When The Going Gets Tough, The Pluripotent Get Going
Resilient Developmental Models

Hugh Hynes
Principal at PROTOinc, Adjunct Professor at California College of the Arts

MECHANISMS OF BIOLOGICAL DEVELOPMENT, SUCH AS IN EMBRYOGENESIS, OFFER PROMISING MODELS FOR RESILIENT ARCHITECTURAL SYSTEMS WELL-SUITED TO VOLATILE OR UNPREDICTABLE CONTEXTUAL CONDITIONS. The resilience of embryonic development as a process is such that successful development—“success” defined here as that which results in the birth of an organism that can survive—can sustain extreme shifts in a normal developmental process, triggered by mutations, environmental pressures, injury, or experimental intervention. More specifically, biological development combines mechanisms of standardization with mechanisms of customization to create open-ended or what biologists call pluripotent systems—poised (“-potent”) to develop into a wide range (“pluri-”) of potential forms—which we can endeavor to reproduce mimetically.

This paper considers biomimesis less a matter of replicating these developmental mechanisms physically or formally, but rather borrowing aspects of the mechanisms’ operation in order to test project outcomes digitally. The discipline of developmental biology affords a virtually ready-made conceptual framework and terminology to guide an open-ended digital methodology, in the hope of incorporating increasing degrees of resilience into the resulting design work. Searching for a capacity to sustain a similar fluidity of differentiation afforded by organisms in early development, we explore a pluripotent architecture for which differentiation might occur over time, and which might be better able to absorb volatility.
Surviving Volatility

The conditions of the contemporary built environment and architectural practice by extension can be characterized as volatile, uncertain, unpredictable, and unstable. Budgets shift, contractors go out of business, codes are revised, natural disasters happen, and people change their minds: this is nothing new. What is new are dramatically increased expectations for the physical and methodological complexity of our architectural responses to these uncertain conditions, many of which can be attributed to digital design and implementation methods. Commonly this complexity affords a tailoring of design work to very specific and localized conditions, such as in methods of mass customization. These methods support great precision—even optimization—as long as the project conditions (program, site, budget, etc.) remain somewhat stable. The challenge for our research is to deploy this complexity in an effective manner when long-term instability is assumed.

Mechanisms of biological development, such as in embryogenesis, offer promising models for resilient architectural systems well-suited to volatile or unpredictable contextual conditions. The resilience of embryonic development as a process is such that successful development—“success” defined here as that which results in the birth of an organism that can survive—can sustain extreme shifts in a normal developmental process, triggered by mutations, environmental pressures, injury, or experimental intervention. More specifically, biological development combines mechanisms of standardization (genericness) with mechanisms of customization (differentiation) to create open-ended or what biologists call pluripotent systems—poised (“potent”) to develop into a wide range (“pluri-”) of potential forms—which we can endeavor to reproduce mimetically.

For our purposes, we consider biomimesis less a matter of replicating these developmental mechanisms physically or formally, but rather borrowing aspects of the mechanisms’ operation in order to test project outcomes digitally (Figure 1). The discipline of developmental biology affords a virtually ready-made conceptual framework and terminology to guide a more open-ended digital methodology, in the hope of incorporating increasing degrees of resilience into the resulting design work.

To explain this search for find alternative computational methods, it may help to place our research in context of contemporary morphogenetic digital practices in architecture. Recent software techniques such as scripting and parametric component instantiation (eg.: Bentley’s Generative Components, McNeel’s Grasshopper) offer powerful means to achieve rule-based differentiation and subtle variation among repeated arrays of units. Our own efforts to learn these techniques and incorporate them into our practice proved fruitful and enjoyable. We encountered difficulties, however, when volatile changes in the project conditions forced us to pause these incremental processes and introduce more functional differentiation or customization at the local level. Stopping the process of morphogenetic instantiation and manually switching the rules at certain moments in response to particular conditions was at odds with the systemic instructions intrinsic to these more automated digital techniques. Conditional “if/then” functions would be necessary to contend with all potential events, requiring a level of foresight difficult, if not impossible, to achieve. Pairing the provisional condition-dependency of embryological development with the rigors of systematic digital morphogenetic techniques seemed necessary.

Epigenetic Landscapes

Morphogenesis (form-giving change) has recently proven a useful concept for explaining digital practices of form-generation in architecture, in which dynamic conditions can be linked to project outcomes: input A triggers instruction B which results in output C. Basic structures become more complex as a result of these conditional cause-effect operations. Similarly, biological development involves collections of generic, pluripotent cells that respond by being activated or induced by conditions in their context (or morphogenetic field), and as a result take on increasing functional differentiation and formal detail. Unlike prescriptive processes such as genetic coding, the process by which this occurs is quite fluid: changes in the morphogenetic field at any time will induce shifts in the ongoing developmental pathways.
Biologist Conrad Waddington described embryological morphogenesis as analogous to a ball rolling downhill across a flexible membrane that he dubbed the epigenetic landscape (Figure 2). Changes to the landscape membrane direct the path of the ball (or the form of the organism). A series of experiments beginning in the early 20th century showed that cells receive instructions to differentiate in a particular manner according to the concentrations of chemicals called morphogens nearby. For example, a gradient of high concentration in one region induces a head to form, a low concentration at the other end induces a tail. These regions are highly condition-dependent, the result of local chemical mixtures rather than essential cellular characteristics. Computer scientist Alan Turing postulated that complex structures of organisms could emerge from a simple series of binary “on/off” choices which activate pluripotent cells through concentration alone, via so-called reaction-diffusion mechanisms (Wolpert, 1991). Observation of organisms such as Drosophila fly larvae have shown that overlapping simple, binary gradient axes results in a multi-dimensional, heterogeneous organism. (Figure 3).

2.1 DIGITAL MODELS: CONDITIONAL PRESSURES

We have developed digital epigenetic landscape models that document constraints driving a project’s morphogenesis throughout its lifespan, the so-called “event-space” of the project (Figure 4). This computational technique borrows heavily from scenario-planning practices, but also embryology research methods that propose hypothetical links between morphogenetic mechanisms and the inputs that trigger them.

As in the Drosophila larvae, these digital diagrams situate critical project constraints along binary gradient axes, labeled inert to intense. The constraints vary from the general (boom/bust cycles) to the specific (owned/leased properties), and are a collection of key factors that would be most likely to direct project outcome rather than an exhaustive list of every potential catastrophe. Hypothetical ‘trigger’ events can be located along these constraint axes; for example, a sub-prime mortgage crisis and a flood of foreclosures would fall at an intersection of boom/bust and supply/scarcity axes. These algorithmic triggers exert a deforming, push or pull influence on an undifferentiated, pluripotent diagram of the project’s relevant attributes (density, materiality, topology, function) that might be affected by volatile contextual conditions. Particular regions of the digital model are designated as ‘sensitive’ to particular triggers, activated only by local changes in the constraint matrix, just as morphogens induce change in specific regions of the organism. (Figure 5).

When a simulated event-algorithm is triggered, the resulting deformed model describes a diagrammatic sampling of new project attributes when compared with the original, pluripotent state (eg: increasing density, material tooling, topological transformations, functional adaptation, etc.). (Figure 6). In our sub-prime mortgage example, differentiating tendencies might be increased housing vacancies, demand for sub-tenant spaces to bolster income, increased material availability from construction industry slumps: in other words calling for space-filling, subdividing, material-intensive architectural proposals.

2.2 SCENARIO EVALUATION

Software platforms such as Autodesk’s Maya make it relatively simple to adjust the sensitivity of these interactions, allowing for mixing of gradient influences, and evaluation of the deformed results. The objective is not to identify fixed, causal relationships between induction events and attributes of a developing project, nor optimize an architectural product for specific scenarios, but rather to expose effective tactics for resiliency and an appropriate sensitivity to certain kinds of volatile conditions. For instance, we may discover that certain attributes are rarely affected, whereas others are commonly induced by a wide range of events. We can reasonably conclude that the first group of attributes can remain static constants within the project, but those in the second group must be designed to be highly flexible. At another extreme, we may see that a particular induction event is so wide-reaching, and the developmental consequences so severe, that it is worth dedicating specialized project components to buffer against events of that sort.

The use of this digital epigenetic diagram parallels developmental biologists’ use of so-called fate maps to speculatively describe complex interactions among morphogenetic mechanisms over time (Figure 7). Ultimately, the hope is to identify effective techniques
for pluripotency and resilience in the resulting design work, such as redundancy, buffering, adjustability, hybridity, etc. The ability to qualify volatile, overlapping, perhaps even counteracting, influences through the use of an epigenetic digital model greatly simplifies the task of defining project scope and resilient methods as the design unfolds.

Epigenesis by Waddington’s definition entails the emergence of new structures within a developing organism over time. While this can serve as a reasonable description of virtually any architectural design process, it may be far more useful to apply Waddington’s illustrative landscape model to changes that occur to architecture already constructed, or the pressures brought to bear by inhabitation. In other words, instead of using the ‘birth’ of a developed embryo as an analogy for completed design work, the form-giving events that occur throughout embryogenesis in this case parallel the conditional pressures brought to bear on built artifacts throughout their lifespan.

3 Pluripotency
With a capacity to sustain a similar fluidity of differentiation afforded by organisms in early development, we can imagine an architecture for which differentiation might occur over time, and which might be better able to absorb volatility. This was the promise of many megastructural projects of the 1960s for example: arrays of components could be deployed in virtually any context, organized to suit, and dismantled or re-organized as that context required it. Design the components and connection systems carefully enough, the logic went, and infinite flexibility would be the result (Figure 8). Pluripotency, as a concept at least, refers a similar open-ended adaptability updated to today’s post-industrial methods.

It is worth noting that in biological systems pluripotency is not unlimited. In contrast to the re-configurable megastructure kit-of-parts, during embryogenesis cells by definition begin to lose their adaptability once the irreversible process of differentiation has begun. The critical difference is that pluripotency terminates in adaptive exhaustion (when the capacity for further differentiation has been reached) as opposed to the obsolescence that plagues a prescriptive, kit-of-parts method. Both methods ‘fail’ in the sense that they can no longer adapt to changing conditions. Despite this irreversibility and eventual developmental termination, though, organisms may still sustain significant shifts in their development. As a way of explaining these shifting mechanisms, let’s look at a specific example applied to architecture.

4 The loft reclamation project
We have relied heavily on developmental biological models for an ongoing project to bolster the adaptability of pre-existing and increasingly ubiquitous developer loft condominiums, a housing type poorly-suited to adaptation despite its ad-hoc, industrial-conversion heritage (Figure 9). The objective is to develop supplementary mechanisms that restore the loft’s adaptability and counteract obsolescence. The first part of this project, as described above, entails digital epigenetic modeling of the induction events that pressure
housing supply and demand locally. These multi-dimensional digital models support scenario-planning exercises with the client group, in this case a condominium board.

The second part of the project is a resilient system of pluripotent architectural ‘organisms,’ upgrade kits that we’ve named habitacles (translated as “passenger compartment” or “cockpit”) to be installed in and around the lofts themselves. These consist of a combination of inert and pluripotent ‘organizer’ components, together forming a generic stick-and-waffle array of framework, cellular filler, and cladding. The habitacle is installed in an early development state, serving essentially as primitive storage furniture, waiting to be induced by events that pressure housing supply/demand and favor adaptation. Once induced, these organizer components differentiate in response to these new demands, a change that is manifested as a literal, physical modification of existing components or even the addition of new ones (Figure 10).

Over time, these generic arrays would become increasingly heterogeneous, the result of many induction events. They would also become more functionally specific, “growing” elevated floor area in response to greater space demands, decreasing the porosity of screening in order to afford greater privacy, etc. In a bust scenario with additional housing density pressures, a habitacle might have to differentiate to accommodate a family of six in an expanded mezzanine, opposed to the childless couple for which most lofts are designed (Figure 11). Some of these sub-components are physically adaptable, using adjustable slip-connections for example; others are shifted and re-oriented, while others are sacrificial, literally removed and replaced.

4.1 IN SITU DIFFERENTIATION

As we have seen, in natural biological development external morphogen gradients usually do create a prescribed system in which specific cells will always develop in largely the same way given the same conditions in the morphogenetic field. Yet development can also sustain extreme shifts. Some cells called organizers actually produce morphogens; once induced, the organizers initiate their own set of induction events applied to surrounding cells irrespective of the context. A series of remarkable experiments have shown that by intervening and physically shifting organizer cells from one region of the developing embryo to another, these cells both carry aspects of their original characteristics and assume new characteristics derived from the new location (Figures 12 & 13). Entirely novel structures then emerge. Developmental biologist Lewis Wolpert conducted a famous experiment in which organizer cells from one side of a developing chick’s wing were extracted from the embryo and positioned on the other side of the wing. The result was that a second, branching limb developed, but in a mirrored orientation relative to the first. As illustration, Wolpert proposed a “French flag” analogy, in which cells developed a certain flag color (blue, white, or red) based on the particular gradient concentration at their location. American flag cells grafted into a French flag organism might develop as stars, but would take on the color specified by their location, as would their neighbors (Wolpert, 1991).
While in nature this interference might result in a non-functional “mutant” organism, the ability to shift differentiation in novel directions has important implications for catastrophic, far-from-equilibrium conditions. Hydra organisms, for example, use such portable organizer/budding mechanisms to allow limb regeneration in the event of injury, prompted by a very simple set of instructions (“Make two opposing poles.” “Split into two branches” (Figure 14).

We have applied this portable regenerative mechanism somewhat literally to the in situ differentiation of the habitacles’ stick-and-waffle composition. Certain function-specific parts, such as connection elements, can theoretically be removed from their original location and re-located to another region of the habitacle to support a different structural configuration. Unlike a simple swapping of cross-compatible parts, as in the megastructure example, in this instance the cellular components adjacent to the connector must be altered or replaced in order to facilitate the new function. In other words, what the connector lacks in unmodified swappability, it gains in location-specific customization (Figure 15).

In order to complete these shifts successfully, we employ parametric expressions to calculate the effect on the surrounding regions of the habitacle. Like Wolpert’s wing experiment, the orientation of the organizer is critical (in what direction are components shifted?), as is the sensitivity of the surrounding material (how many cells are affected? How much can any given cell shift?). Since these variables will affect future adaptability, making decisions about how this shift should be enacted involves some informed guesswork. This is precisely the sort of problem where the scenario-planning exercises of the digital epigenetic models become invaluable: what sort of differentiation do the current contextual or conditional pressures warrant and what are the implications for future events?

5 Delaying optimization

Through this process, the habitacle becomes a manifestation of the circumstances that lead to its differentiation, a mapping of events related to housing density, boom/bust cycles, etc. Compared with scripted or parametric modeling techniques, which result in differentiation enacted through tightly regulated design processes, the adaptive techniques described here result in a collection of opportunistic modifications that accumulate over time. The delay involved in this methodological shift is of course significant: the morphogenetic process has not yet begun when the pluripotent object is first installed, the point at which a typical architectural design process would be complete.

The potential resilience offered by mimetic study of biological development and a judicious application of pluripotency requires a bit of restraint on our part as architects. Forecasting possible scenarios together with the developmental outcomes of pluripotent work can tell us a great deal about the shortcomings of differentiation, customization, and optimization. However, resisting our impulse to develop and differentiate complex projects when such sophisticated digital tools are available to us is easier said than done, especially when a client must be convinced that a primitive, generic and pluripotent short-term solution has the greatest long-term advantages. Paradoxically, it is the ability of digital tools to help us identify the limits of complex differentiated design work that offers the greatest resilience in the face of uncertainty.

6 References