EXPLORING TOOLS, TECHNIQUES AND TECHNOLOGIES FOR A PERFORMANCE-ORIENTED INTEGRAL DESIGN PROCESS

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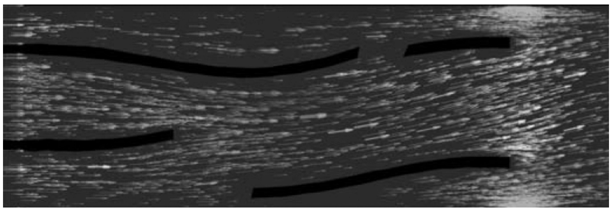
Performance Oriented Integral Design Process focuses on complex hierarchical organisations and higher-level functionality in biological systems to extract analogies for design principles. In order to understand and explain biology's strategies for diversity, embedded complexity and functionality, scientists deploy advanced tools, techniques and technologies to model, simulate and analyze biological systems. The purpose of this paper is to investigate specific tools, techniques and technologies that may provide potentials for both the generative and analytical aspects of the proposed design process.

INTRODUCTION

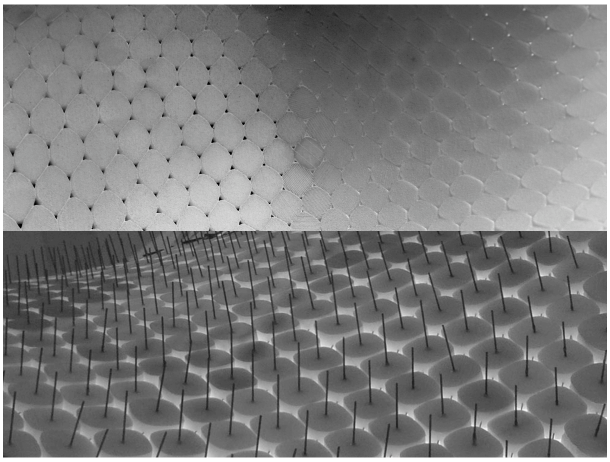
Proposed research by design in architecture draws interdisciplinary adjacency to biology. The research aim is to develop a performance-oriented integral design process. This enquiry is based on a generative design process with the ability to computationally integrate a particular system's material capacities and structural, environmental behavior and performance knowledge to inform it's design evolution/morphological development. The ambition is to drive at highly articulated building systems of complex morphologies utilizing high performance capacities that are material and context specific. In this context two pilot projects are proposed: [i]Timber Assemblies, [ii] Brick Assemblies.The proposed developmental design process of material and energetic space, evolves over time in interaction across system hierarchies and degrees of magnitude and relates to the sciences of complex systems and nonlinear dynamic behavior. Morphological development in the process of integration by means of *hierarchical organization* (Whyte, Wilson, 1969) through *developmental processes* may be promising. We shall therefore investigate hierarchical organization and developmental processes in the field of biology and how specific tools, techniques and technologies may be instrumental for the development of this thesis.

Hassan Fathy discussed material characteristics and building morphology to calibrate climatic differentials and variations for generating environmental effects to provide comfort for habitation. Fathy discussed traditional architectural features (windcatcher, mashrabiya, claustrum, etc) and their spatial organization and potential to regulate natural ventilation, heat control, penetration of light, visual connectivity, etc.(Fathy, 1986, 47) This serves as a reference to environmental performance in architecture.



1. Environmental effects resultant from environment - system interaction, analysis of air flow.

In search of performance in architectural design, what may the potentials be in rethinking *hierarchy* in building systems that results from a generative design process. This design process aims to computationally integrate material capacities, structural and environmental behaviour through the development of two pilot projects: timber and brick systems. The performance studies will focus on system hierarchical interrelations, interdependencies and interactions across scales for developing recognizable structure and effect at each order of magnitude. How should developmental processes for such an approach be applied?



2. Complex brick assemblies project - self-shading effects and brick structural system experiments.

Tools, techniques, technologies from biology may offer a potential answer to this question. Several theories and concepts from biology are of relevance: D'Arcy Thompson's growth processes and forces that govern organic form, Darwinian Evolutionary Theory and genetics. Evolution through natural selection evolves diversity and varied morphologies. With respect to Evolutionary Theory, the developmental processes on the molecular level, however, still proves challenging. Lewis Wolpert at the University College London posits that 'development is essentially the emergence of organised structures from an initially very simple group of cells.' (Wolpert, 1998) It is a process of construction that emerges through the interaction of proteins, cells, genes and the environment that give rise to organisms.

Julient Vincent identified the need to study 'hierarchies and the control of interactions at the interfaces … In a hierarchical solid it is not important that the elements are constructed in a self-similar manner (The concept of fractals, Mandelbrot, 1977)[1]. The order or degree of hierarchy in structure can be defined as the number of levels of scale with a recognized structure.' (Vincent, 2006) Varied strategies are capable of building up complexity from low-level modules, features to developing *complex integral hierarchical assemblies*. We will thus concentrate on growth, evolution and development as key.

In order to understand, model, and analyze complex interacting systems, which arise from the interaction of lower level units and the environment, advanced tools, techniques and technologies need to be identified. Computation makes it possible to handle complex information. Evolutionary computation is used as a 'problem solver' for various applications from design optimization to robotics. There are four types of traditional evolutionary algorithms, these are: the genetic algorithm (GA) (Holland, 1975), genetic programming (GP) (Koza, 1992), evolutionary programming (EP) (Fogel et al., 1966), and evolutionary strategies (ES) (Rechenberg, 1973).

Although these are powerful search engines and solvers, they lack the process of development. Kumar and Bentley state that 'rather than including an explicit development stage between genotype and phenotype, evolutionary algorithms of all classes have focused on modelling evolution and omitted complex genotype to phenotype mappings.' (Kumar & Bentley, 2003, 12). In biology, the relation between genotype and phenotype is not linear and the genotype does not include information of the phenotype in a one to one mapping. A genotype contains a set of instructions to construct the phenotype, which then evolves and is modified in interaction with a dynamic environment. In computer science, this is called *generative program* or *developmental encoding*. Kumar and Bentley argue that 'development requires the idea of separate entities or modules, hierarchies of such modules and multiple interactions between each other and between different levels of the hierarchy.' (Kumar

[1] The French mathematicion Benoit Mandelbrot first coined the term *fractals*.

& Bentley, 2003, 13) This is an important aspect of development, and essential for our purpose. They further argue that the multiple interaction between separately defined entities, make capabilities of 'emergence' and 'self organisation', concepts of complex systems possible. (Kumar & Bentley, 2003)

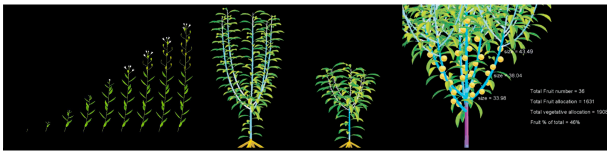
With regards to the two main performance aspects of the case based research now underway, which investigates structural, environmental performance of systems that are material and context specific, it can be stated that if the developmental code of system hierarchies and the interactions, interrelations and interdependencies across orders of hierarchies and scales of magnitude are established we are able to work with a powerful developmental mapping from 'genotype' to 'phenotype'. Thus we place the emphasis on the developmental processes and successive generations rather than the single final design output.

Maturana and Verela termed the interaction between the embodied system and its environment, *Structural Coupling* (Maturana and Verela, 1992). "When an organism is embodied in its environment, its response to environmental events or perturbations is determined by its structure (its components and the relationships between them) and vice versa." (Kumar & Bentley, 2003) In result a system is modified by and in turn modifies the environment, and *integral design* shall be a result of this coupling.

What is interesting is the non-linear mapping of genotype-phenotype relations by implementing development. In computation, traditional linear evolutionary algorithms are prefered, as they are easier to handle, due to the high predictability of the results. In non-linear mapping on the other hand, a small change in the genotypic coding may result in drastic changes in the phenotype, the development of which may be further discussed in the light of evolutionary changes of species. "Development would behave like a finetunable bias for evolution, making the future evolution of some phenotypes more likely, others less likely" (Gordon and Bentley, 2002, 241).

With respect to development, a non-linear casuality is proposed, which allows for a *gradual developmental system* through the ability of fine-tuning of all its constituent elements by computing physical and energetic behaviour and developmental logics.

In architectural design, a direct reference to this projected approach to performance-oriented integral design does not exist, therefore the intention is to outline selected computational strategies that attempt a particular approach to genotypic-phenotypic relation. The ambition here lies in the synergetic processing of complex sets of information for design development, through devising growth, evolution, genetics and developmental processes as key parameters.

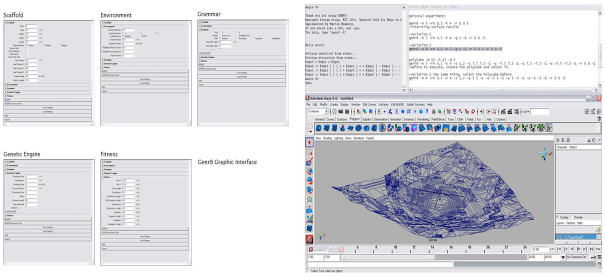


3. L-Peach model: Research done by M. Allen, P. Prusinkiewicz, T. Dejong, using L-Systems

Interesting in this respect are L-Systems (Lindenmayer, 1968), a mathematical grammar for plant growth modelling that produces branching structures. The work has been undertaken by Professor Przemyslaw Prusinkiewicz and his collaborators at the Department of Computer Science at the University of Calgary in Alberta and focuses on growth grammar, context-specific L-Systems for computational simulation of plant growth. When L-Systems are coupled with physiological, chemical and environmental input parameters, they become a very powerful tool. Prusinkiewicz refers to three classes of plant modelling: [i] models of plant architecture (continious description), [ii] models of organs and tissues (discrete description) , [iii] models incorporating genetic regulatory networks (molecular description).

The first model implements L-Systems and context sensitive behavior in two ways: [i.1] the model enables interactions between organisms and develops a competition environment, in search of food and light; [i.2] 'functional-structural' models can implement biomechanic behavior. (Fruh and Kurth, 1999) The second and third models deploy development on the tissue and molecular level as the key generator. The second model defines development parameter as differential surface growth without direct genetic control, where growth corresponds to shape change. The third model explores genetic control for plant development.

The *Virtual Laboratory* of Algorithmic Botany offers a computational tool that use L-Systems augmented with a set of functions including physiological processes, environment interaction and ecological modelling. Although these methods have been explored widely, Prusinkiewicz states that "a combination of established models that operate at the architectural level with emerging models that operate at the tissue and molecular levels may produce rapid advancements in modelling methodology."



4. Genr8 developed by Martin Hemberg under the supervision Una-May O'reilly in the Emergent Design Group at MIT.

Genr8, a complimentary extension to L-Systems, developed by Martin Hemberg at MIT was designed as an architectural design tool, that generates surfaces through implementing growth algorithms of 3D map L-Systems (Aristid Lindenmayer, 1968) with physical environment interaction and Grammatical Evolution. It is a simulation tool that is based on 'growing' surfaces, while being exposed to environmental pressures. This design tool combines extended L-Systems and search mechanisms of the Grammatical Evolution GE, based on a standard GA. Two mapping processes link to one another to enable the process. One maps the genome to a grammar, the other processes the grammar and constructs the phenotype. Fitness evaluation (EA), a mathematical model evaluates the outcome with regards to user-defined criteria. Such tools hold concrete examples to be investigated for the development of proposed performance-oriented integral design process .

CONCLUSION

Combining growth, evolution and genetics through development both as a generative and analytical computational tool to process information and digitally simulate biological processes is powerful. Beginnings of interesting methods of implementing nature's strategies have shown great potential. The field of robotics and neural network show the beginnings of effectively implementing developmental growth and evolutionary strategies. (Kumar and Bentley, 2003)

"A central question of modern evolutionary developmental biology is how development may help explain evolutionary processes and outcomes. Another is how an evolutionary perspective can assist the further understanding of developmental processes, with respect to their functions, their evolutionary origins and their phylogenetic patterns of conservation and change." (Jessica A Bolker, 2000, 40)

These are some of the key potentials for the proposed research into developing the computational means of generative processes to derive at performance-oriented integral design solutions that are material (wood, brick as proposed) and context specific. Methodologically this enables generative and analytical processes with outcomes that are not a priori determinable, but of superior performative capacity.

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