

REDISCOVERING GOETHE'S CONCEPT OF POLARITY: A NEW DIRECTION FOR ARCHITECTURAL MORPHOGENESIS (1)

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1. This paper is a brief summary of a Ph.D. dissertation on Goethean morphology and architecture (Gokmen, 2017).

INTRODUCTION

In the recent past, architecture has undergone a rapid change in its theoretical and practical discourse with the advent of technology and the introduction of emerging concepts from other domains, particularly natural sciences and biology. Digital technologies have primarily effected the way architects produced designs, by initially opening up a new repertoire of novel forms and later introducing algorithms and intelligent processes that provide dynamic behaviour and outputs. An emerging field in this domain is "architectural morphogenesis" that offers a bridge between natural and artificial processes combining performative, material and generative systems to develop computational perspectives towards design (Kolarevic, 2004; Leach, 2009; Menges, 2007). This new paradigm has shifted the use of computation in architecture from a merely modelling or visualization tool to the medium of processes or scripts that are capable of executing generative rules that produce emergent and self-organizing behaviour. To develop a theoretical background, these approaches have been supplemented with borrowed concepts from natural morphogenesis, particularly from cellular studies in biology to generate research on the formal analysis, classification, comparison and performance of various building types (Steadman, 2008; Roudavski, 2009; Hensel, 2010). With the ongoing influx of interdisciplinary knowledge into design, the theoretical and historical foundation of architecture has been undergoing a major shift that requires a reevaluation. To provide an alternative theoretical perspective to morphogenesis, this article will look into a historical theory-laden approach to form by revitalizing one of Goethe's key ideas. Polarity, a dynamic term that pervades Goethe's main body of work (Tantillo, 2002) will be explored by primarily revisiting its formulation in botany to speculate a new way of comparing and studying building forms. As a theoretical outline, this new reading of Goethe could provide a new perspective to the study of both natural and artificial morphogenesis while

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developing a novel link between biology, architecture and computation (Gokmen, 2017).

MORPHOGENESIS

The term morphogenesis primarily represents the developmental process of organic growth found in nature that combines distributive, transformative, differentiative and evolutionary relationships among parts of an organism. It is a combination of two words originating in Greek: *morphê* meaning the form of an organism such as an animal or plant, and *genesis* the origin or process of dynamic transformation (Roudavski, 2009). In biology, this hybrid term is primarily used in explicating developmental mechanisms found in embryogenetic processes concerning how the form of an organism unfolds from simple to complex shapes and acquires a much-articulated organization. While the pursuit of revealing these mechanisms originates from the ontogenetic debate in the early nineteenth century (Roe, 1981), in the early twentieth century with pioneering work of biologists, morphogenetic research took on a more quantifiable approach combining multiple fields that can reveal inner dynamics of organisms. An early account of morphogenesis is found in D'Arcy Thompson's seminal book *On Growth and Form*, where he outlines a mathematical and physical framework for the study of structure, patterned development and symmetry mechanisms in organic forms "as a material and mechanical configuration" of formative forces of nature (Thompson, 1992, 14). Building on this foundation, recent investigations in biology introduce new terms towards understanding growth through the dynamic activity of networks, interactions and genetic expressions between cells. These "morphogenetic field(s)" consider organisms as robust dynamic systems that are influenced by genes or environment that "determine parametric values in the equations which describe the structure of the field" (Webster and Goodwin, 1996, 99). Recent developments on evo-devo (evolutionary developmental biology) offer a detailed look into the interconnectedness between homeobox genes and patterned development of organisms that show remarkable similarities among different species (Carroll, 2005). With all these accumulating discoveries, morphogenesis is emerging as a theoretical and computational field that is concerned primarily with the material qualities of an organism offering novel formulations for the study of form in nature.

In architecture, the term morphogenesis employs a large repertoire of digital operations that provide speculative and generative methods in design, combining computational geometry, mathematics, material performance, fabrication strategies and algorithms (Kolarevic, 2004). While early developments in computational architecture feature topological modelling or animation that require direct input by designers, current advancements showcase generative algorithms that can simulate self-organizing behaviour to achieve optimal design solutions. Due to their dynamic nature, this type of architectural applications has been directly influenced by biological sciences where emergent behaviour between multi-agent systems can yield to stabilized outcomes, a process-oriented approach that is often defined as form-finding. Leach (2009) argues that the introduction of the term morphogenesis into architecture, as a natural process-oriented methodology or computational approach, has caused a shift in terms of design thinking where top-down approaches are replaced by bottom-up processes and emphasis is given to "material performance

over appearance, and on processes over-representation". Menges (2007) also highlights this distinction by defining two types of morphogenesis, where the "digital" approach is referred to as a "cliché" because it reduces generative capacities of technology to modelling techniques that are evasive towards material or constructional principles of architecture whereas the "computational" is able to "encode logic, structure and behaviour as well as the underlying principles of natural morphogenesis". When natural processes are embedded in digital morphogenesis, formation and materialization overlap where internal crystallization of a dynamic structure is related to programmable performative material capacity and activity. This system enables various environmental input or data-driven protocols, simulating a process akin to natural growth to define architecture through self-organizing systems.

Since the 1980s introduction of computational tools has caused a stream of influence on the critical and practical reception of the architecture that resulted in a greater emphasis on the utility of technology and material behaviour. DeLanda (2004) calls this development as the 'New Materialism' that replaced early form-giving approaches such as topological modelling and morphing with emergent artificial algorithms where "morphogenetic potential is best expressed, not by the simple and uniform behaviour of materials, but by their complex and variable behaviour". This defines a new paradigm shift in an architectural discourse where interdisciplinary methods combining science and technology are emerging and replacing historical theoretical views of architecture where architects are not only developing new design tools but also tools to think about design and research (Carpo, 2017). To fill this gap, biology has become a major source of inspiration and resource for morphogenetic research in architecture. By drawing links between natural and computational processes, Roudavski (2009) shows that complex and flexible systems that are capable of self-organization, as in the case of cellular morphogenesis found in plant biology, could suggest new procedural and generative applications for architectural form-finding. Under the term biomimetics, architects have started transferring acquired knowledge and techniques from natural processes towards developing generative strategies for structural and performative design iterations. As these dynamic approaches are becoming more widespread, new digital techniques that utilize time-based simulations, morphing tools and parametric systems are being introduced into generative studies of form. Yet, there seems to remain a large theoretical gap between the developments of natural sciences and humanities, where reconciliation between digital and natural morphogenesis is required for an organic formulation of architecture. Addressing this problem requires a fresher look into the historical development of morphogenesis which can potentially offer a viable alternative formulation for architecture.. To develop this perspective in the following parts, morphology – a science originating from early 19th century will be presented through Goethe's works, who develops polarity as a common principle applicable towards multiple fields of study. Using Goethe's writings on natural sciences and art, the following sections will argue for a novel techno-historic formulation of morphogenesis while developing links between polarity, form and growth.

GOETHEAN MORPHOLOGY

Prior to the modern formulation of morphogenesis, during the eighteenth century, biological sciences were being shaped around ideas speculating on the source of organization for early development of organisms (Roe, 1981). A central figure during this time is Johann Wolfgang von Goethe (1749–1832) who applies similar concepts and methodology towards the study of natural sciences in an attempt to develop a cumulative theory of organic forms (Richards, 2002). Goethe's definition of the term morphology, in late eighteenth century marks the emergence of a new science that concerns itself with the structure and form of organic bodies while offering theoretical perspectives to the formulation of generative organic types (Goethe, 1988; Webster and Goodwin, 1996; Richards, 2002). As a sub-discipline in service of biology, morphology offers novel theoretical formulations and concepts dealing primarily with form and growth mechanisms found in organic forms. As a theory-laden science, morphology combines generative archetypes and the development of organisms using the concept of metamorphosis as a core principle. In *The Purpose Set Forth*, Goethe outlines this approach by comparing *Gestalt* (structured form), which excludes "what is changeable and assume(s) that an interrelated whole is identified, defined, and fixed in character" to *Bildung* (formation) which describes "the end product and what is in process of production (Goethe, 1988, 63; Brady, 1998). For morphology, he reduces the use of *Gestalt* only towards the formulation of the archetypes or temporarily fixed stages, while *Bildung* finds its expression in the epigenetic process where metamorphosis is directed towards understanding the relationships among parts of an organism. But, rather than focusing on the continuous flux of changing forms, Goethe draws attention to the study of parts within a whole through a duality, which manifests antagonistic proximal relationships to produce either similar or dissimilar forms as an expression of dynamic formation. This is achieved by formulating and applying polar principles towards the study of form, structure and development of organisms.

The overall aim of morphology is to offer a unified field of study for natural forms that can potentially bridge between arts and sciences while offering an alternative theoretical perspective to other fields. To achieve this, the foundation of morphology is supplied by developments of other subsidiary sciences such as taxonomy that recognizes consistency among different specimens to study the relations of external characteristics; and anatomy, focusing on the inner structure of forms (Goethe, 1988). As a theoretical approach to the study of nature, morphology seeks the origin of self-organization in nature, speculating whether it is a property external to matter bestowed by divine power or something inherent to matter itself (Roe, 1981). Furthermore, the true purpose of morphology is to consolidate Goethe's discoveries throughout his life where his observations, experiments, and assessment on natural phenomena present similar ideas among different scientific branches, particularly on botany, meteorology, geology, osteology and colour. For instance, Goethe's early descriptions on the presence of intermaxillary bone (*Zwischenkiefer*) in humans dates back to 1784 (Goethe, 1988); his book on the development of plants occurs in 1795 as *Metamorphosis of Plants* (Goethe, 1989); and he also compiles his experiments on colour in *Theory of Colors* in 1809 (Goethe, 1971). In order to examine the material aspects of life sciences, Goethe describes polar magnetic forces that transform generative archetypes under epigenetic processes (Tantillo, 2002). This formulation remains

consistent throughout his works, where colour becomes observed through interactions of light and dark surfaces (Goethe, 1971, 33), bones in anatomy are described through their polar relationships such as the tibia and fibula bones in legs (Goethe, 1988, 127) and growth mechanisms of flowering plants are described through antagonistic formal manifestations of organs (Goethe, 1989). As a scientific study of natural sciences, morphology can be redefined as a precursor to the modern formulation of morphogenesis, where form, transformation and growth is studied through dualisms to define the physiological activities of generative archetypes.

Goethe's Concept of Metamorphosis

One of Goethe's core ideas for the foundation of morphology is the concept of metamorphosis that shows an application of polar terms towards understanding growth mechanisms and formal expressions in nature. This dynamic idea is primarily presented in Goethe's work on botany. In *Metamorphosis of Plants*, he presents his hypothesis on natural morphogenesis where nature creates variation and progressive development by modifying leaves using polar forces of development (Goethe, 1989, 31). Developed from the observations on annual plants, metamorphosis presents two polar forces as the driving mechanism for dynamic formal expression and variability of natural growth. In the essay, this activity is narrated using observations during the growth of an annual plant that produces three alternating stages of expansive and contractive movements where growth is terminated into an offspring before the cycle is repeated (Goethe, 1989). Goethe describes growth like a rhythm, as the plant is continually pumping internal fluids and respectively filtering these juices, new parts are produced along the axis of the plant that establishes antagonistic relationships between organs. The justification for the presence of polar forces is obtained from the comparison of subsequent forms. For instance, Goethe compares contracted petals to expansive sepals, where the difference of size of the latter is related to the continuous filtering activity of the former. This renders polarity as an "internal and formalist" idea for morphology where expansion and contraction, as the two antagonistic principles of polarity, not only relate sequential parts of an organism to a whole but also establish a developmental rhythm for production of organic forms (Gould, 2002, 289).

Revisiting Goethe's writings to develop new theoretical ideas and analytical tools for morphology has presented many challenges to Goethean scholars who seek to find generative formulations of natural types and morphogenetic processes (Webster and Goodwin 1996; Reigner, 2013). Within this perspective, visualizing the concept of polarity through quantifiable methods poses both theoretical and practical problems. The core idea of polarity is that growth requires dual formative rhythms that are developmental, temporal and sequential where opposite formative movements yield to progressive differentiation of forms. To offer a computational perspective to morphology, a geometric study of leaf morphogenesis is proposed where polarity rules are defined and applied in terms of recursive algorithms. This is achieved by scripting polar terms of expansion and contraction into a parametric algorithm where mechanical rules of growth can generate a wide array of leaf forms (Gokmen, 2017). In this study, the left and right halves of a leaf are considered as complementary, thus considering the leaf archetype to be an axial, symmetric and geometric construct (Gardner, 1990, 20; Wely, 2005, 4). Starting from a single axis, a complex leaf form can be generated by

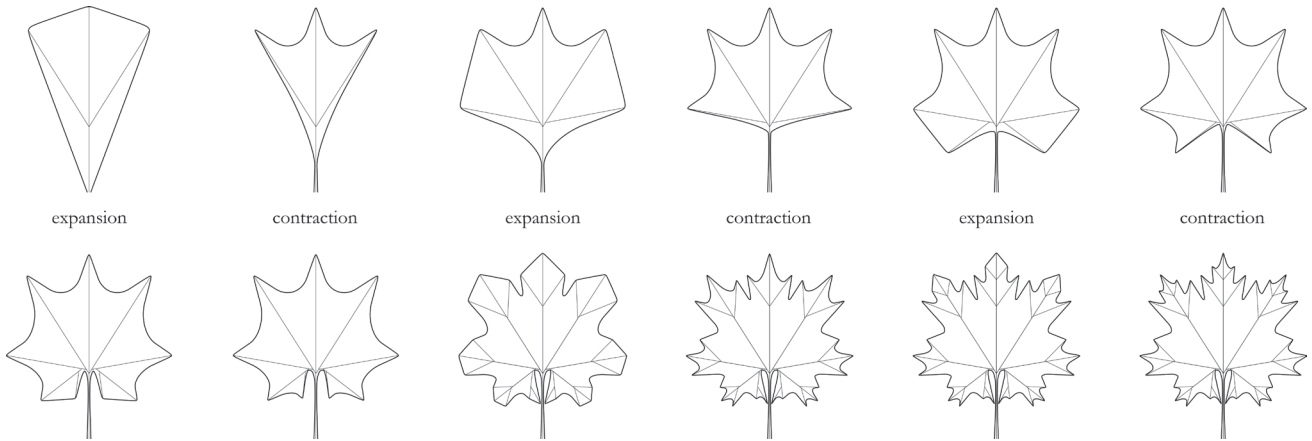


Figure 1. Metamorphic development of a maple leaf showing alternating geometric operations of expansion and contraction on an axial form.

applying expansive and contractive geometric operations in a sequential and variable manner that progressively differentiate form (**Figure 1**). In this example, the leaf form primarily develops along its physical boundary while metamorphosis is visualized through sequential steps ignoring scalar changes during growth, mimicking a process similar to morphing shapes (Kolarevic, 2004). During metamorphic computation, form topology is transformed by recursively breaking a linear outline simulating progressive development of a geometric fractal. In this sense, polarity behaves like a Koch curve, where expansion and contraction alternatively break a formal outline in opposite directions while increasing the amount of information on the form (Addison, 1997, 17). In the sequence, expansion enlarges form by moving outwards, while contraction collapses the boundary towards an antecedent centre. This parametric form-finding process combines organic growth where development occurs more gradually and computational metamorphosis where development occurs recursively as the activity of time is transferred to geometric steps and polarity operations are parametrically varied. This way Goethe's theoretical views to morphology can be investigated through algorithms where mathematical and physical laws of organics are studied to explicate and visualize growth and structure of form (Thompson, 1992, 14). As a theoretical and practical concept, polarity provides dual principles for recursive algorithms that can both explicate natural morphogenesis and provide insights to the study of geometry, topology and form.

POLARITY AND ARCHITECTURE

Historically architectural discourse presents a vast array of contrasting terms to establish and advance its own theoretical development. While polarity, as a generative and formalist term, has not found its place within architectural thought yet, it shows a close affinity to the historical and contemporary developments of architecture. Firstly, polarity shows kinship to symmetry and proportion by explicating dynamic relationships between parts and wholes. In his writings, Goethe considers "architecture as an art that develops structurally" where the architectural form is not studied through fixed types, forms, symmetries or proportions, but rather through processes of differentiation that mimics natural growth (Eck, 1994, 111). This aspect renders polarity as a generative term that is extendable to the historical development of organicism in architecture. Secondly, as a computational tool based on growth, polarity could be used towards

2. An early example of "Goethean" approach towards architecture was developed by Rudolf Steiner in the early 20th century that is not discussed in this text (Adams, 1992).

geometric and abstract studies of building forms from a morphogenetic and comparative perspective (Hensel et al., 2012; Roudavski, 2009; Kolarevic, 2004). This way, architectural forms can be studied through recursive algorithms to reveal structural and formal relationships between parts of buildings. While the historical – theoretical reevaluation of architecture questions the core principles and rules of architectural form by examining its organic relationships to nature, the computational studies relate architecture to biology in order to develop qualitative and quantitative computational tools that can redefine it as a "building science" (Steadman, 1983, 247). Although an early formulation of an architectural style influenced by Goethe's writings exists in early modernism (2) this article will instead offer a summary of the new theoretical and computational perspective to be pursued through polarity (Gökmen, 2017). To achieve this dual formulation, polarity is initially directed towards the analysis of historical building forms that display symmetry. Using these building forms, ideas of morphogenesis are explored where parts can be both compared using polar terms, as well as their morphologies can be generated through binary rules of formal development and differentiation. This way, digital morphogenesis will be related to morphology where Goethe's ideas on polarity can inform computational rules that can offer a robust study of architectural form and growth. As a case study, this part will first focus on Goethe's essays on Gothic architecture to extract an organic and aesthetic view of architecture prior to developing computational approaches for the extension of polar concepts towards the geometric study of architectural form.

Polarity and Organicism

One of the core aspects of an organic formulation of architecture is the application of natural principles and forms towards developing technical and philosophical models and methods to understand its operations. Within the historical development of architecture, the early theoretical essays that aim at establishing and transforming architecture's flexible principles show kinship to the historical development of natural sciences, particularly biology. In *Organicism in Nineteenth-century Architecture* Caroline van Eck (1994, 28) gives an extensive "reconstruction of the philosophical and theoretical origins of nineteenth-century organicism, and the analysis and clarification of its role as a strategy of invention and interpretation in the context of the search for style". Although organicism is often considered as a reaction towards the mechanical understanding of architecture that is more rational and functional, Eck opposes this trend and considers organicism as part of a historical continuum where the main tenet is that "architecture should imitate the purposive unity of living organisms" (Eck, 1994, 21). During the nineteenth century, with the advent of discoveries in biology, a new organic formulation of architecture is sought that borrows the laws of growth and form in living nature to establish structural and morphological principles to understand architectonics of built forms and works of art. As an influential figure working on aesthetics, Goethe contributes to this formulation with his morphological writings and essays on architecture while drawing links between them. In his writings, Goethe doesn't show any preference over a specific style of architecture but instead defines the possibility that "architecture can be considered from the perspective of formal development, and that architecture can share the autonomy of the living organism, despite its functional character" (Eck, 1994, 125). In this sense, morphology offers both a way to study natural processes and products

and a way to imitate and aestheticize nature's formative principles on man-made forms. This opens up the possibility to employ similar concepts and principles of growth towards the study of building forms that can be analyzed without resorting to a static system of rules or fixed types.

Compared to his writings on natural morphogenesis that present a scientific understanding of form and growth, Goethe's essays on architecture offer an aesthetic formulation for how architectural form should be observed, studied and analyzed. In a short essay published in 1773 titled *On German Architecture* he presents an admiration for Gothic style and shows almost a nationalist tone of defence against the architectural styles being practised in France and Italy during that time (Goethe, 1986, 5). In the text, Goethe not only criticizes the adjacent stylistic developments in Europe and their inclination to imitate ancient styles through monotonous repetition, but he also praises Edwin von Steinbach, the architect of Strasbourg Cathedral, who displays a fine example of this new style of architecture. As an organic system, Gothic architecture contrasts the classical system of columns with its formal development of walls that shows proliferative quality akin to plant growth.

"Your buildings present mere surfaces which, the further they extend and the bolder they soar to the sky, inevitably oppress the soul with ever more unbearable monotony. Fortunately, Genius came to our aid and inspired Erwin von Steinbach, saying: Diversify the immense wall raise it toward heaven so that it soars like a towering, wide-spreading tree of God. With its thousands of branches and millions of twigs and as many leaves as the sand by the sea, it shall proclaim to the land the glory of the Lord, its master" (Goethe, 1986, 5).

According to Goethe, Gothic architecture presents an inherent harmony and reciprocal relationship between parts of a building that resemble the organic growth of trees. With this naturalistic perspective, Goethe makes various comparisons between parts of the cathedral showing similarity to his morphological writings where he makes polar comparisons between parts of a plant. For instance, he compares and contrasts the main portal with two smaller entrances on its side, the rose window with the nave and the tower with its surrounding pinnacles (Goethe, 1986, 6). Contrary to the modern critiques of his time that believe fine arts to follow an anthropocentric origin, he considers the Gothic to display an autonomy like an organism where natural principles of growth are employed to produce

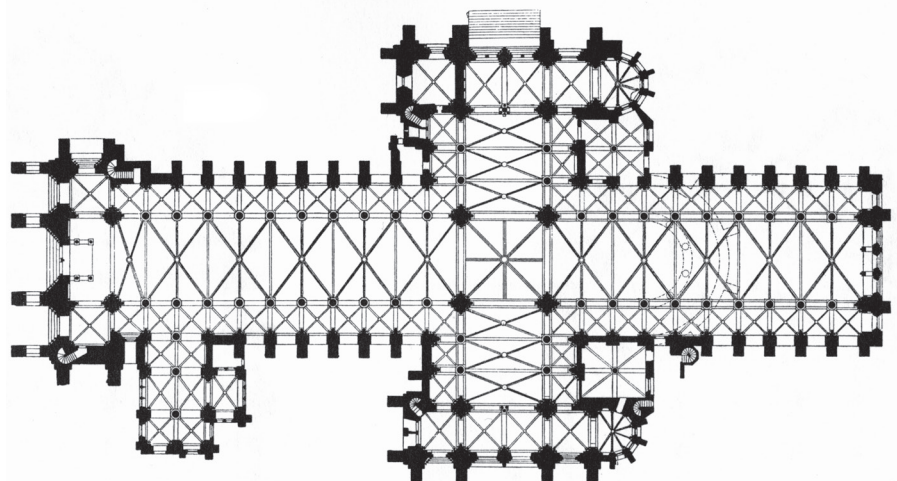


Figure 2. Laon Cathedral showing expansive (linear) tendencies

contrasts and harmony that aim to produce beauty in return (Mücke, 2009). Under the concept of polarity contrasting building elements not only produce harmony among themselves but also mimic natural processes of growth. This way, Goethe extends his morphological principles to the domain of art forms, where parts of buildings can be studied under various polar relationships that transform architecture as a practice of rhythm, proportion and symmetry.

Polarity in Gothic Morphology: Laon and Noyon

As an architectural system employing rigorous geometric and physical principles, Gothic architecture is often studied through its parts showing progressive differentiation of structure that is organized according to symmetry, repetition and variation (Panofsky, 1957; Simson, 1952). In plans, the Gothic exhibits cases of bilateral and radial symmetries where large structural spans are segmented into similar repetitive vaults that can support orthogonal transepts, aisles or circular apses. In sections, the progressive differentiation of vaults, buttresses and columns define how the total height of the structural load is distributed to the ground while producing various proportional rhythms among parts of the structure. In order to study this geometric complexity of the Gothic, scholars often utilize a comparative perspective that can highlight contrasts between historical works of architecture. An example of such method is found in Paul Frankl's *Gothic Architecture* where he explores the stylistic development of Gothic forms from earlier Romanesque churches that utilizes arches, colonnades, vaults and buttresses (Frankl, 2001). He contrasts the horizontally organized English Cathedrals, such as Salisbury, with the vertical French ones that mark two different approaches in early Gothic. To compare and analyze the morphologies of cathedrals, Frankl compares Laon (1155–1230) and Noyon (1150–1290) Cathedrals that share similar four-storeyed choir and quadripartite vaults. Among the two, Frankl considers Laon Cathedral to follow a “picturesque” approach towards producing a “multiplicity of images” that is present in the towers and the polygonal apse that removes “the discrepancy between the curved window surrounds and the flat surface of the glass” (Frankl, 2001, 75) (**Figure 2**) (**Figure 3**). In Noyon, this termination is met with a radial order that not only closes the end of the choir but also the perpendicular transepts that rise to the height of the cathedral with short buttresses (**Figures 4**) (**Figure 5**). Historically, the apse usually appears as a semicircular element and is also found in preceding styles to the Gothic, marking the main symmetry axis of the cathedral. But as Laon shows, termination of the horizontal growth of the cathedral can employ polygonal geometry as well, that allows for multiple entrances from the environment to the interior structure.

While comparative methods offer stylistic similarities and contrasts between Gothic structures, there hasn't been any consensus among scholars on the morphological tendencies exhibited in cathedral plans that display different kinds of radial and polygonal geometries. In *French Gothic architecture of the 12th. and 13th. Centuries*, Jean Bony (1983) defines two main contrasting tendencies in Gothic, through horizontality and verticality that are embraced by Parisian and Northern Gothic. The latter tends towards more vertically expanded volumes and a “marked preference for compact plans, in the Northern group for articulated cruciform plans” that appear more articulated on the ground plane (Bony, 1983, 131). This distinction between the horizontal and vertical planes also defines

Figure 3. Laon Cathedral with multiple spires

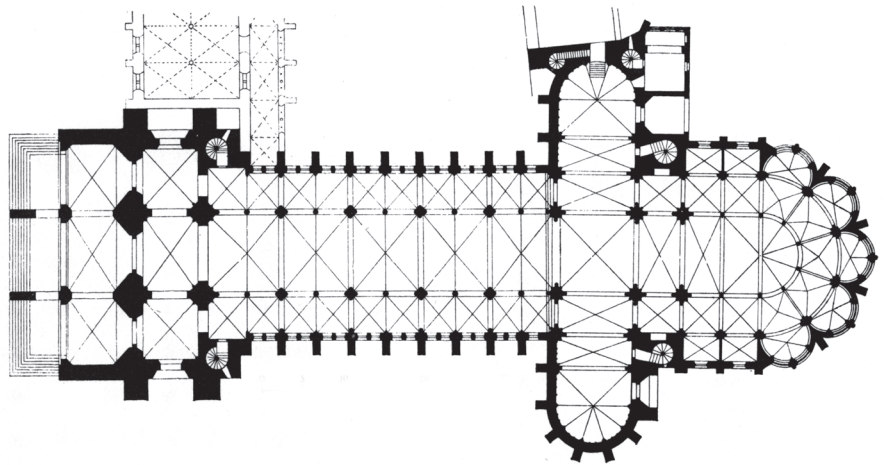


Figure 4. Noyon Cathedral showing contractive (radial) tendencies.

different practices of symmetry where the anatomical coordinate system becomes extendable towards the orientation of the architectural system and treatment of built forms as an organic body (Feuerstein, 2002, 7). While a stylistic comparison between cathedral forms is common among scholars, a morphological perspective using Goethe's concept of polarity can provide an alternative analysis of the Gothic. By analyzing and contrasting parts of Laon and Noyon Cathedrals various architectural relationships can be defined that show either radial-contractive or linear-expansive forms (Figure 2) (Figure 5). In Laon, the transepts appear highly proliferative and produce vertically expansive spires. In contrast, in Noyon, the transepts are terminated with radial ambulatories that prohibit the formation of multiple towers or additional entrances. Interestingly, in Laon, the expansion is so dominant that the chancel is terminated orthogonally without an ambulatory thus lacking radial geometry (Frankl, 2001, 75). The polygonal apse still embodies two adjacent spires that are drastically contracted in size compared to the towers sprouting at the end of the transepts and nave. While the radial tendency is missing in the planar development of Laon cathedral, this tendency reoccurs in the termination of the spires that

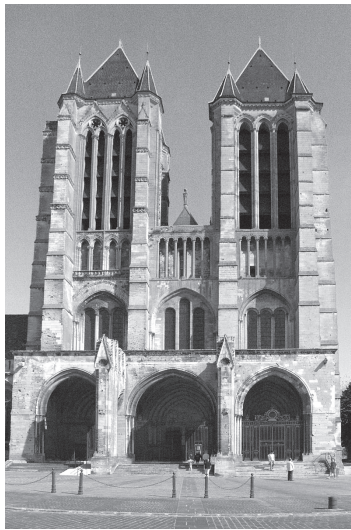


Figure 5. Noyon Cathedral showing expansive twin spires at the narthex.

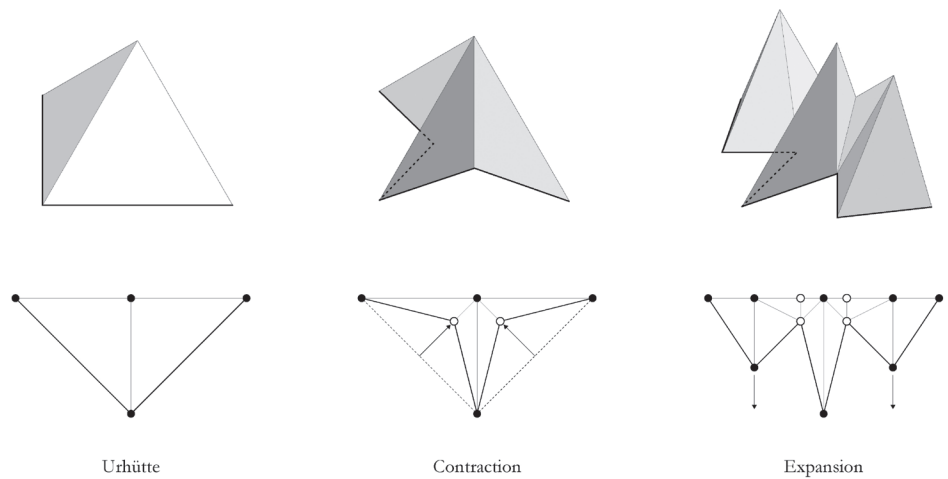


Figure 6. Metamorphic operations for horizontal morphogenesis.

show a radial distribution of tabernacles (Bony, 1983, 134; Frankl, 2001, 91) (Figure 4). In Noyon, the towers lack polar development as they are terminated with a square pyramid and four pinnacles only lacking further proliferation; however, to compensate, the ambulatory and transepts show an excessive development of radial symmetry (Figure 5). Due to this excessive contraction, the narthex appears overly expanded with a protruding entrance. When viewed as a self-organizing organism, the cathedral shows a distribution of different polarities among its parts where some of them remain smaller in size or underdeveloped compared to other elements that are expanded, enlarged or overly articulate.

Computational Morphogenesis of Gothic

To further analyze and compare the form of the two cathedrals under morphogenesis, a polar developmental model formulated around Goethe's concept of metamorphosis is considered. This model offers an abstract geometric technique for computing architectural form capable of progressive development and differentiation. In the past, similar computational tools such as shape grammars have been proposed for generative modelling of historical buildings that offer parametric rules for differentiation (Stiny, 1980). In these studies, the geometry of buildings or artefacts can be modelled using replication or transformation rules anchored at shapes that are defined from recognizable and repetitive parts of a whole (Grasl et al., 2018). Compared to the formulation of shape grammars, metamorphic computation aims to define morphogenetic mechanisms that can extend an organic perspective to architectural morphology, where all cathedral forms can be evaluated and compared through generative and parametric models (Steadman, 2008). To achieve this, metamorphic rules of natural morphogenesis are transferred to architecture, where it becomes possible to visualize architectural formal development of buildings in a similar manner. In comparison to the two-dimensional morphogenetic studies in leaves, the geometry of the cathedral is modelled through abstract parts—triangles, visualizing transformation of a simple pyramidal form towards a complex structure simulating metamorphic growth. At first, this process develops on the horizontal plane by breaking up the geometry into repeating parts that share local symmetries (Figure 6). Once the plan organization is established, development then turns towards the vertical planes and further breaks

down the geometry using expansive and contractive movements (**Figure 7**). As a time-based morphing technique, the progressive differentiation mimics natural growth where scalar change is omitted, but instead, topological change of form is visualized. During the first stage of planar development, the initial symmetrical pyramidal form breaks into symmetrical triangles by collapsing each polygonal edge towards a centre that aligns with the apex projected on to the ground plane. During vertical development, each triangle edge is capable of establishing a new local symmetry axis with the creation of a new apex along the vertical planes. When this occurs, the triangle located in between the two apices acts as a bridge to topologically reconnect divided segments while in later development it subdivides through contraction producing its own local axis of symmetry.

After the definition of rules for three dimensional form generation, Laon and Noyon cathedrals are modelled to show how their forms can be generated and studied using the concept of metamorphic development. In these stages, the architectural form is progressively differentiated simulating a process akin to natural morphogenesis, where the formal complexity of an organic whole can be achieved by parametric reconfiguration of its parts through subdivision. During this digital morphogenesis, the expression of expansive and contractive operations on horizontal and vertical development are captured, showing a method similar to morphing forms with increasing distribution of geometric parts (Kolarevic, 2004). In the development of Laon, the sequence shows that expansive properties predominate, where the cross body plan does not produce any distinctive apses; instead, the contractive narthex is reproduced at the ends of transepts that produce asymmetrical spires, one showing contractive termination with no distinctive roof, whereas the other one becomes highly expansive with octagonal radial distribution of pinnacles (**Figures 8-10**). Laon's expression of the vertical development produces multiple spires in addition to the single spire located at the crossing that protrudes directly from the crossing. Compared to Laon cathedral, in Noyon, the metamorphic development remains mostly contractive with the cross body plan terminating with radial apses on three ends and a highly expansive narthex (**Figures 11-13**). This results in underdevelopment of transepts and crossing that produce no distinctive spires. Polarization also occurs mainly in the development of the narthex that shows a primarily an expanded plan; however, in the vertical direction, it remains mostly contractive with its twin spires' premature termination. Noyon's narthex appears highly expansive on the ground plane compared

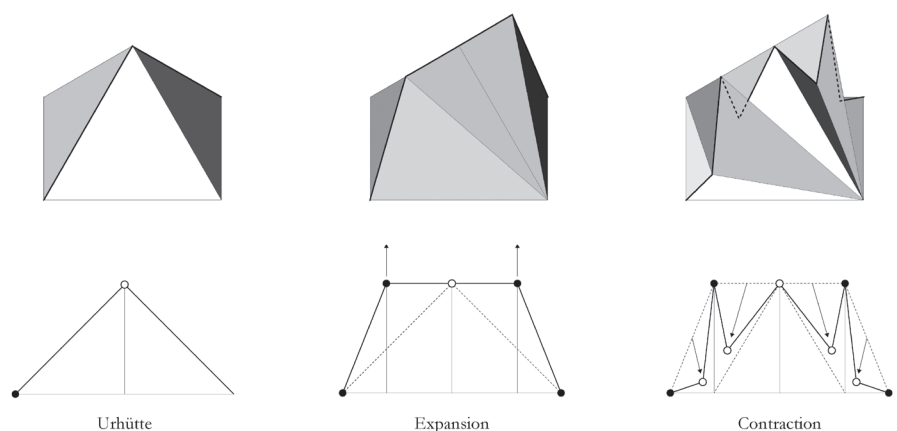


Figure 7. Metamorphic operations for vertical morphogenesis.

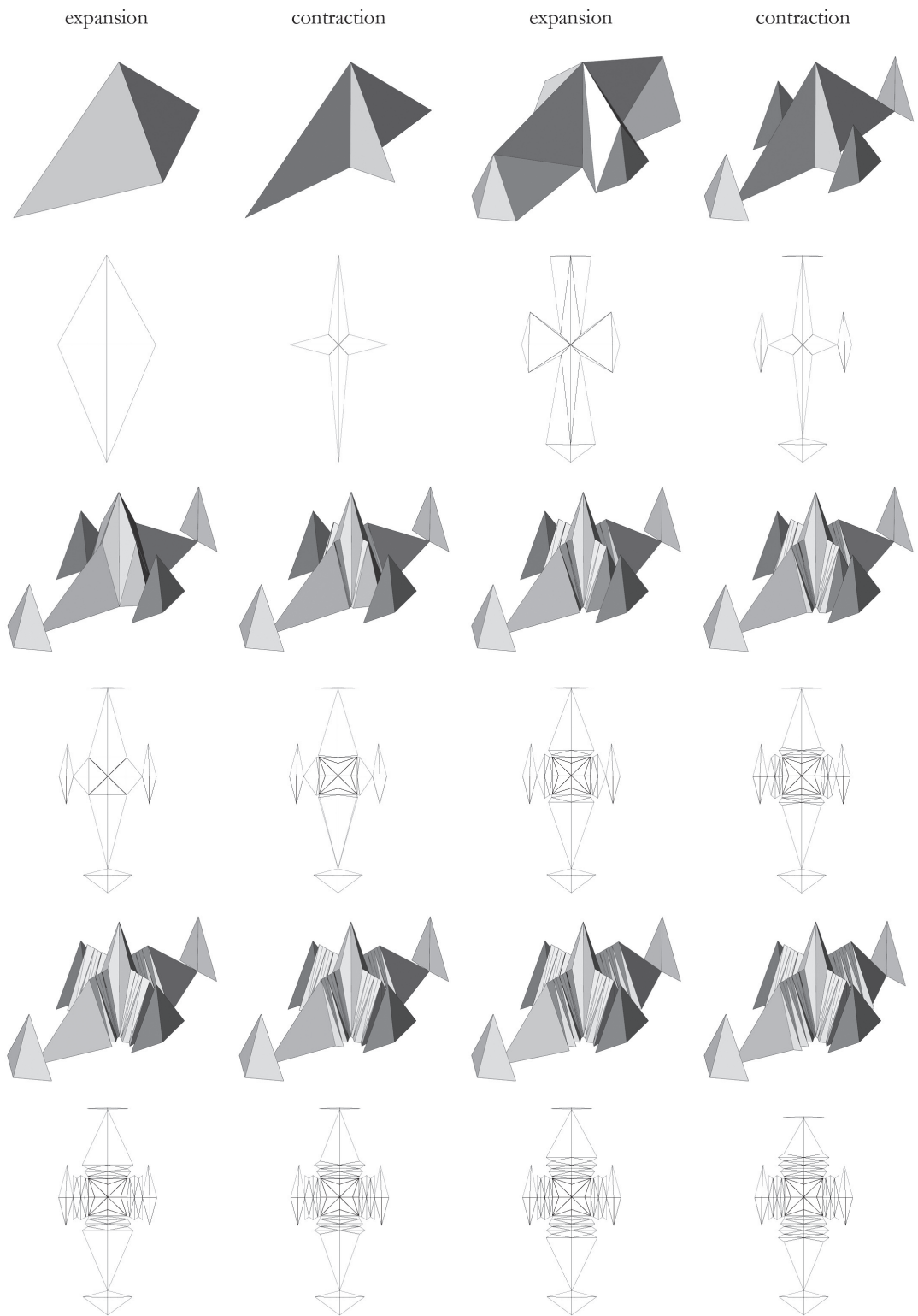


Figure 8. Metamorphic development of Laon Cathedral, phase 1.

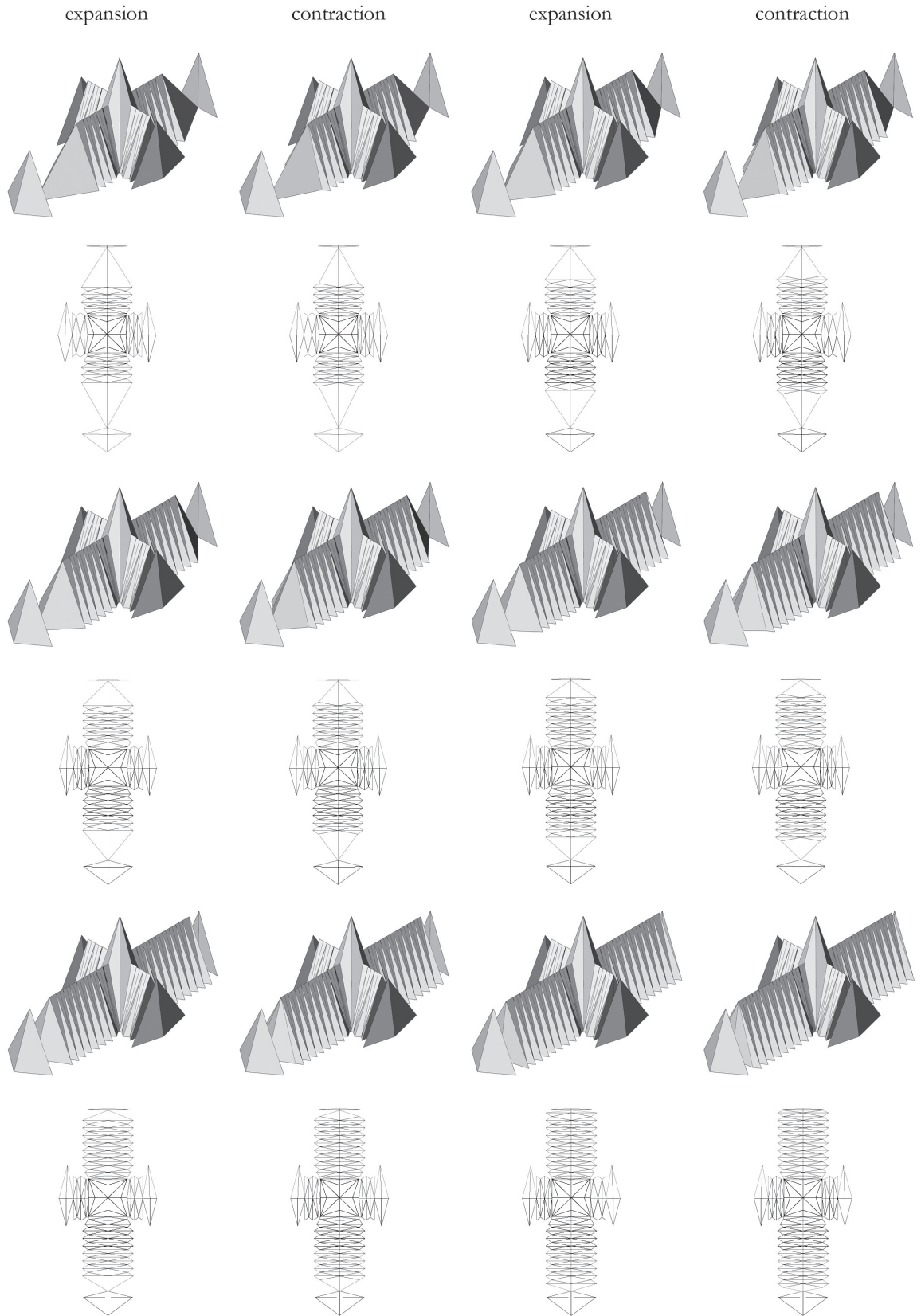


Figure 9. Metamorphic development of Laon Cathedral, phase 2.

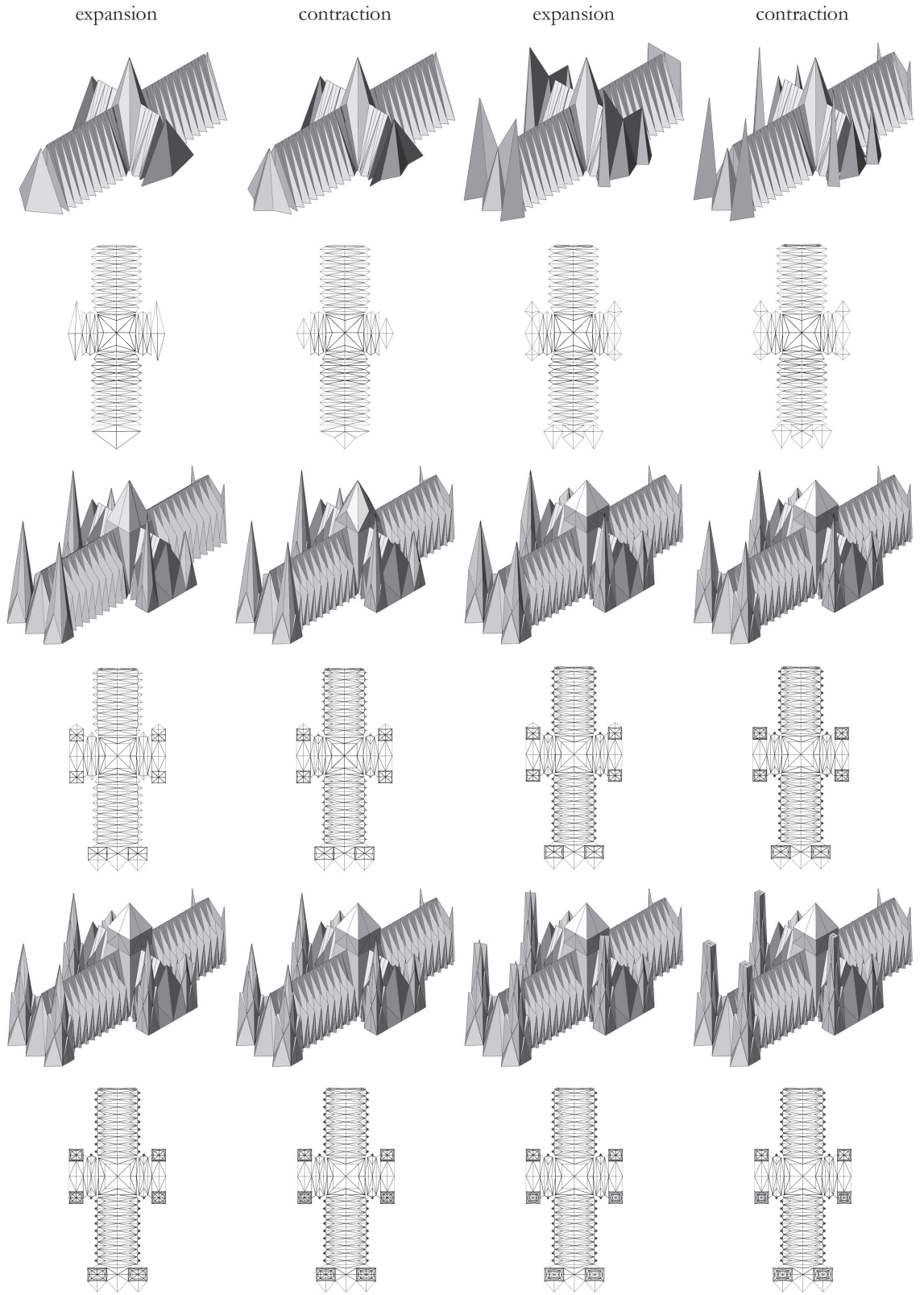


Figure 10. Metamorphic development of Laon Cathedral, phase 3.

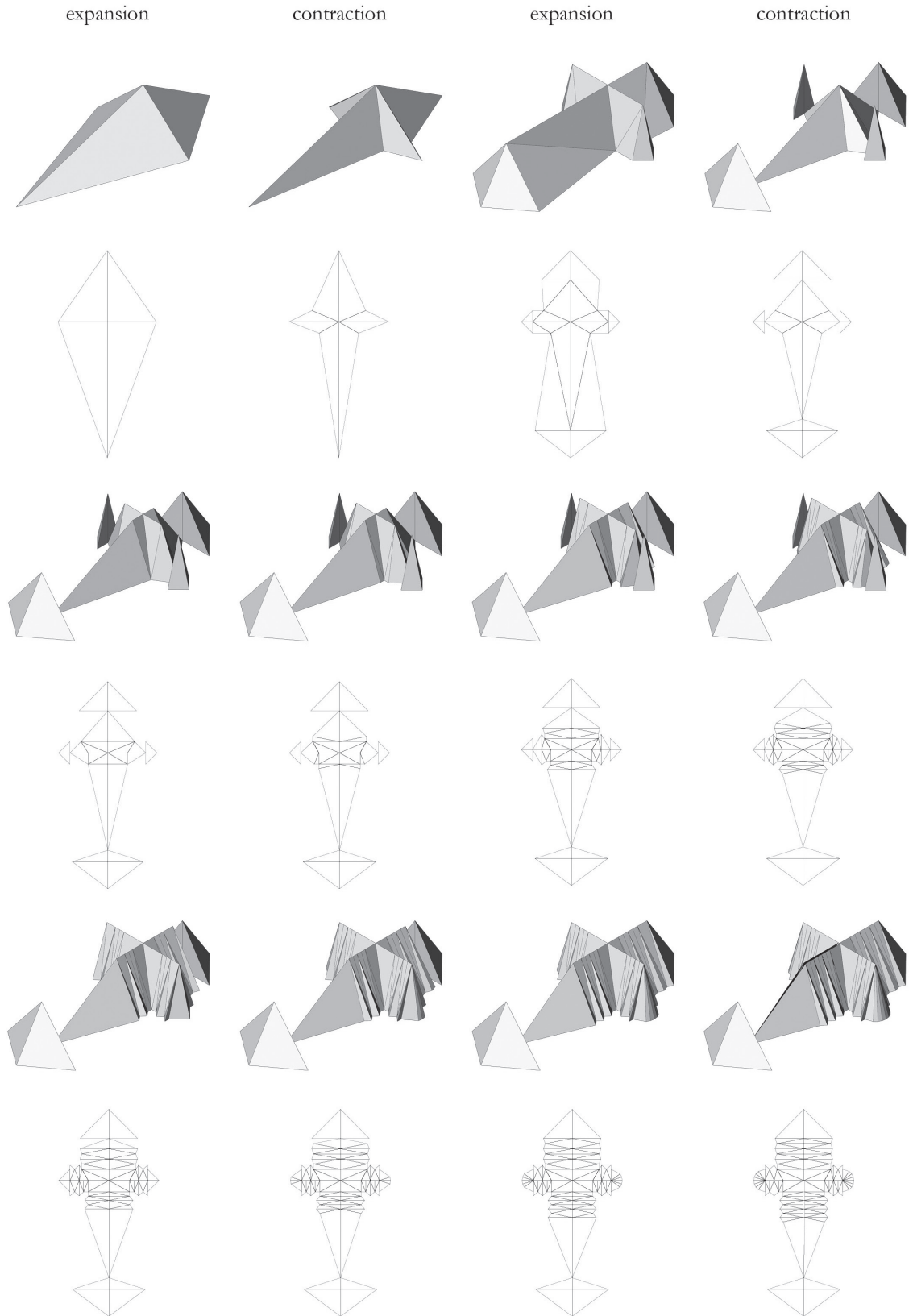


Figure 11. Metamorphic development of Noyon Cathedral, phase 1.

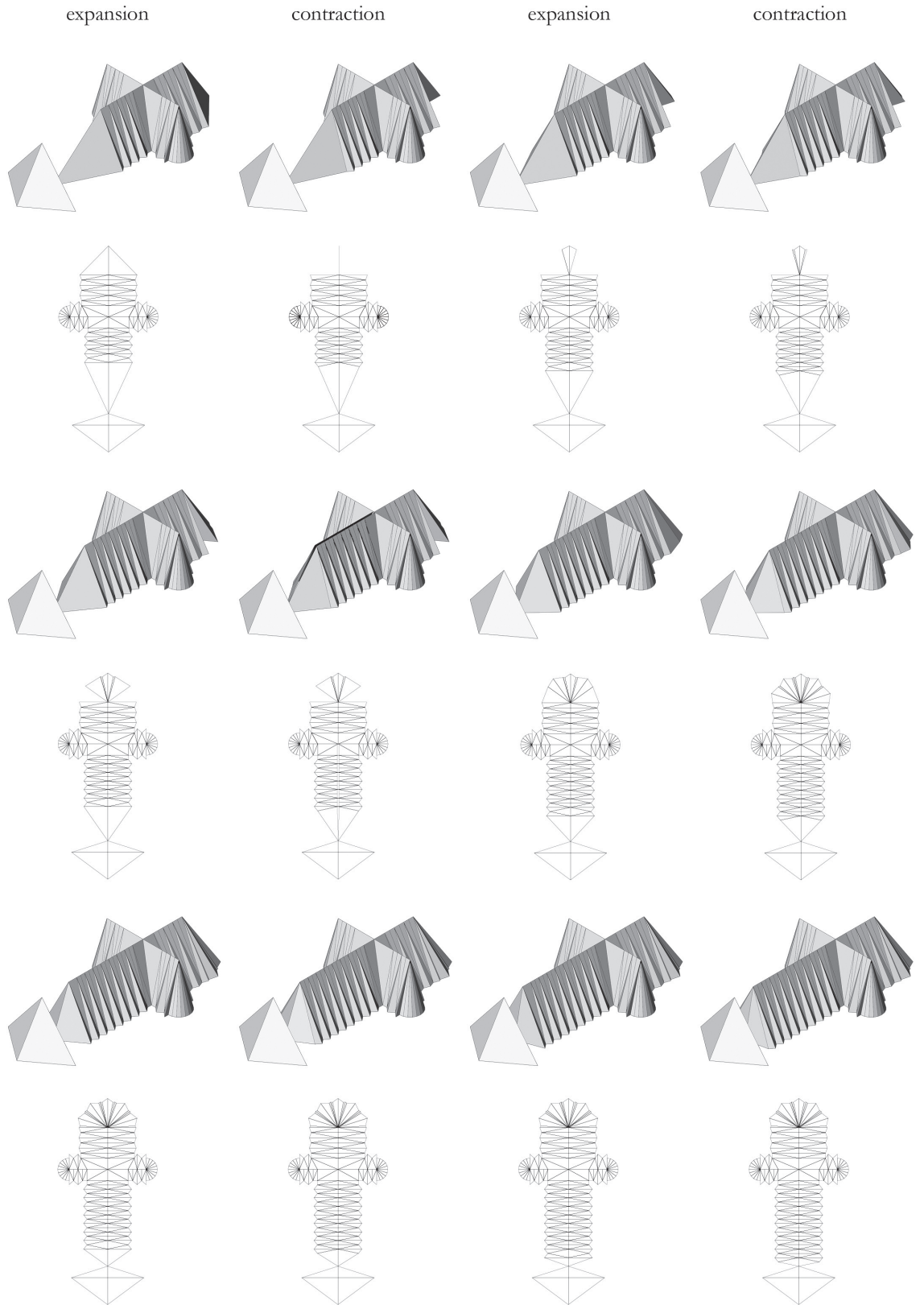


Figure 12. Metamorphic development of Noyon Cathedral, phase 2.

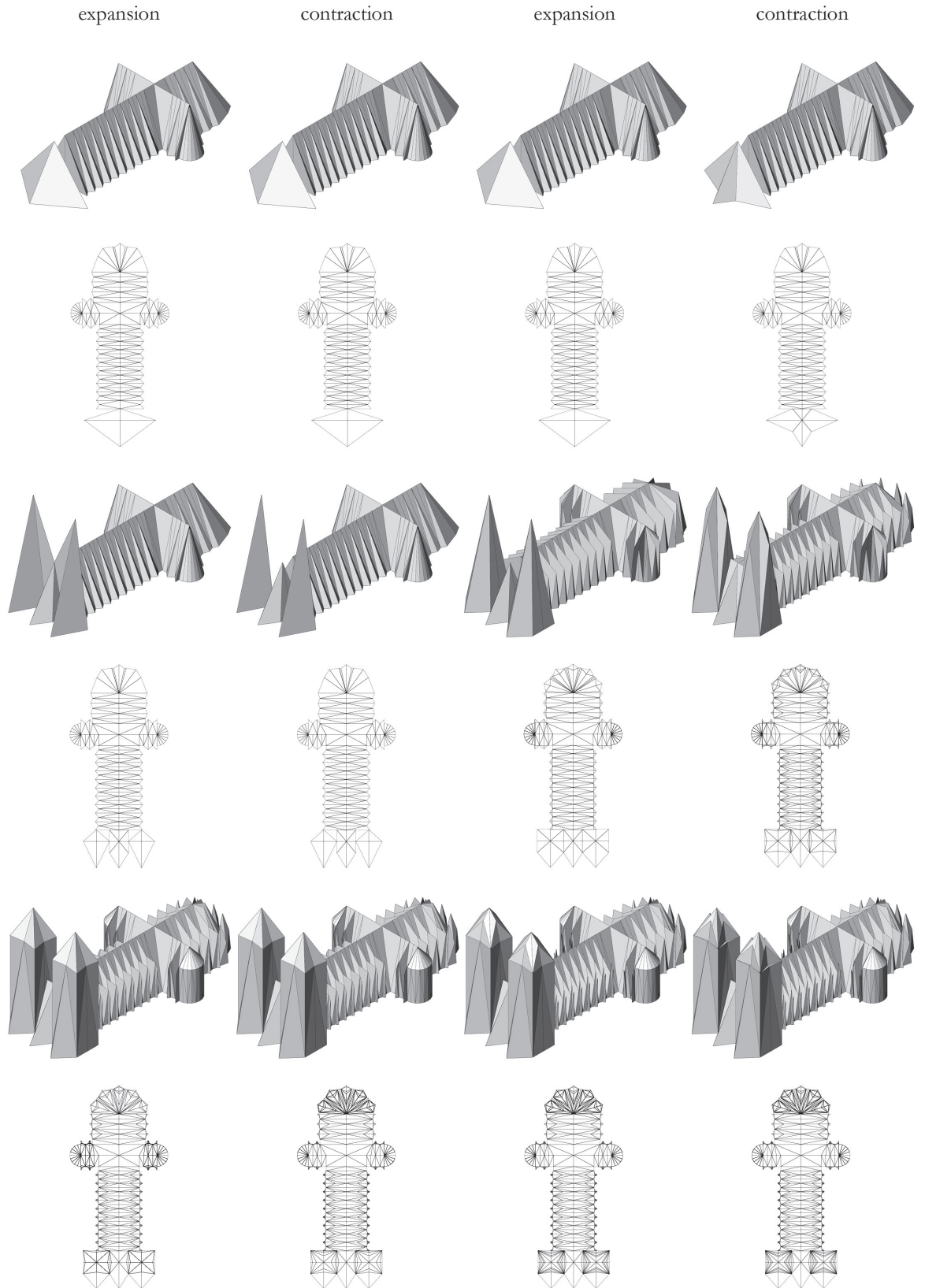


Figure 13. Metamorphic development of Noyon Cathedral, phase 3.

to Laon, where vertical development predominates horizontal expansion. Similarly, the expansion of transepts in Laon overpowers the development of the main axis. In contrast, in Noyon, the transepts appear contracted and underdeveloped that counters the expansion of the narthex and choir. These morphing sequences show that cathedral forms exhibit various organic qualities that can be visualized and examined through morphogenetic operations revealing symmetrical relationships between their parts where formal polarities and developmental similarities could be visualized in steps.

CONCLUSION: A GOETHEAN ARCHITECTURAL MORPHOLOGY

This article presents a new formulation for architectural morphogenesis based on Goethe's ideas on polarity by combining knowledge from biology, history-theory and computation. The premise of this new perspective is threefold. Firstly, Goethe's theory-laden approach to form, structured around the concept of polarity is directly related to the contemporary studies in biology that can offer an alternative perspective for generative studies of natural and architectural form generation. Secondly, Goethean morphology offers a novel theoretical and historical perspective to morphogenesis that can aid the theoretical foundation of organicism in architecture. This approach can redefine architecture as formal development that is primarily directed towards the study of buildings exhibiting symmetry and proportion among parts and wholes. Thirdly, through the concept of polarity, Goethean morphology offers novel computational tools that can lead to both analytical and generative studies of building forms revealing novel aspects of symmetry, proportion and types. With this structure, it becomes possible to develop polar comparisons of building forms as well as use sequential morphing techniques to visualize architecture as formal development.

From an architectural perspective, morphological research on historical works of architecture can provide common computational models that outline a cumulative understanding of built forms utilizing notions of symmetry and growth (Steadman, 1983). By describing building types that are generative, exploring parametric variations can suggest common developmental models for the quantitative analysis and qualitative classification of the building stock. This will result in establishing rules for further morphogenetic research that could potentially redefine architecture as a "building science" capable of developing its own tools of design as well as outline common morphological properties among different types of buildings (Steadman, 1983, 2008). Furthermore, these tools can aid further evaluation and generative studies of performative, ecological and structural models of architectural morphogenesis (Kolarevic, 2004; Hensel, 2010).

As a transdisciplinary and theory-laden concept, polarity is not only limited to natural sciences but is extendable towards an architecture where aspects of growth, symmetry and computation could be investigated in a morphogenetic framework. As a preliminary case study, the comparison of Laon and Noyon cathedrals shows how Goethe's concept of metamorphosis can be extended towards architectural formal computation. This computational study features the utility of abstraction to simplify geometric and stylistic representation and employs sequential morphing techniques that can gradually transform the complexity of a simple form using repetitive and parametric geometric rules. While the presented developmental models use procedural modelling as a technique to visualize metamorphosis of built forms, future models can employ

algorithms to further investigate the computational capacity of polarity on various historical examples to develop comprehensive theoretical views to architectural morphology.

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GOETHE'NİN POLARİTE KAVRAMINI YENİDEN KEŞFETMEK: MİMARİ MORFOLOJİ İÇİN YENİ BİR YÖN

Bu makale Goethe'nin polarite kavramını, doğal ve mimari morfojeniz çalışmaları için geliştirilebilecek teorik ve hesaplamalı bir yöntem olarak tanıttacaktır. İkileme dayalı bir ilke olan polarite, Goethe'nin çalışmalarının

çoğunda, özellikle de renk ve botanik yazılarında yer almaktadır. Bu kavram, Goethe'nin aydınlanma çağında doğa bilimleriyle olan ilişkisini yeniden şekillendirmek, biçim ve büyüme üzerine fikirlerini mimariye aktarmak için morfojenetik bir perspektiften incelenmiştir. İlk bölümde, organik büyümeyi araştırmak için morfojenetik kavramı biyoloji ve mimarideki modern araştırmaları birleştiren bir alan olarak sunulmuştur. İkinci bölümde, polarizasyon ilkeleri üzerine kurulmuş bir alan olan morfoloji, morfojenetik tarihsel bir bakış açısı sunmaktadır. Burada, Goethe'nin metamorfoz kavramı, ikilemler üzerine kurulmuş, dönüşümlü olarak çalışan genişleme ve daralma döngüleri ile formüle edilmiş bir ilke olarak vurgulanmaktadır. Bu kavramların, doğal morfojenetikte görülen form ve büyüme çalışmalarına morfojenetik uygulamasını tartışmak için yaprak gelişiminin algoritmik bir çalışması gösterilmiştir. Son bölümde, Goethe'nin morfolojik görüşlerini ve polarite kavramını yapısal çevrenin estetik algısına ve biçimsel gelişimine yönelten organizmacılık çerçevesinde mimariyle doğrudan ilişkilendirilmiştir. İki Gotik katedral olan Laon ve Noyon'un formunu karşılaştıran makale, mimaride morfolojik araştırma için alternatif bir yöntem olarak metamorfoz kavramına dayanan bir gelişim modeli sunmaktadır.

REDISCOVERING GOETHE'S CONCEPT OF POLARITY: A NEW DIRECTION FOR ARCHITECTURAL MORPHOGENESIS

This paper will introduce Goethe's concept of polarity to discuss its theoretical and computational implications on natural and architectural morphogenesis (1). Polarity, as a dualist principle, is found in most of Goethe's body of works, particularly in his treatise on colour and botanical writings. This concept is explored from a morphogenetic perspective to reconsider Goethe's engagement with natural sciences during Enlightenment where he transfers his ideas on form and growth to architecture. In the first part, morphogenesis as a concept for the study of organic growth is discussed that combines modern research in biology and architecture. In the second part, Goethean morphology as a unified science founded on polar principles is presented to discuss a historical perspective to morphogenesis. Here, Goethe's concept of metamorphosis is highlighted as a principle founded on polarity, formulated with alternating cycles of expansion and contraction. These concepts are explicated using an algorithmic study of leaf development to discuss its morphogenetic application to the study of form and growth in natural morphogenesis. In the last part, Goethe's morphological views are extended towards architecture within the framework of organicism where his ideas on the polarity are directed towards the aesthetic reception and formal development of the built environment. Comparing the form of two Gothic cathedrals, Laon and Noyon, the paper will offer a developmental model based on the concept of metamorphosis as an alternative trajectory for morphological research in architecture.

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