N. Gu, S. Watanabe, H. Erhan, M. Hank Haeusler, W. Huang, R. Sosa (eds.), *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2014,* 873–882. © 2014, The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong

"FORMATIVE IMPULSE": A THEORETICAL OUTLINE FOR THE STUDY OF GOETHEAN MORPHOLOGY USING COMPUTATION

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Abstract. In this paper a theoretical and computational framework for a contemporary study of morphogenesis will be presented using a pulsation model. This study will revisit some of the valuable historical ideas on form developed by Goethe in the late eighteenth century. This investigation will be developed in three main parts. In the first part a brief outline of Goethe's scientific methodology will be described positioning his achievements against the epistemology of Kant. In the second part Goethe's main works on morphology will be presented with a focus on his botanical writings. Using a fragment titled "Formative Impulse" some of Goethe's ideas on polar tendencies and metamorphosis will be used for a computational framework in the final part. By bridging among history, theory and technology the paper aims to present a novel approach to the study of computational form and growth in architecture.

Keywords. Goethe; morphogenesis; pulse; computation.

1. Introduction

Recent developments in computational architecture have shown an interest in digital morphogenesis as a way to study form through generative algorithms and dynamic programming techniques (Hensel et.al. 2004). Some of these techniques provide direct input to foster predetermined isomorphic results, while others use growth mechanisms to generate a hierarchy of parts without having much control of the overall structure. Nevertheless, there is still lack of theoretical development that can provide a viable study of form and growth. In this paper a novel framework for a contemporary study of form will be introduced following the ideas of German polymath Johann W. von Goethe (1749-1832). In his botanical works Goethe provides a generative notion of form based on dynamic and intrinsic principles. This considers form as an expression of inner forces that guide the epigenetic development of an organism. Using Goethe's thoughts on form as a theoretical foundation the paper will provide a prototypical computation model to facilitate the study of morphology using digital tools. The goal is to instrumentalize Goethe's valuable ideas on form for architectural morphogenesis.

2. Enlightenment crisis: Preformation vs. Epigenesis

Prior to the Enlightenment biology there was an intense disagreement on the origin of organization for natural forms. In her book *Matter, Life and Generation*, Shirley A. Roe writes about the conflicting ideas on the source of organization and form in nature, drawing on the tension between the preformationists and epigenesists (Roe, 1981). While the former suggests the final form of an organism to exist in a miniature form in the egg or spermatozoon, epigenesis states that form is not a pre-given or fixed entity but a product of gradual development of unorganized matter (Roe, 1981). A different explanation came when Johann Blumenbach (1752-1840) provided a view of embryological development that had an inherent organization which he called *Bildungstrieb* [Formative Drive] (Richards, 2002). This concept was responsible for generation, transportation of nourishment and restoration of parts that controlled the formation processes and maintenance of the organism.

2.1. KANTIAN DICHOTOMY: ANALYTIC VS. SYNTHETIC

During Enlightenment period Immanuel Kant (1724-1804) established a philosophical framework for the advancement of biological sciences. In his *Critique of Judgment* (1790) Kant aimed at giving a teleological cause for the production of natural forms favouring mechanistic laws to explain their formation (Kant, 1957). After reviewing Blumenbach's concept of *Bildungstrieb* [Formative Drive] he developed ideas on organic forms. He maintained that organisms had archetypes [*Urbilde*] that could only be understood as crafted products of an intellectual being - "intellectus archetypus" (Kant, 1957). This assessment explained the nature of biological processes by assuming a teleological causality prior to generation. Otherwise there needs to be a source of organization to explain the transition from the inorganic to organic products in nature. In this respect he maintained an in between position between epigenesis and preformation, re-interpreting Blumenbach's *Bildungstrieb* to state that only pre-organization could yield to material organization (Richards, 2002).

Kant also presented two types of judgments for the study of natural sciences which were reflective (subjective) and determinative (objective) judgments (Kant, 1957). While the former derived the whole from an analytic study of parts, the latter operated through synthesis where the scientist observed the whole to intuitively derive its parts. Embracing Newton's mechanistic formulations, Kant only bestowed the analytic method for scientific investigation as it acted as a regulative principle. Kant boldly stated that there it is irrational "to hope that another Newton will arise in the future, who shall make comprehensible by us the production of a blade of grass according to natural laws which no design has ordered" (Kant, 1790). He claimed that biology could not become a proper science since the teleological cause could not be explained through mechanistic laws (Richards, 2002). Other successive biologists and scientists in the period, including Goethe, thought otherwise.

3. Goethean Science

Johann W. Von Goethe (1749-1832) is mostly considered as a poetic genius of the Enlightenment, however he extensively wrote on natural sciences focusing mostly on botany and osteology. He tried to consolidate the ontogenetic debate among preformationists and epigenesists in his *Metamorphosis of Plants.* In this work he presented "the leaf" [*Urpflanze*] as a generative principle that goes under metamorphosis to produce all plant organs during growth (Goethe, 1993). This archetype not only considers all plant forms to be generated through the same intrinsic rules, but also explains how variations of types could be achieved under changing external conditions. Goethe saw such concept as a universal law that combined internal and external conditions for production of structural forms and variations in nature.

3.1. GOETHE'S CHANGING KANTIANISM

During his study on nature philosophy Goethe shows changing views on Kant's philosophical development. Initially, he was deeply influenced by Kant's derivation of common types and considered Kantian method of thinking analogous to his own. However he considered the distinction between analytic and synthetic methods of scientific investigation to be problematic. In a short fragment titled "The Influence of Modern Philosophy" Goethe considered nature to follow "an analytic course – development out of a living, mysterious whole- but then seems to act synthetically in bringing together apparently alien circumstances and joining them into one" (Goethe, 1988). In reading Kantian philosophy Goethe declared that he either does not agree with Kant's way of thinking, or he always finds something to be missing. In

"Analysis and Synthesis" he advises scientists to prefer a dual approach, namely a balance of analysis and synthesis during scientific research (Goethe, 1988). In this regard he condemns Newton's approach, which follows only analysis, but lacking synthesis. Although scientific investigation often progresses with such analytic approach, Goethe claims this methodology to be error-prone. While he supports the idea of collecting empirical evidence through analysis, he also favours synthesis as a way to validate the conformity of individual facts with an overall "idea. " This type of judgment would be determinative in Kantian framework that would essentially link all natural products through an intuitive perception (Richards, 2006). Such a dynamic approach becomes the core of Goethe's scientific studies.

4. Goethean Morphology

A guide to how Goethe studied nature's epigenetic notion of form could be traced in a short fragment he wrote called "The Formative Impulse" (Goethe, 1988). In this text, Goethe emphasizes how Blumenbach successfully converted formative forces as an "impulse" that can explain how organization and growth of an organism occurs during development. Since preformation fails to explain how all the changes during development could occur, a predeterminative or stabilizing concept needs to be present within the organism to guide formation (Goethe, 1988). Such an action regards forces to coexist with the underlying material. This way the forces guide the formation processes by controlling the transportation of nutrients that control growth and maintenance of the organism. Thus, the "formative impulse" offers a synthesis of epigenesis and preformation by considering the latter as not predetermining development from the beginning but acting as a stabilizing principle throughout growth working within the concept of metamorphosis.

4.1. METAMORPHOSIS

In *Metamorhosis of Plants* Goethe provides an epigenetic explanation for how plant forms grow "by the modification of one single organ", or "the leaf" [Urpflanze] (Goethe, 1790). Starting from the cotyledons, "the leaf" progressively forms different parts of the plant through the alternating forces of expansion and contraction. In order to explain such progressive development in annual plants, Goethe looks at retrogressive instances of growth. This type of metamorphosis causes some parts of the plant to appear in "an indefinite and soft state" as they show atypical transformations due to the influx of nourishment (Goethe, 1790). Goethe draws further emphasis on the central role of such vital impulses acting on individual leaves. For instance the formation of the calyx occurs through the anastomosis of multiple leaves joined around a single centre due to the contracting effects of juices. Such modifications occur through the activity of two driving tendencies within the plant which are vertical and spiralling tendencies. While the vertical tendency "enables the plant to take root" as it "forces itself upward, or in some other direction," the spiral tendency acts as the "nourishing system" that is "relegated to the periphery of plant growth" (Goethe, 1989). Although the two polar tendencies define the primary intrinsic activity of a plant, Goethe also considers extrinsic factors having influence on growth. He states that the leaves are mainly differentiated through the influx of nourishment but "for their increased perfection and refinement they are indebted to the light and air" (Goethe, 1989). While the internal forces act together to control the distribution of veins and fluid among plant organs, their activity becomes regulated with external factors. As a result, the plant's overall morphology becomes a dynamic interplay between its internal polarities and external conditions that are present during growth.

4.2. FORM AND GROWTH

In *Form and Transformation*, Garry Webster and Brian Goodwin consider Goethean "concept of a 'type' or kind" to describe "the concept of a 'law' in terms of which all the variants of that kind can be intelligibly connected" (Webster et al., 1996). Such a concept relates metamorphosis of parts to both differentiation and modulation of reciprocal activity resulting in coordinated spatial and temporal patterns of development. This morphogenetic field becomes "a dialectic between rational systematics and explanatory theory of morphogenesis" that "could be extended to relations between parts of an organism as Goethe anticipated" (Webster et al., 1996). As parts acquire changing behaviour during growth, they guide the pattern of development internally. In this sense, Goethe's notion of metamorphosis and impulse could be considered complimentary to the inherent laws of morphogenetic fields. While the former could explain how parts transform, the latter provides an inherent and consistent principle that regulates patterned growth.

5. Computational Morphology

Goethe's ideas on metamorphosis and impulses could provide a valuable and productive model for their study in computational architecture. This notion of digital morphogenesis offers a dynamic understanding of form that can have analogous relations to the process of growth and development in nature (Roudavski, 2009). In morphogenesis, overall form and parts are not pregiven or fixed but are developed over time following intrinsic principles under the influence of extrinsic circumstances. This aspect of digital morphogenesis could provide immanent characteristics of form such as self-organization and generation (Hensel et al., 2004). Since organization is established following immanent laws or principles, this places computation as a viable tool to test the applicability and potentials of the system. However in order to instrumentalize Goethean morphological concepts it becomes necessary to develop a Goethean notion of computing. This could be considered as a dynamic framework that can test the theoretical development within a set of computational experiments (Menges, 2007). This is why Goethe's theoretical work on plant morphology becomes important in our research. Using his fruitful ideas as a foundation it is possible to construct a methodological and computational framework. This places form as a product of forces that can be acquired through the internal structuring of parts and their interaction with the environment. Such a computational tool could provide a deeper understanding for both a study of Goethean morphology and its implication on architectural morphogenesis.

5.1. IMPULSE AND FORM

In this section we will be considering a computational methodology to further investigate and experiment with Goethean notion of metamorphosis and impulse. Using Processing we have created an object-oriented program to simulate how impulse could be carried through cell to cell networks to produce material outcomes. We are using an impulse model that was proposed earlier for signal propagation along branching pathways (Motoike et.al, 2010). In this paper the model is not based on cellular automata but on circular cells (leaves) that facilitate growth through internal polarities. The computational implementation allows a dynamic notion of cell reproduction, cell state (metamorphosis) and cell polarity using two kinds of impulses that propagate throughout the system.

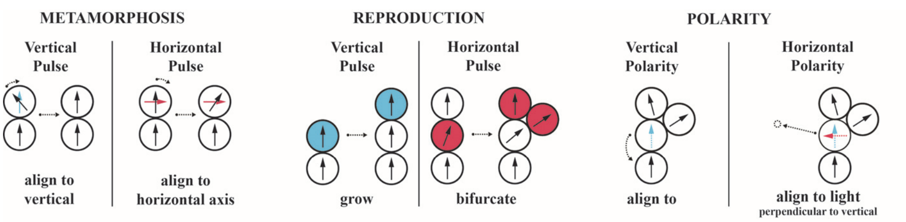

Figure 1. Diagrams showing the rules for pulsing algorithm, black arrows indicate cell polarity, blue arrows show vertical axis, red arrows shows horizontal axis.

Following Goethe's descriptions of vertical and spiral tendencies, the impulse model is constructed along two perpendicular axis that control cell polarity. Among these tendencies, Goethe defines spiralling forces as "entwining itself around the vertical" and being "temporary and almost independent of the vertical" (Goethe, 1989). To achieve similar effect in our two dimensional simulation model we have defined the spiralling tendency and spiralling pulse as acting horizontal. While the vertical pulse directs polarity using cell's nutrient supplier, the spiralling (horizontal) pulse acts perpendicular to the vertical aligning polarity towards light sources (Figure 1). This way when a cell receives a horizontal impulse, its polarity is rotated to facilitate lateral bifurcation. In order to focus our attention to the study of impulses within the system, we have created a uniform distribution of light sources for all test cases in our simulations. During simulation growing cells are marked using their proximity to the light sources to determine their horizontal axis of growth. When a growing cell receives a horizontal pulse it rotates its polarity toward light to allow bifurcation (Figure 1). This allows a dynamic space colonization of growing forms (Runions et al., 2007). Light sources are removed from the simulation when they are reached by growing buds.

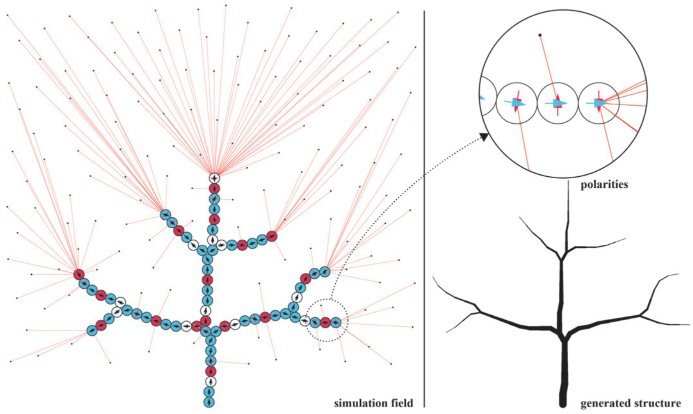

Figure 2. Left: Image from simulation showing pulse and proximity to light sources. Blue: Vertical pulse, Red: Horizontal Pulse, Black Arrow: Cell Polarity, Red Arrow: Horizontal Polarity, Blue Arrow: Vertical Polarity

5.2. SIMULATION OF IMPULSE

Using this model we have made numerous simulations to test how both types of impulses could work in a patterned fashion. The impulses are sent individually through the simulation from an initial seed cell. When a cell receives an impulse it updates its current polarity for reproduction, and transmits the pulse to its neighbours (Figure 2). A cell can reproduce when it has enough nourishment, light proximity and no existing neighbours along its active polarity. Both vertical and horizontal impulses contribute for the nourishment and reproduction. These rules consider each cell to be an independent part of the system and device local changes for the manipulation and propagation of the impulses in patterned growth (Figure 3). Since cell polarities are constantly updated the morphogenetic field provides a dynamic understanding of how metamorphosis could act throughout development.

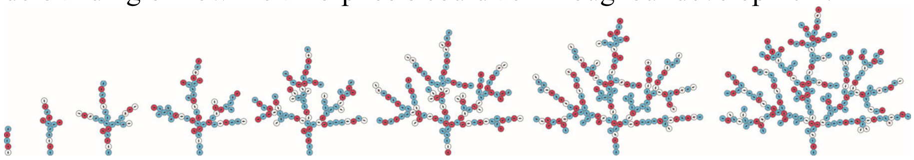

Figure 3. Snapshots from the simulation showing stages of growth and propagation of pulses.

The pulsation model offers various parameters to control the production of different structures such as pulse patterns, rotation values for pulses and nutrition amounts (Figure 4). The pulse patterns are input as an eight digit number with different values of vertical pulse (0) and horizontal pulse (1). This pattern is repeated throughout the simulation. The rotation values indicate how much cell polarity is tilted when the cell receives a corresponding impulse. The nutrition amounts define the amount of reproductive juices carried to each cell for reproduction and thickening of structure. When the cell reaches its own nutrition limit it is allowed to bifurcate. Our experiment results show that rotation values and nutrition amounts produce more bifurcation when horizontal pulse is greater than vertical. Similar results could be observed by changing the frequency of pulses. For instance, when more horizontal pulses are sent throughout the system, the structure bifurcates more, creating a tendency for lateral growth. Similarly more vertical pulses tend to create more elongation along branching pathways. Different combinations of pulse patterns and values create diverse morphologies from vertical (no bifurcation), to horizontal zigzagging structures (Figure 4).

5. Discussion and Future Work

The pulsation model offers a viable avenue for future research considering cell polarity and pulse propagation as driving agents of morphogenesis. Our results indicate that form could be considered as a direct imprint of the polarity of forces that gives each unique output a diagrammatic character. This model supports how Goethe envisioned growth in plant morphogenesis as an expression of vertical and spiralling (horizontal) forces that can be studied by combining analytic and synthetic methods.

The computational model presented in this paper is still a work in progress. The current implementation supports various input impulses and parameters as a way to control growth mechanisms that have direct effects on the outcome of the patterned structure. To observe a balanced growth alternating pulses have to be sent throughout the system. The frequency of pulses controls topological changes that can also be observed in final structural outcome (Figure 4). Our future work is to fully experiment and adjust the pulse model to accommodate more dynamic interaction among cells and produce comparable results. These investigations could answer various research questions on form, such as the correlation between internal and external forces on growth and the effects of nutrition and polarity.

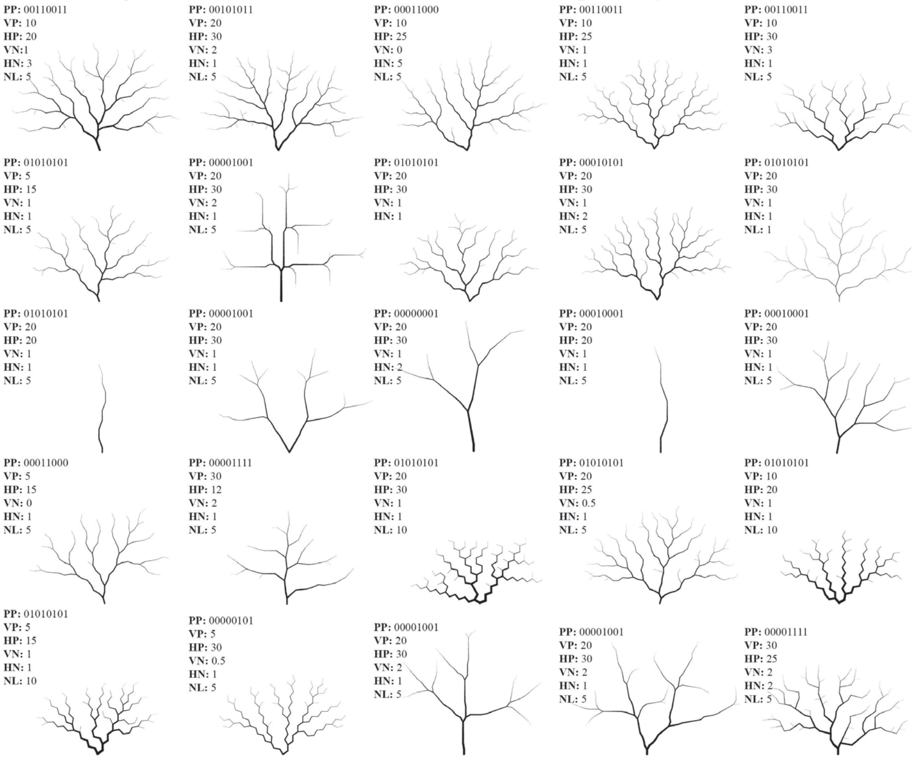

Figure 4. Generated forms using the pulsing algorithm. (PP: Pulse Pattern, VP: Vertical Pulse Rotation; HP: Horizontal Pulse Rotation; VN: Nutrition transported by vertical pulse; HN: Nutrition transported by horizontal pulse; NL: Nutrition limit for reproduction).

6. Conclusion

In this paper a theoretical and computational model for the study of Goethean morphology is presented. In the theoretical section Goethe's work on plant morphogenesis and scientific methodology is compared to the ontogenetic debate on the origin of development during Romanticism era. Although Goethe was influenced by Kantian philosophy he supported an epigenetic notion of form. Using impulse and metamorphosis he explained how morphology was guided by intrinsic and dynamic principles in nature.

Goethe's notion of form and metamorphosis could be studied devising generative simulations based on simple rules. This computational model considers pulsation and cell polarity as intrinsic parameters of a self-organizing system. This approach supports Goethe's ideas on plant morphology and metamorphosis which could lead to a valid framework for the study of growth and form.

The simulations show that generative forms could also be achieved by not giving parametric properties to the overall system but to the parts that have the ability to interact and guide morphogenesis. Such computational model presents a new type of analytic-synthetic study of form. This way the input parameters and activity could be observed in the outcome as a diagrammatic imprint. Such a model could produce a new dialectic for generation and provide a viable productive framework for the study of computational morphogenesis in architecture.

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