have a strategy for adapting to the environment as in the case of bio-remidiation of sites where an individual agent fights against other unwanted individuals to make a cleaner and safer environment for it to survive. Site is essential for the process of exploring and evaluating form algorithmically in the same manner as an algorithm does not become computation unless data is provided.

Another implication genetic algorithms bring to spatial design is access to a high degree of complexity in architecture. They provide a framework for combining and evaluating a large number of diverse characteristics of a space. The framework has the capability to employ large number of variables.

Figure 23.0. *Models evolved from the genetic design explorer.*

Figure 24.0. *Texture Mapping of Models evolved from the genetic design explorer.*

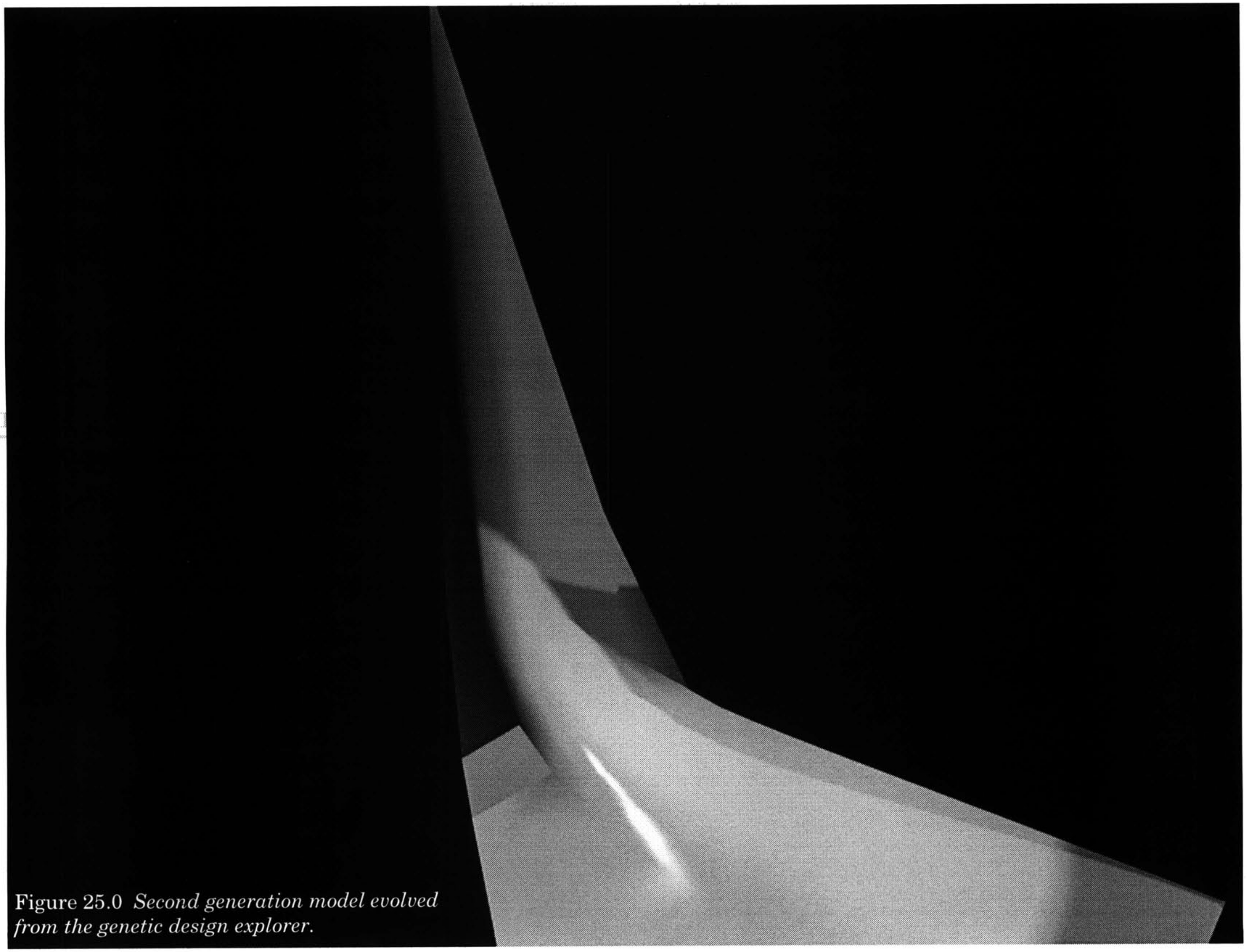


Figure 25.0 *Second generation model evolved from the genetic design explorer.*

A Synthesis of Science

Compilation

9.0 ON PARALLEL DISCUSSIONS

As I reach the end of my exploration, I begin to look outside to find works of contemporary architecture and current discussions parallel to this thesis within the discipline of architecture.

9.01 Projects and experiments in Genetic Architecture.

Architectural Association, London – Evolutionary Architecture.

One of the significant work in the area of evolutionary or genetic architecture that parallels this thesis, is the work of John Frazer's group at the Architectural Association in London. In his book titled "Evolutionary Architecture" he discusses the conceptual and theoretical basis of his work. It proposes the model of nature as the generating force for architectural form. Architecture is considered as a form of artificial life, subject , like the natural world, to principles of morphogenesis, genetic coding, replication and selection. Frazer, in his book introduces the concept of Evolutionary

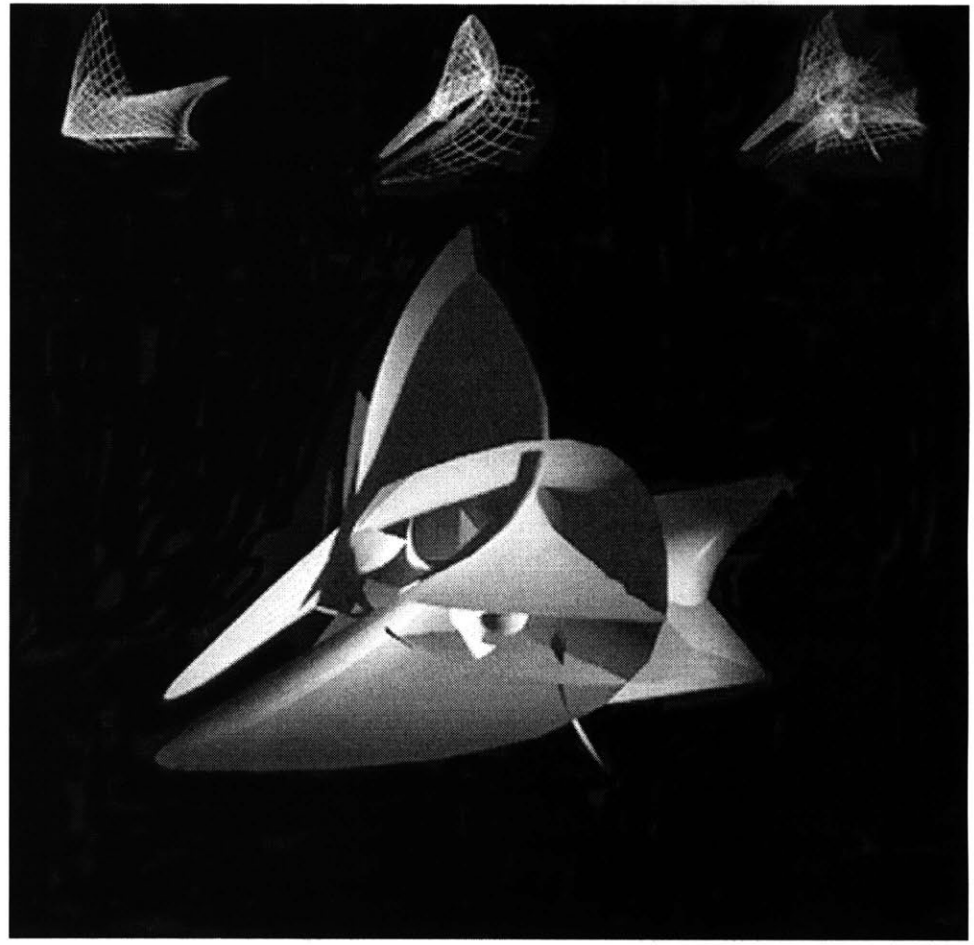
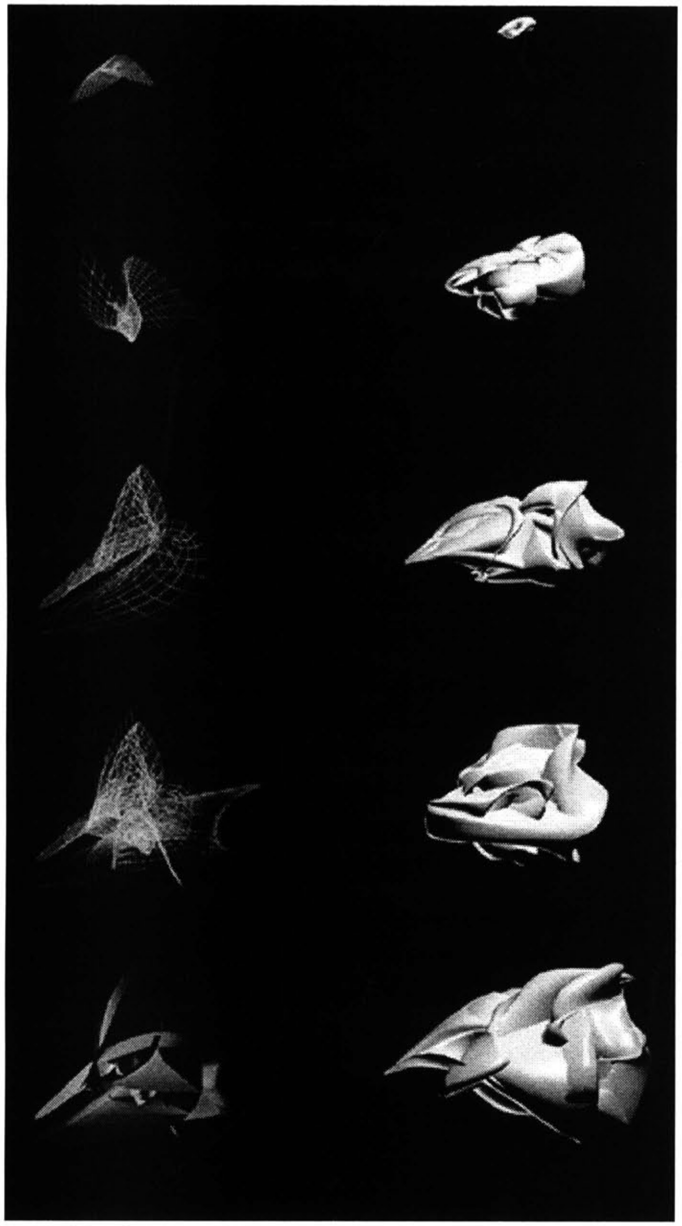


Figure 26.0 *Evolutionary Architecture Model developed by John Frazer's group at the Architectural Association, London. 1994*



architecture, indicates the nature of biological and scientific analogies , and relates the idea to the wider context of present scientific discourse. It relies heavily on natural science and the newer sciences of cybernetics, complexity and chaos. Architectural concepts are expressed as generative rules so that their evolution may be accelerated and tested. The rules are described in a genetic language which produces a code script of instructions for form generation.

His system is based on a computer-based technique for design which models inner logic rather than external form. Frazer's interactive computer model called the "Interactivator" is sophisticated and fully automated than our system, it creates evolving virtual architecture in response to a changing environment. Frazer points out that an essential part of this evolutionary model is some form of generative technique which is different than the generative system as laid out by William Mitchell.

Figure 27.0 *Evolutionary Architecture Models developed by John Frazer's group at the Architectural Association, London. 1994*

9.02 Genetic Algorithms and virtual environments in "Designing Digital Space - An architects guide to Virtual Reality" by Daniela Bertol
John Wiley & Sons, Inc. New York, 1997

Eric J. Bucci, Marcos Novak
Advanced Design Research Group, University of Texas at Austin

Eric Bucci discusses the experimental work on genetic algorithm and virtual environments , of the Advanced Design Research Group at University of Texas at Austin. According to him, cyberspace provides a world in which to give form and texture to entities that are invisible in the physical world : transactions, ideas, databases. The benefit of visualizing information comes from the ability to bring a degree of comprehensibility to an otherwise unwieldy body of data.

The structure of genetic algorithm (GA) model, with its interrelated fitness criteria and large range of potential phenotypic outcomes, provides a vehicle with which to engage complexity. The genetic algorithm can use a simulated environment as the fitness test for selection rather than explicit criteria. The use of the GA model in the evolution of virtual spaces actively engages this abstract notion of accessibility. GA, by specifically addressing the temporal and evolutionary aspects of cyberspace, provide us with the access to new environments and the ability to design complex and meaningful spaces within them.

University of Texas Austin's work was uses the software -Mathematica. Four geometric elements each exhibiting "behaviors", relationship with other elements, are rewarded or penalized. Construction procedures devised as a system of rules by which elements are placed next to each other. The algorithm presented, even with its very simple set of criteria, produces spaces which can continue to exist and evolve indefinitely, in keeping with the temporal dimensions of virtual environments. (as well as nature). Article point out that the algorithm presented and its use in evolving virtual spaces have tested the feasibility of a paradigm for design with new implications for the theory and practice of architecture.

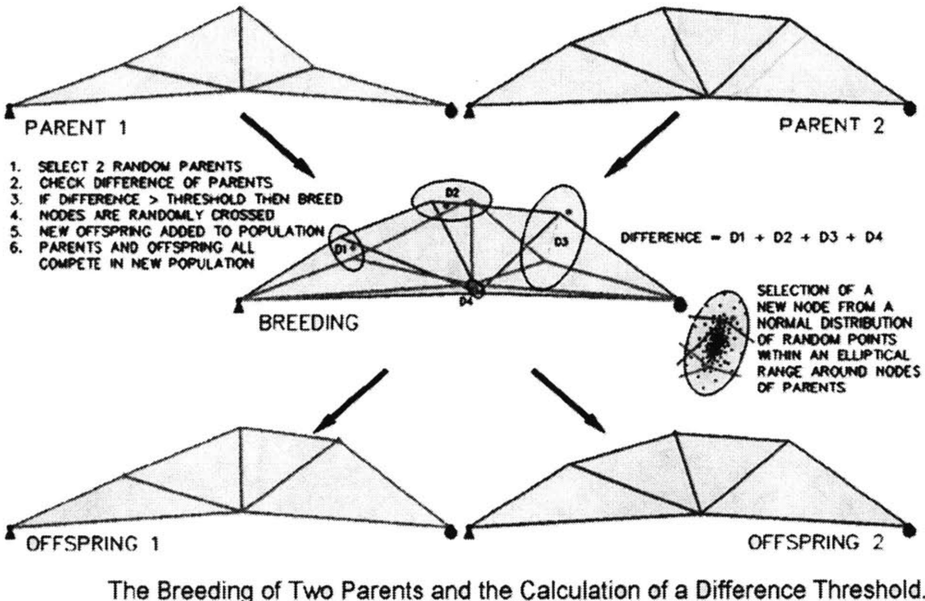


Figure 28.0 *Intelligent Genetic Design Tool for truss design. developed by Peter Von Buelow. Germany.*

Figure 29.0 *Forest of Evolved plants. by Karl Sims. Using Genetic Algorithms. 1991*

Development of an Intelligent Genetic Design Tool (IGDT) : A White Paper

By Peter Von Buelow

This paper describes the application of an intelligent genetic design tool in the design of architectural, structural elements. As an example, the design of a cantilever truss is explored. Using the coded criteria optimization criterian of weight, and the designers non-coded criteria of visual aesthetics and performance, a series of possible design solutions are explored.

Relevant Articles in Artificial Life and GA community.

Interactive evolution of equations for procedural models - By Karl Sims, Thinking Machines Corporation, 245 First street, Cambridge, MA.

Evolving Virtual Creatures - By Karl Sims, Thinking Machines Corporation, 245 First street, Cambridge, MA.

Artificial Evolution for Computer Graphics - By Karl Sims, Thinking Machines Corporation, 245 First street, Cambridge, MA. Computer Graphics, Volume 25, Number 4, July 1991.

Evolving 3D Morphology and Behavior by Competition - By Karl Sims, Thinking

Machines Corporation, 245 First street, Cambridge, MA.

Shape Representation and Evolution Schemas – Marc Schoenauer, Ecole Polytechnique, France.

Relevant Literature in Architecture : There are only few literature in architecture that addresses the emerging paradigms of design, such as evolutionary/ genetic architecture, non-linear architecture, biological analogies in architecture. It is beyond the scope of this thesis report, to discuss all these literature that may have some relevance to this work. But, I would list some of the articles for the benefit of further research and discussion.

Greg, Lynn. The Renewed Novelty of Symmetry (Das erneurte Neue der Symmetrie)- Summary in English, In Arch plus 1995 Sept., n.128, p. 82-85
Lynn uses biological processes of growth and change to trope traditional architectural design assumptions. Lynn and Ed Keller use the computer as a generative instrument for systems of symmetrical and asymmetrical organization using theories of biological

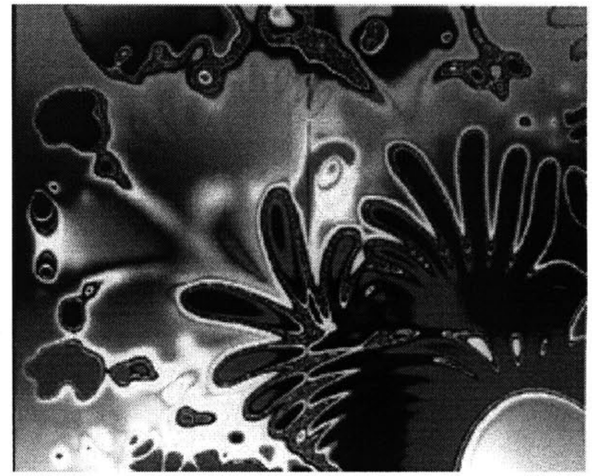


Figure 30.0 *Genetic Art developed byKarl Sims. Thinking Machines, Corp.*

Figure 31.0 *The Guggenheim Museum, Bilbao, Spain. Frank O Gehry & Assoc. 1997*

variations. Information from the Cardiff Bay Opera House competition site, in particular the Oval Basin, is used to govern and pressure design process. Greg Lynn's Cardiff Opera House project is based on the theories of symmetry and discontinuous variation developed by William Bateson in 1894. William Bateson invented the term 'Genetic'. According to him, Genes are not generators but modifiers or regulators that are intermittently applied during growth and regeneration.

Greg, Lynn. In *Computer animism's (two designs for the Cardiff Bay Opera House).* Assemblage 1995 Apr., n.26, p.8-37, ISSN 0889-3012.

Joachim Krausse - Information- *Folding in Architecture*. Translated in English. In Arch plus 1996 April., n.131, p. 74-77

Charles Jencks - *Architecture of the Jumping Universe*. Academy Editions. London

Charles Jencks - *Nonlinear Architecture, New Science = New Architecture.* Architectural Design, Vol67 No 9/10 Sept-Oct 1997

Manuel Delanda, (1992), *Nonorganic Life.* In Incorporations. Zone 6. New York: Urizone

Peter T Saunders - *Nonlinearity- What it is and Why it Matters.* Architectural Design, Vol67 No 9/10 Sept-Oct 1997

Gerry Webster and Brian Goodwin – (1996) *Form and Transformation. Generative and Relational Principles in Biology.* Cambridge. Cambridge University Press.

Listed below are some of the Contemporary theorists and designers who either use computational tools in the design exploration process, or are developing the paradigm and draw their analogies from nature, biology and non-linear processes.

Frank O Gehry - in:
- The Guggenheim Museum, Bilbao Spain
- Samsung Museum of Modern Art, South Korea
- Model of Berlin Conference room,

Figure 32.0 *The Guggenheim Museum, Bilbao, Spain. Frank O Gehry & Assoc. 1997*

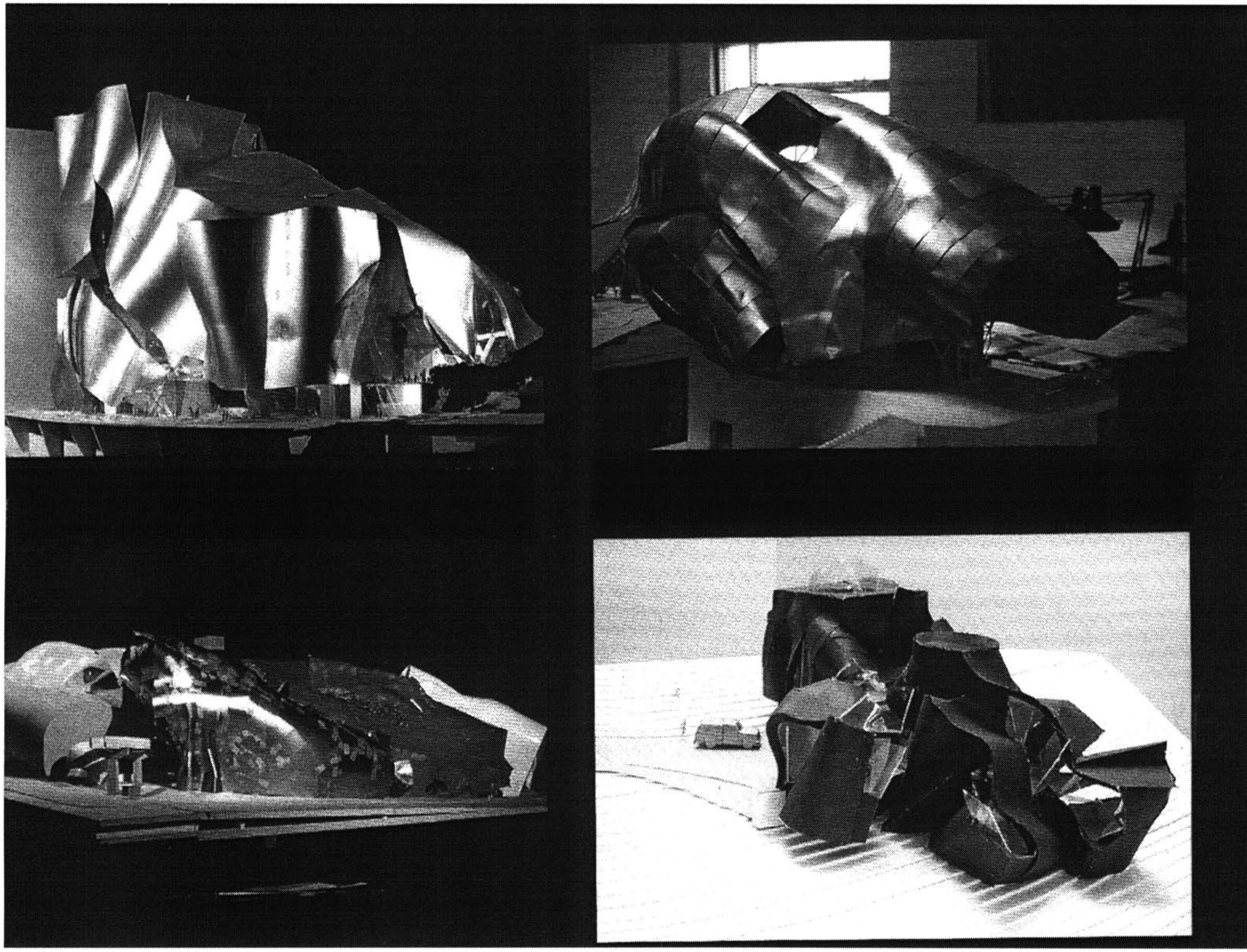


Figure 33.0 *Various designs in the making - Frank O Gehry & Assoc. 1997*

Pariser Platz 3
Model of Chiat House, Telluride, Colorado
Model of Experience Music Project Museum

Peter Eisenman
Staten Island Institute of Arts and Sciences, St. George Ferry Terminal, New York

Daniel Libeskind
The Victoria & Albert Museum Boilerhouse extension, London

Foreign Office Architects
Yokohama International Port Terminal, Yohohama, Japan

Ben van Berkel
Yokohama International Port Terminal, Yohohama, Japan

Coop Himmelblau

Greg Lynn
Cardiff Bay Opera House

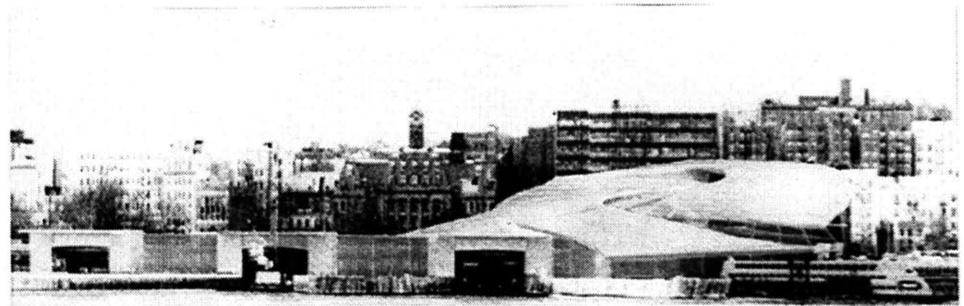


Figure 34.0 *Proposal for Staten Isalnd Institute for arts and sciences. New York. Peter Eisenman*

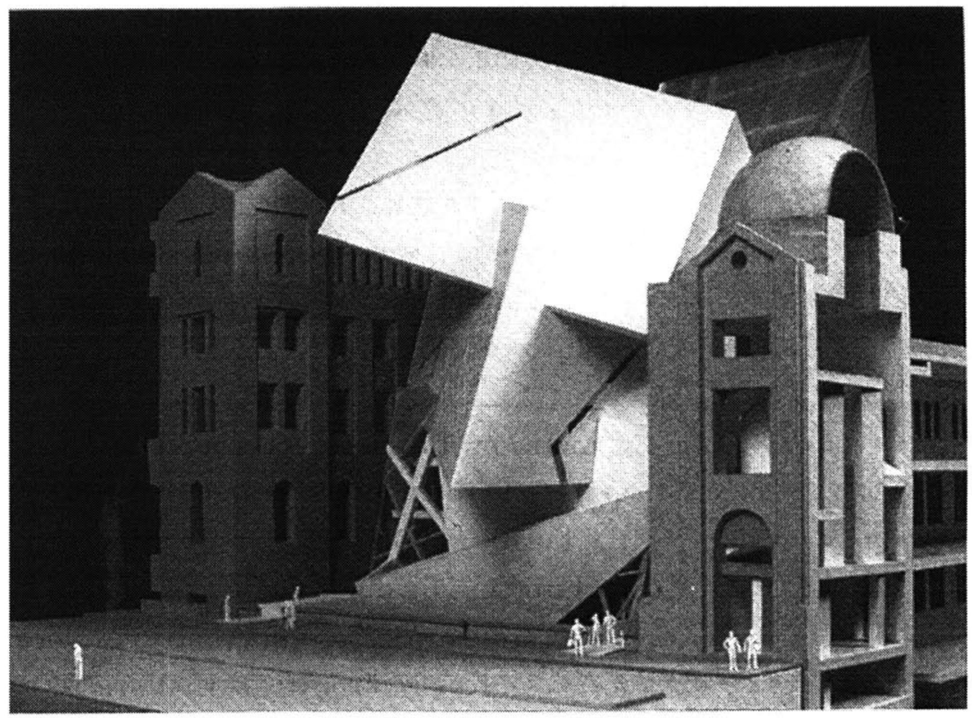


Figure 35.0 *The Victoria & Albert Museum Boilerhouse extension. London. Daniel Libeskind.*

10.0 CONCLUSION

The thesis is a conscious computational description of the unconscious biological processes active on the site. It charts a new course for architectural exploration. In the scientific disciplines where examining, learning, refuting, judging is an on going process, the final product does not matter as much as the process, likewise, the final product of this thesis is not precious. It is a prelude for further investigation and exploration in architecture.

Genetic/ evolutionary forms enable architects to understand and interpret the language of nature in a way that architecture field has never seen before. Generative processes allow one to explore forms and spatial construct that are unimaginable and unexpected. In genetic architecture, forms can inherit characteristic of other forms.

Several variations on the methods used by us for evolution might make interesting experiments.
It might be interesting to automatically evolve a lisp expression or to select a lisp function randomly. Thus, giving the system a complete control over the process. Complete automation of this system could then generate a series of random results with few variations for the user and the user would be able to direct the entire evolution process visually. The question I would like to ask is at What point do we stop evolving and how do we determine when to stop evolving?

Though the efficiency of a GP could be vastly improved by automating the selection and fitness criteria, it still remains to be seen how it could serve the designers interest. The criteria's used by the designers in the initial phases are dynamic and are subjected to change. The ability to adapt to changing criteria is essential for the program

Learning from the user - The GGDE must have the capability to learn from the designer and anticipate the designer's direction. If a user picks phenotypes with particular characteristics from the parent, mutations for the next generation might have a tendency to continue in the same direction. This would allow the program to make intelligent, rather than simple random proposals back.

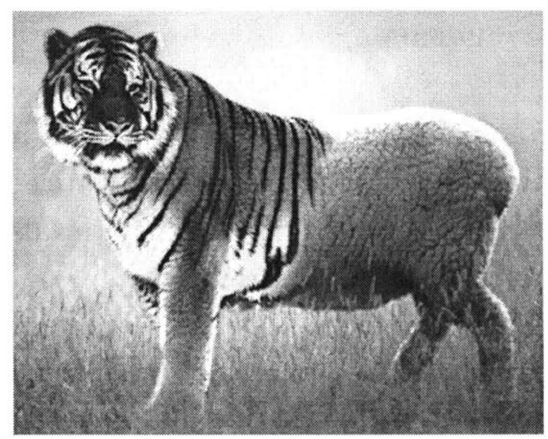
As we embark into a new era, this shift in our thinking will lead to an architecture which may use new forms of biomaterials, memory shaped alloys, adaptive technologies and systems. The realization of such complex architectural forms using emerging smart materials and manufacturing technique should be explored. An interesting extension of this work would be to establish a link to CAD/ CAM based rapid prototyping techniques such as –3D printing, 5-axis milling machines, numerically controlled bending of metal and glass, and laser cutting tools, for prototyping and fabrication. Another aspect which needs to be explored that could be of interest to the architectural community has to do with assigning materials or texture to various surfaces based on certain pre-defined criteria.

There is a need to be able to generate and display evolved models fast enough to keep the user interested and to stimulate some thinking. It should be responsive to evolving in not just a virtual but a real environment. Warren Brodey in his article 'The Design of Intelligent Environments: Soft Architecture' proposed an evolutionary, self-organizing, complex, predictive, purposeful, active environment.

The prototype code developed for this thesis is primitive and could be used only by computer literate people or the designers of GGDE. There is a need for a higher level of abstraction of the programs and for a user friendly interface.

In my opinion, this experiment serves not only the discipline of architecture but to all other disciplines who have interest in modeling, interpreting and visualizing processes in nature – evolution of forms in nature. It is my understanding that this thesis serves in explaining the following: that architecture could interpret and model natural form making processes, can draw analogies from other disciplines such as biology, interface without conceding architecture to other disciplines, re-invigorating architectural thinking, a generative modeling or evolutionary modeling tool for design conceptualization and exploration.

The term “after architecture….” could be interpreted as a closure to traditional architectural thinking, which to many seem to have come to an end and offers the potentiality to re- invigorate architectural thinking.



Philosophy Art

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Materials

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