HyperCell

A bio-inspired information design framework for real-time adaptive spatial components

Nimish Biloria¹, Jia-Rey Chang²
HyperBody Lab, TU Delft
¹http://www.hyperbody.nl, ²http://pandalabccc.blogspot.com
¹N.M.Biloria@tudelft.nl, ²J.R.Chang@tudelft.nl

Abstract. Contemporary explorations within the evolutionary computational domain have been heavily instrumental in exploring biological processes of adaptation, growth and mutation. On the other hand a plethora of designers owing to the increasing sophistication in computer aided design software are equally enthused by the formal aspects of biological organisms and are thus meticulously involved in form driven design developments. This focus on top-down appearance and surface condition based design development under the banner of organic architecture in essence contributes to the growing misuse of bio-inspired design and the inherent meaning associated with the terminology. HyperCell, a bio-inspired information design framework for real-time adaptive spatial components, is an ongoing research, at Hyperbody, TU Delft, which focuses on extrapolating bottom-up generative design and real-time interaction based adaptive spatial re-use logics by understanding processes of adaptation, multi-performance and self sustenance in natural systems. Evolutionary developmental biology is considered as a theoretical basis for this research.

Keywords. Adaptation; Swarms; Evo-Devo; Simulation: Cellular component.

INTRODUCTION

Contemporary explorations within the evolutionary computational domain have been heavily instrumental in exploring biological processes of adaptation, growth and mutation. On the other hand a plethora of designers owing to the increasing sophistication in computer aided design software are equally enthused by the formal aspects of biological organisms and are thus meticulously involved in form driven design developments. This focus on top-down appearance and surface condition based design development under the banner of organic architecture in essence contributes to the growing misuse of bio-inspired design and the inherent meaning associated with the terminology. Formal attributes of bio-inspired architecture have always been a fascinating topic in CAAD (Computer Aided Architectural Design), however, the desire to imitate organic form as opposed to understanding inherent biotic processes as bottom-up systemic interactions resulting in outward appearances needs definite persuasion within the architectural domain.

Janie M. Benyus (1997), the author of “Biomimicry” states that there are three phases of learning from nature to improve our technology: imitating
the form, learning about natural processes, and getting involved with natural systems. It is time for architecture to take a step further by looking deeper inside the multi-faceted field of biology to understand the processes via which factors such as evolution, adaptation, self-organization as well as growth occur in a sustainable fashion. The symbiosis between organisms and nature without hurting each other, and the continuous balance during the growing process of living things in order to envision sustainable ecologies at a larger scale via local interactions of its sub-systems should thus be logically applicable to architectural and urban design principles.

Contemporary academia and praxis-based research into bio-inspired systems for spatial usage are on the rise. Responsive, interactive, adaptive, kinetic, robotic, emergent etc to name a few, are the nomenclatures under which applications of such investigations have been prevalent. The shift from CAAD to Computational Design in order to encode rules and interaction protocols for experimenting with simulations based on dynamic natural systems has thus become predominant within the architectural domain. Some prominent research investigations focus on exploring the intricacies of natural systems to evolve programmable matter as well as to synthesize material performance with computational design, which are the following:

- Rachel Armstrong (2011), PhD from AVATAR, Architecture Associate has recently started cooperation with Martin Hanczyc (2011), Institute of Physics and Chemistry University of Southern Denmark, to develop a new material from protocell, an artificial cell which can metabolize itself.
- Neri Oxman (2012), an assistant professor in MIT Media Lab works on the relationship between buildings and natural environment by designing on principles inspired by nature and applying it via digital technology and digital fabrication means.
- Skylar Tibbits (2012), a PhD candidate from MIT Architecture Department, researches on self-assembly system tries to do the coding in physical materials to reach the goal of programmable component. Through the input energy, the components will actively grow to form an architecture body with a bottom-up logic, similar to the organisms growing process. HyperCell, a bio-inspired information design framework for real-time adaptive spatial components, situated within such experimental context, is an ongoing research investigation at Hyperbody, TU Delft. Via HyperCell, we aim not only to derive intricate information frameworks, built upon the understanding of dynamic natural systems but also focus on the applicability and thus the performance of such bottom-up formulated spatial systems within the context of economy, society and multi-usability aspects of space.

With the development of advanced medical science and technology, human life extends much longer than before, which leads to a population density issue. The population projection of 2050 shows that there will be 9.2 billion people in the world, out of which half of the population will be stayifing in urban areas. As a result, the price of real estate will inevitably become extremely high owing to increasing spatial requirements within urban areas, which will automatically create urgent economic and societal challenges. The problems mentioned above are irrefutably hard to solve by using conventional design methods, which stress on additive methods, devoid of customization and real-time adaptive re-use based possibilities. On the contrary, living organisms with self-adaptive traits allow their bodies to achieve optimal internal and external states in accordance with dynamic environmental variations.

Existing architectural spaces and their inherent static nature owing to their material make-up as well as the nature of linear processes, which lead towards their conception, thus are unable to provide the much needed flexibility as regards functional diversity, user-driven customization of space as well as adaptation within a dynamic context. HyperCell, aims to challenge such linear, non-dynamic processes and by means of inculcating built-in adaptive be-
behavior within the smallest constituting component of architectural space (the cell) intends to make a transition towards understanding architecture as a multi-performative, real-time interactive construct.

EVOLUTIONARY DEVELOPMENTAL BIOLOGY: AN INSIGHT INTO BIOTIC PROCESSES

Evo-Devo, a revolutionary field of biology in late 20 years, is involved with extensive research on: how organisms form from the difference of embryos; the invisible logic inside of the genes controlling the organism's growth; and the evidence that all animals use the same gene tool kits. Sean B. Carroll's (2005) book “Endless form most beautiful” states that all organisms grow on the basis of a simple on/off rule, akin to a switch, which regulates their genes. Computer programming, which also operates on a binary 1/0 logic, can form a parallel to the gene switch. Analogous to the on/off logic in genes that is responsible for the diversity of species in nature, Cellular Automata experiments, developed by Stephen Wolfram (2002) exhibit differential patterns based on 1/0 logic, thus providing with a definite path to experiment with computational routines as a mimicking medium. The HyperCell research extracts three distinct ideas from the field of Evo-Devo: “simple-complexity”, “geometry rules” and “switch and trigger”. These are discussed in the following sections:

Simple-Complexity: The simple to complex logic is a crucial aspect in Evo-Devo. Every complex organic body is composed of numerous amounts of simple elements with on/off logics. The quantity and the diversity of these repeated elements are controlled by the automated regulation of embedded genes. For example, Hox6 is the gene in all cases of vertebrates, which mark the boundary conditions of the vertebral type from the cervical to the thoracic regions, thus defining the neck profile. (Figure 1A) This differentiation takes place via simple on/off switch logic. Through Evo-Devo, we know that all animals share a common gene tool kit, but different numbers and combination of genes, which govern the patterns and formation of their bodies and body parts. In the architectural domain, the idea of working with a similar logic, in order to produce diversity via variable combinations of spatial genes contained within a generic spatial toolkit which auto-regulates adaptation with respect to functions and dynamic environment could be an interesting research domain.

Geometric Rules: Every organism's formation follows certain rules rather than growing randomly. When we look at the construction of cells, it has the significant geometry characteristic. In addition to
repetition of modular parts, symmetry and polarity are common features in organisms. In most of the organisms, there are three axes of polarity where symmetry can be witnessed: head to tail, top to bottom and near to far from the body. Geometric rules also play important parts during the embryo formation. What is interesting to note during embryogenesis is the process via which each cell knows where they are and to what tissue or structures they belong. In Evo-Devo, such a process is controlled via the “Fate-Map”. Sean B. Carroll (2005) gave a clear metaphor for explaining the Fate-Map: “In the terms of our geography analog cells, tissue, and organs have a specific position on the globe of the embryo defined by their longitude, latitude, altitude, and depth, as well as a ‘national’ identity (nerve cells, liver cells, etc.).” The biggest difference between such inherent automation based natural growth processes and architectural design is the instinctive nature of organisms to adhere to the Fate-Map and thus result in bottom-up formation of outward form as opposed to conventional architectural design processes where aesthetics based top-down form generation is still predominant. The HyperCell research tries to explore bottom-up possibilities of “evolving architecture” via computational simulation methodologies similar to natural growth processes while establishing real-time information exchange protocols amongst the material components constituting the formal make-up.

Switch and Trigger: The gene switch plays a key role in the formation of an organism, and has the ability to control very subtle details of organic form on the basis of complex combinatorial rules. Hox genes are the predominant genes, which control the formation process. The switches inside the Hox genes tell an organism where and when to evolve different body parts in time. The characteristic of the output (form, color, pattern etc) itself is the resultant of multiple nested sets of inputs. The idea of switches is also applied to how DNA translates to mRNA to produce proteins. (Figure 1C) The DNA will switch on when it is needed and transcript to mRNA, and the mRNA will be translated into a protein molecule. Cell differentiation is based on these genetic switches rules to build up more complex organs. The functions of blood, brain, and muscle cells are marked by the production of proteins specialized to undertake the task of these tissues (Sean B. Carroll, 2005). The other way of forming cells in a particular way is to pass specific cell clustering information via neighboring cells. For instance, the circle-shape patterns on butterfly wings called “eyespots”; the center cell of the eyespots is the example of a “morphogene”, which can produce chemical substances to influence the development of its neighbors. To get the ideal result, the switch of the morphogene dominates and directs the information passing though the neighboring cells.

For architecture, such embedded intelligence based processes responsible for the context aware performative development of form are of particular importance. Different stages of interactions (during growth as opposed to maturity) and the efficient usage of computational processes to simulate bottom-up formations via utilizing optimal triggers to appropriate computational sequences can thus be learned and applied. This will help in controlling the computationally heavy operations, preserving energy and thus faster performance ratios within the soft, information-processing domain.

PROPOSED HYPERCELL PROPERTIES AND THEIR BIO-INSPIRATIONS

In light of such ingenious natural properties and regulatory phenomenon, the challenging issue for architecture is the inherent multi-performative nature of its most essential building block: the architectural cell/component. HyperCell, tries to seek a solution to manifest multi-performative criteria by means of a much needed integration of material performance, real-time information communication and physical adaptation.

Materials System: Material systems in nature have the ability to react, modify and adapt in order to provide an appropriate response towards dynamic natural forces. The external skin and the tissue of organisms are cellular formations, where each cell
has the inherent capacity of structural support, information transmission, and environmental interaction. Take the skeletal system for example, there are two kinds of cells in the skeletal system: Osteoclast and Osteoblast. Osteoclast creates the empty space in the bones for marrow to manufacture blood cell, nerves, and prevents the production of redundant materials; Osteoblast's function is to grow bones with protein, calcium and phosphorus to support the body weight and protect the organs in our body. Both Osteoclast and Osteoblast work perfectly together to generate optimal skeletal systems. In most cases, artificial materials however, are developed for specific purposes while natural materials embody multiple functionalities. 

In the architectural domain, however, researches are more focused on a structural point of view, such as “Cellular Solid” by Lorna J Gibson and Michael F. Ashby (1999), which calculates how cells construct in an organic way to support themselves. However, recently, there have been more research investigations on developing smart materials and natural material formations. Researchers such as; Manuel Kretzer, PhD candidate in chair of CAAD, ETHZ, works on the topic of smart materials, using electroactive polymers (EPS) to make kinetic architectural components, Neri Oxman uses 3D printing techniques to simulate how natural materials grow. HyperCell, in its material aspect, aims at going beyond purely structural issues to create a direct relationship between adaptive material formations and customized multi-usability of space.

Real-time information communication: Information exchange in the biological world, for the purpose of this research is categorized in two parts: Global and Local communication. Information transmission to and from the brain via nerve cells attached to various tissues in the body is considered as a global medium of information communication. Parallel to this, a local level of information communication can be found embedded within skin cells, which adapt their pore openings autonomously in

Figure 2
Different mediums of information communication by HyperCells: A) Global communication from central command with touchpad by users. B) Local information distribution among HyperCells. C) Reflexive and interactive medium driven by users’ actions. D) Local environmental Adaptive System.

Figure 3
Experiment of controlling the visual 3D model through smart phone device.
According to external environmental conditions. These two modes of information transmission will form an essential part of the HyperCell’s makeup. User-driven spatial customization wishes will be communicated via global information dispersion protocols (while considering the overall spatial formation and usability patterns in use) to an appropriate number of HyperCells. From here on, autonomous information communication amongst the HyperCells based on a distributed computing logic will be initiated. Local adaptations in terms of physical alterations, ambient transitions etc will aim at achieving the desired spatial customization. Analogies from the IT world such as the iPhone which at a global level operate on an operating system, but at a local level can be customized by downloading various applications is thus also in sync with the HyperCell’s information structuring protocols. (Figure 2) Adaptive System: Adaptive processes play important roles in both growth and sustenance processes in nature. The adaptive process in growth refers to the ways in which cell differentiation and positioning based on specific Fate-Maps per organism, develop. After becoming a mature body, local adaptations such as blood flow regulation, heart beat modulation, pore opening patterns, skin color, structure adaptations etc. result in the self sustainability of the body amidst dynamic contextual scenarios. Swarm behavior as well as flocking behavior seen in bigger ecologies of birds, fish etc are also representative of local level adaptations which result in global synchronization.

HyperCells, adhering to such local information transmission and physical adaptation processes will create a novel approach in which real-time local adaptations result in topological and functional differentiation. For instance or elderly people, HyperCell via local sensing can predict user actions and can thus adapt its physical and ambient self as a reflexive and interactive medium to ensure a safe as well as calming environment. Spaces built up using HyperCells can also be fully adaptable to fulfill multiple usability of space criterion while interacting with multiple users through time. Adaptive re-use in the literal sense of the word can thus be efficiently attained via such intelligent spaces.
HYPERCELL EXPERIMENTS

HyperCell and its propositions as an ongoing research, has commenced with experiments in computational simulations. Currently the authors are involved with building up computationally optimized simulation interfaces and testing initial physical prototyping possibilities for the HyperCell. The simulation sets and their parametric input variables will be developed as a software application, which can correlate inputs based on customizable rule sets akin to a contextual set-up. The research experiments currently in the testing phase focus on small-scale furniture design in order to control the behavioral aspects of the proposed system before getting involved with a bigger architectural scale venture.

Four fuzzy characteristics incorporated during this experimental process; “Property-ness”, “Design-ness”, “Material-ness”, and “Geometry-ness” are further explained: Designers will need to decide on the typology of the furniture system eg. Chair, Table, Shelf, or can even combine these typologies eg. Chair + Shelf as combined units. This typology connects with the “Property-ness” of the object. (Figure 4) For instance the typology of Chair would involve setting out basic parameters such as the surface area of the seat, the number of legs, back rest etc. Such information

Figure 5
Experiment of computationally optimized simulation interfaces built by “Processing” with the design formation process.
becomes an integral part of the DNA, which will be inherited by all the generated chair variants. The Fate-map principle, as an intrinsic logic for informing cell distribution and differentiation is currently being incorporated in the simulation interface as intuitive power lines, which can be drawn by the designer as a rough indicator of desired topological outcomes. The simulated/virtual HyperCell agents interpret this rough idea as a blueprint for initiating swarm based behavior and self-organization patterns. The pattern formation in-turn informs the agents as regards their geometric make-up in accordance with their location within the object’s body, thus resulting in adaptive differentiation. This, currently subjective mode of influencing the fate-map by the designer is termed as the Design-ness fuzzy input. (Figure 5)

The Material-ness fuzzy input is a subsequent feature, which, via the interface allows designers to allocate materials and thus affordance properties to the generative process. This also dictates the variations and the adaptive differentiations, which each HyperCell can incorporate. Different materials have different costs, which will also influence the generated outcomes. The interface will subsequently display the cost difference to give the designer a general picture.

During the growth process, the differentiated geometries, which the HyperCells inherit, shall be displayed as geometric types along with the total number per typology. This constitutes the Geometry-ness of the system. Differentiated species can thus further be assigned specific ambient features, which again can be fully automated based on the adaptation and role, per HyperCell acquires during further interactions with its context. Alternatively designers will still be able to change the configuration based on dynamic design decisions or cost issues.

At the architectural scale, dynamic environmental conditions will be used as essential parametric input during the simulation phase. This, apart from affecting the geometric make-up and differentiation aspects of the HyperCell will also result in ascribing specific energy generation attributes by means of generating topologies conducive to solar, water or wind based energy harvesting.

After these parameters are set, the system will automate self-organization procedures and start distributing data to HyperCell agent population. Swarm logics and flocking behavior will thus become vital at this stage and will result in differentiated growth formations akin to adaptive evolutionary strategies. The physical world however, will play a vital role as regards setting up initial rule-sets for maximum and minimum physical adaptations, which a generic HyperCell can afford. The digital manufacturing process will thus involve manufacturing the basic structural shell of the HyperCell which will, in accordance with pre-simulated and designed deductions be embedded with actuators and sensors. The basic geometry of HyperCell as of now is developed as a cubic form, which can adapt into different hexahedron-forms based on the location, structural and functional usability pattern per HyperCell. (Figure 6)

Additional customization options can also be initiated via an online interface, which is currently being developed as well as a touch-screen interface, which allows you to select a population of HyperCells and ascribe a functional pattern to them. This implies a global communication to a local population of the selected HyperCells and thereon this population locally communicates information as regards structural, physiological and ambient adaptations to attain the desired topological output.

**CONCLUSION**

The HyperCell research thus proposes a new approach to bottom-up design. The research does not state that HyperCell is the ultimate answer for the future of adaptive re-use in architecture, but instead tries to propose an innovative, bio-inspired design methodology for real-time adaptive architectural and interior spaces. The research, via self-similar componential redundancy will strive to develop variations in overall morphology based upon associative (amongst components) context aware real-
time adaptation. Each component can also operate as an autonomous entity with its own sensing and actuating mechanism, though each autonomous adaptation will have an associative impact on the overall morphology of the built form. The research thus aims at deriving the most essential information structure for optimal computing (almost like the hox gene) in a regulated sequence which will in turn be auto propagated but autonomously regulated by each cell throughout such bio-inspired systemic spatial formations.

REFERENCES