Biology

Computation

Material & Space

Synthesis Strategies based on Evolutionary Developmental Biology

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Material

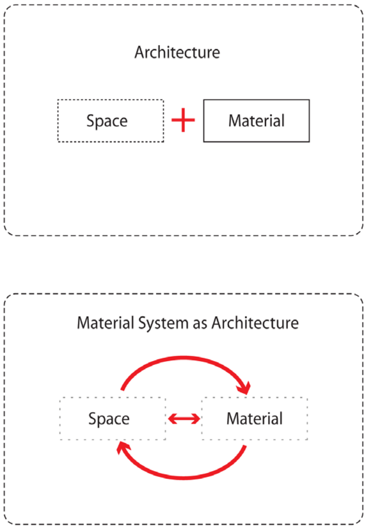
Parametric

A MATERIAL SYSTEM CAN BE DEFINED AS A SET OF SELF-ORGANIZED MATERIALS, DEFINING A CERTAIN SPATIAL ARRANGEMENT. In architecture, this material arrangement acts as a threshold for space, though space often only appears as a by-product of the material organization. Treating space as a resulting, therefore secondary, independent product minimizes the capacity to generate architecture that is astutely aware of concerns of functionality, environment and energy. An effective arrangement of material can only be determined in relation to the spaces that it defines. When proposing a more critical approach, a material system can be seen as an intimate inter-connection and reciprocal exchange between the material construct and the spatial conditions. It is necessary to re-define material system as a system that coevolves spatial and material configurations through analysis of the resultant whole, in a process of integration and evaluation.

With this understanding of material system comes an expansion in the number of criteria that are simultaneously engaged in the evolution of the design. The material characteristics, as well as the spatial components and forces (external and internal), are pressures onto the arrangement of material and space.

This brings a high degree of complexity to the process. Biological systems are built on methods that resolve complex interactions through sets of simple yet extensible rules. Evolutionary Developmental Biology explains how growth is an interconnected process of external forces registering fitness into a fixed catalogue of morphological genetic tools. Translating the specific framework for biological growth into computational processes, allows the pursuit of an architecture that is fully informed by the interaction of space and material.

System



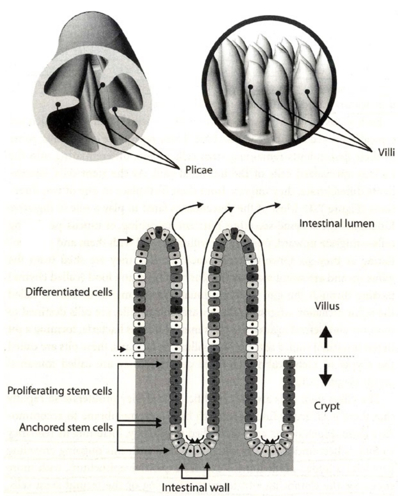


FIGURE 1. ARCHITECTURE CREATED WHERE SPACE AND MATERIAL ARE DEVELOPED AS SEPARATE PARALLEL PROCESSES. MATERIAL SYSTEM IS REDEFINED AS THE INTERRELATED EVOLUTION OF SPATIAL AND MATERIAL CONDITIONS.

FIGURE 2. THE DEVELOPMENT OF THE INTESTINES REPETITIVELY USES THE METHOD OF FOLDING TO HANDLE VARIOUS TYPES OF DIGESTION AT VARIOUS SCALES. (TURNER 2007)

1 Material and Space

It is understandable to have a design approach that isolates the design of material assemblies from that of spatial arrangements when viewed with the concern of complexity. In conventional processes, even parametric processes, the coherency of the system can be lost when too many parameters and criteria are engaged simultaneously. Parameters and variables can conflict and/or override one another. A design system, which stratifies performances and conditions, and engages design through separate but parallel processes, allows control over multiple parameters. It produces, though, a limit to the level of integration between the components of the material system. Current examples of parametric design strategies (surface population, geometry-based, hierarchical models) engaged through new software packages (Grasshopper, Generative Components) by highly recognized developers (McNeel, Bentley) from the CAD/CAM field are one example for parallel, but limited implementations of material systems into architecture.

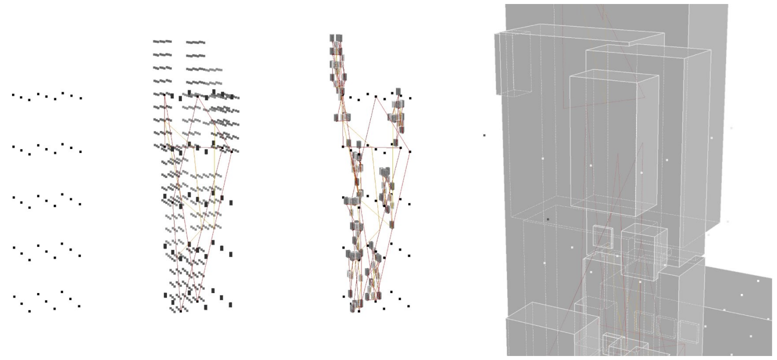
When looking at an integrated system, a larger set of criteria is considered, along with the number and degree (priority) of connections between the criteria. The aim of such a system is to produce an "effective" result, which can only be achieved through the testing of many variations of geometrical form. Within this complex rule-based process, the evolution of material configuration and space as well as their analysis towards internal and external fitness-criteria happen simultaneously.

Previous applications of evolutionary processes (algorithms) to architecture have dealt with such an intention through understanding biological models. John Frazer refers to an adaptive biological model where form develops through "progressive modification of a given structure by the repeated actions of certain operators," (Frazer 1995) citing chromosomes as the metaphor for the operators. Evolutionary Developmental Biology provides further clarity in the definition of these "operators" for the evolutionary system. Their capacity is described through procedures of minimized complexity while still providing for specificity in the generation of form.

2 Biological models for process

Biological models for evolution and growth provide a framework for how to navigate through scenarios of complexity in criteria, function, and form. Evolutionary developmental biology, in short "Evo-Devo", observes many evolutionary-based strategies that can negotiate multiple components, pressures and dimensions. Embryology, the growth of the organism, is the mechanism that registers, and displays the effects of evolution through the adaptation to the external pressures on the organism. Through the manipulation and interplay of repetition, modularity, and local interaction, a fixed set of rules constructs multiple, varying, and evolving structures. Looking specifically at Evolutionary Developmental Biology (Evo-Devo), the genome and the interaction of proteins, make up a process of limited complexity that builds evolving systems, and constructs very different structures using the same set of mechanisms.

The development of components of the butterfly wing, and in comparison to that of a fruit fly, offers a picture of how the same tools responsible for growth can work (and also evolve) to produce different structures. They utilize the mechanisms of geography and switching, main topics of Evo-Devo. A primary component in the formation of both the butterfly and fruit fly wing is the expression of the Distal-less tool kit gene. It is one of the homeobox genes. Given a certain time in the process of development and a location within the embryo, the Distal-less gene will lay down proteins that spur a chemical interaction to grow the wings (and also the legs). The interesting trick in the system was the development of a new "switch" that allowed the gene to also generate the eye spots on the wings (patterns of modular scales). In the fruit fly, wings are created using the same gene, though there is no ability in the embryology of the fruit fly to produce colored spots. The conclusion is that the Distal-less gene in the butterfly evolved a new switch, not a whole new gene, to produce a different expression of form. The same tool is utilized; it was simply re-configured to gain a new capability. In terms of Evo-Devo, "re-configured" means, that in the process of growth, a new capability is gained through minimal alterations. The



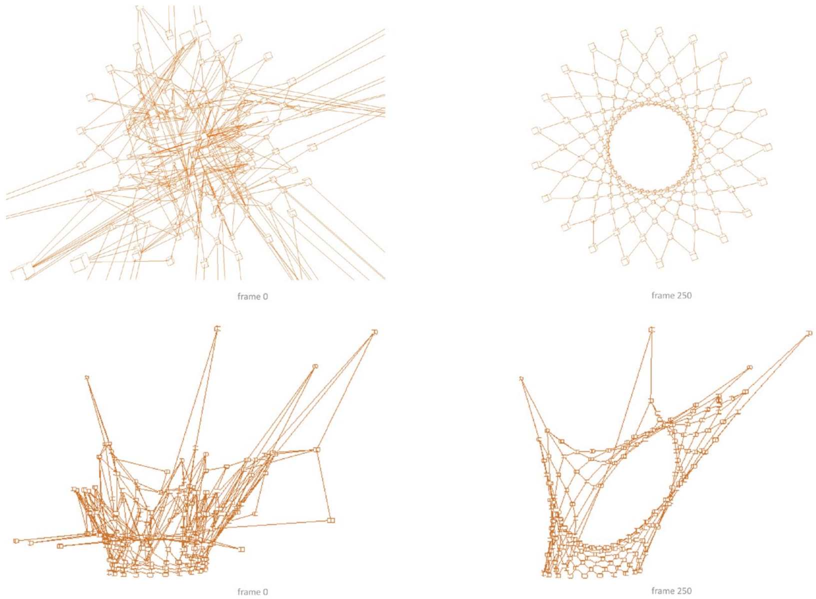


FIGURE 3. TRANSLATION OF TOPICS OF GEOGRAPHY, AND SWITCHING TO A GEOMETRIC ASSEMBLY OF DIVERSE AND LOCALIZED "GROWTH"

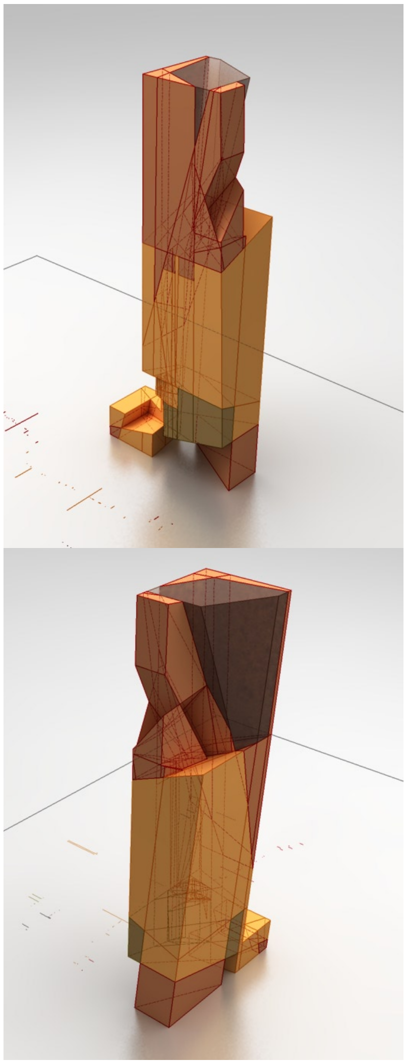
FIGURE 4. SIMPLE RULE FOR CONFIGURATION OF THE NET. CHANGE IN GEOGRAPHY (BODY PLAN), AND NUMBERS ALLOWS FOR VARIED CONFIGURATIONS.

"switch" is the simple function that provides this extensibility. Turning the specific gene on or off at a specific time and place, when interacting with other switches being engaged - a unique and specific growth occurs. Growth emerges from the coincidental action of different genes at the same time and place.

Development is not a simple process. There are multiple forces acting upon and within the system, often in competition with each other. The competition of pressures, criteria and functionality is resolved through the desire of the system to arrive at a homeostatic state. There is no predetermination in what "balance" is; rather it is the organism's interaction with the environment that establishes when homeostasis is achieved.

Determining a "fit" (formal / geometrical) solution is something (architectural) designers often struggle to achieve. Too many criteria have to be satisfied in and processed simultaneously. Often certain decision are made (subjectively – that is why we turn to certain designers) during the process, that are hardly changed at a later stage. Every following step builds upon these decisions. Of course, attempts are made towards an optimization of these designs (using Analysis & BIM software, like Mode Frontier, Ansys, Revit in the latest development), but the question rather is, whether these designs are effective towards what they try to achieve rather than optimized within their limits.

In nature, the design of the gut, the intestines, is an example of how biological systems can build mechanisms to handle multiple demands. There are different challenges for digestion and they require different architectures, yet all purposed for the absorption of nutrients. As explained by J. Scott Turner, he defines the challenge of relating the parameters of the gut to its necessary functions: "Optimize the intestine for the easily digestible bits, and the hard-to-digest bits, along with the nutrients locked up inside them, pass through



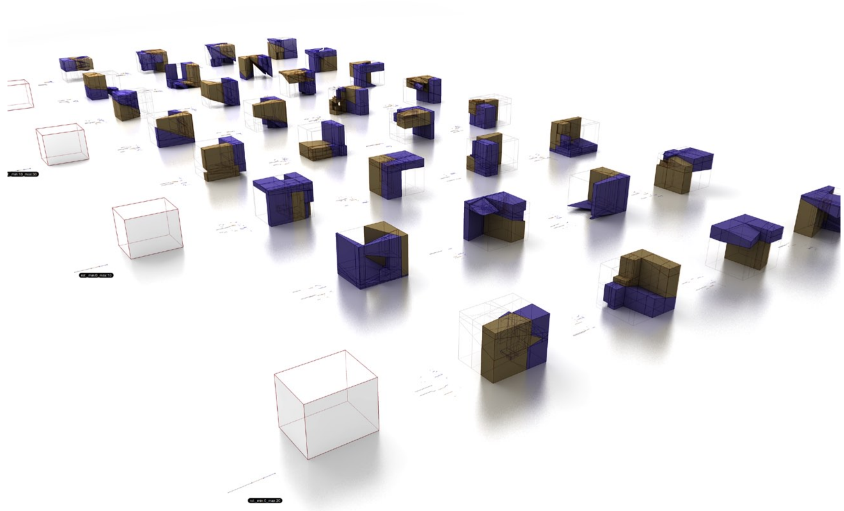


FIGURE 5. ENVELOPES HAVE BEEN SUBDIVIDED TO DIFFERENT DEGREES AND ALONG DIFFERENT VECTORS ALLOWING FOR LOCAL DIFFERENTIATION IN SPACE AND ORGANIZATION.

FIGURE 6. SEVERAL POPULATIONS OF SPATIAL ARRANGEMENTS ORIGINATING FROM SIMPLE CUBE.

unscathed. Make the intestine long to get the hard-to-digest bits, and the system performs poorly for the easily digestible components"(Turner 2007).

These competing criteria need to be settled within a single architecture. The mechanism that is realized is accomplished through the method of folding at multiple scales. Folding is not unique to the intestine; it is a commonly used method, for growth/expansion of the organism. The folds create multiple pathways and micro-environments for the different demands of digestion and absorption of nutrients. The folds at the most minute scales help to expand the amount of surface area of the entire system to meet the demands of nutrient absorption. (Figure 2) This process occurs as a part of embryology, and the desire to reach homeostasis.

Development of the gut works, generically speaking, through the method of repetitive folding. Multiple criteria, digestion and absorption, are dealt with individually and resolved through different components of the single intestinal system. The organism does not try to build one single mechanism that can accomplish all tasks. If it did, that mechanism could only do, at best, an average job for each of the tasks that it has to handle. Rather, it has integrated multiple individual systems into a single, continuous architecture.

It is important to see evolutionary developmental biology as describing a framework for process, not form. For instance, the mechanism of "folding", allows for unique articulation only achieved through process and context. Outside of the specific context, the mechanism of the fold would be meaningless and should not be used as a formal application on an architectural scale—at least not with the same intention. In more general terms, growing an organism is not akin to "growing" architecture. The space and form of biological systems are not directly relevant to the space and form of architectural systems.

The examples described in this chapter show different strategies for a process evolving integrated multi-criteria systems. As design (the arrangement of matter) in Evo-Devo is understood as the effective output of a process, which negotiates multiple, sometimes opposing criteria, it seems pertinent to pursue the topics of Evo-Devo for the development of strategies for architectural arrangements (matter and space), rather than looking formally at the construction of complex biological systems. The model expands the evolutionary process (generation, fitness and recombination) to describe the intimate connection between the mechanisms of growth (process of generation) and the challenges of adaptation and fitness.

3 Translation to computation

In computation, the framework for using criteria, analysis, and recombination remains consistent with the evolutionary biological model. What transforms is the method of "growth" within the system, and the consideration of hierarchy within the sets of criteria. Through evolution, a growth method for organisms based on DNA, proteins, etc. has been devel-

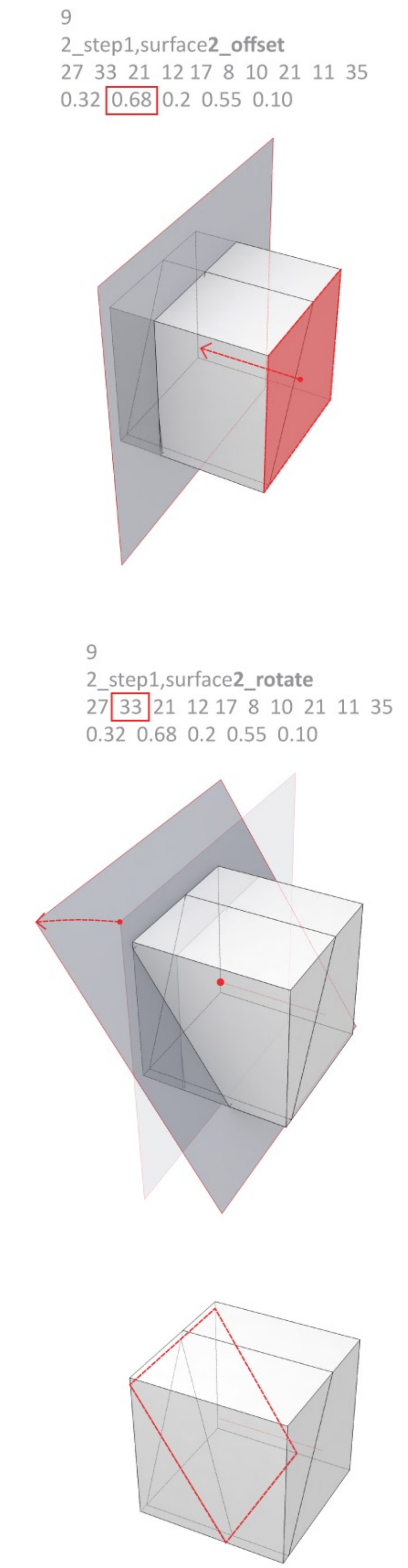


FIGURE 7. RECURSIVE GEOMETRIC SUBDIVISION METHOD USED FOR SPATIAL SUBDIVISION STUDIES.

oped. In architecture, the growth method can be equated to the combination of geometry (line, surface, volume) and transformation method(s) (scaling, subdivision, Boolean, etc).

The selection of method is very context sensitive and is not "proven" in the way that the systems of embryology have been evolved to produce "fit" organisms. Given the context of a specific set of criteria, the geometric transformation method has to be considered as a part of the evolutionary design cycle. Testing the "growth" method as well as the balance of criteria and product is necessary in executing the evolutionary process. This is a critical reflection of the Evo-Devo model which relies heavily upon the simplicity/extensibility aspect of the devices for growth. Precedents for evolutionary models typically focus on the fitness/recombination aspect of the solution-solving process, looking more at the universality of the system.

Sequence is critical in establishing the framework and understanding how to step (and cycle) through the different modules of the evolutionary algorithm. Determining the order of the steps is done through establishing a level of priority for each criterion. Ideally, the algorithm is recursive, consistently cycling through the same set of geometric transformations, testing different inputs and analyzing the output. In practice, though, there is a consideration of the entry point, the first step, into the system. In the spatial subdivision studies (Figure 5), the condition of "neighbors" is the highest priority and works recursively, always looking for the nearest volume to connect with and insert program. At the starting point of the system, though, no volumes have been selected or programmed.

Relating objects by proximity demands at least two elements. Therefore, this initial step has to select the one individual element to which later can help to define its nearest neighbor. In this experiment, the first step is to determine a volume that most closely fits, in size, to a particular program bit. This step, program by volume, works repetitively but happens within a larger loop, whereas the program by proximity occurs recursively and happens continually until programs are fully distributed into the volume. This algorithm produces – and this was the intention – "similar" geometries. All individuals have the same volume, the same amount of program and the same ratios between the different programs. The distribution of program and void space, managed through the amount and point in time at which it is being inserted in the process, highly determines the (strategic) output: from solid (no void) to porous (small voids taken out) to iconic (large void volumes taken out) shapes can be produced based on the decisions made prior to the process.

Intertwining time and geography allows for transformations to be localized. In biology, "changing a specific switch enables specific modules to change without affecting other body parts" (Carroll 2007). This is critical when considering transformation on different levels of hierarchy. When looking at parametric design, shifts or switches in the topology are very difficult. Transformation is typically done through gradient affects. This minimizes the control for how localized an affect can be. A transformation will always influence its neighbor and to only a gradient degree. In working with switches, and being context and geography sensitive, higher differentiations in form can be achieved (Figure 6). Geometries can be more sensitively responsive to their immediate context. This is important for an "integrated" architecture that considers local specificity rather than generalities.

The geometric transformation of subdivision, in the spatial subdivision studies, uses rules based on local conditions. An envelope utilizes is own surfaces to subdivide itself into smaller bits (Figure 7) and provide for volumes that are appropriately sized to the program inputs. Articulations within small regions can happen differently than in other parts of the whole assembly.

There is also the consideration of intention, a notion that is, arguably, somewhat foreign to the evolutionary process. Intention to a certain degree can be instituted in the evolutionary process through the balancing of criteria. Part of the process in determining fitness is weighting the criteria to which the "fit" product has to meet. The advantage of the evolutionary process, at this step, is that different solutions can be determined by shifting the criteria and inputs, rather than having to reconstruct the coding or method. (Lightman et al. 2006)

Along with introducing multiple criteria and utilizing simple controls for transformation comes the challenge of complexity and coherence in the system. All criteria cannot be solved simultaneously, but they can be interrelated. In the Evo-Devo model, the solution for meeting certain criteria is mapped out in the initial stages, but not fully met. The structure of a bone, for instance, begins formation in early stages of development with individual, weak fibers. It is not fully structured until increasing forces over time act upon it, producing more fibers and organizing them in a particular manner to withstand all the forces. The criteria shift over time. This is one way to manage the complexity of the computational system: consider layers of criteria than can shift and/or change over time in the evolution of the form.

4 Conclusion

In applying this logic to architecture, there is an opportunity to resolve the effective integration for the entire entity of the building based on specificity of conditions and characteristics, not simply only address the "skin" as a responsive mechanism. Where material system is isolated from the consideration of space, "skin", in the least, is an additive solution, subservient to the massing design. Or, its definition may be a part of parallel processes where there is minimal interaction between it, the definition of space, and the internal organization. When material system is a larger construct joining both conditions, it is understood that material and space develop concurrently and with repercussive affects. To establish the interaction, a clear definition of space has to be constructed. This is a challenge on both a conceptual and physical level. Space has to be defined to then be broken down into a series of calculable conditions that can enact pressures upon the organization of material and evolution of the form. It is ultimately critical to have a distinct view of what defines space, what are the characteristics of threshold, and how the constituent parts interact. A material system defines environment. Environment can be seen as a collection of dynamic micro-climates, with changing values of light, temperature, humidity, etc. In the playing out of an evolutionary design process, an effective balance between these conditions and those of more distinct architectural terms can be determined through process as observed in Evo-Devo - feedback that inhibits or accelerates the architectures that deal most effectively with their contexts.

The effort of design is in defining these criteria and establishing the relationships and hierarchies between them. In determining the effective solutions, it may be found that architectural conditions are, in fact, not isolated from environment, but interrelated and can work in the same dynamic manner.

The homeobox is a set of genes, highly common amongst all organisms, which regulate the genetic switches for growth.

5 Acknowledgements

The research described in this paper has mainly been conducted as a part of the Emergent Technologies and Design Program at the Architectural Association in London in 2007/2008. The work has been developed through various seminars and studios and is being further investigated through the dissertation work of Sean Ahlquist and Moritz Fleischmann for the Masters of Architecture degree. Additional contributions have been made from Michael Weinstock, Michael Hensel, Achim Menges and Sam Joyce.

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