GENERATIVE ARCHITECTURE AND PARAMETRIC DATA FROM THE FIBONACCI SEQUENCE IN DESIGN

Kiến trúc tạo sinh và dữ liệu tham số từ dãy số fibonacci trong thiết kế

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ABSTRACT: The advancement of digital technology, and generative design methods is fundamentally reshaping contemporary architectural discourse. Today, integrating natural laws into generative architectural design has gained significant academic interest and emerged as a prominent trend. These natural laws have transcended their role as mere formal references to become the logical foundation for algorithmic design systems. The authors identify a framework for applying natural laws—exemplified by the Fibonacci sequence—to generative architecture across three dimensions: as an input dataset for algorithmic systems, as a generative rule for data production during the design process, and as a recursive mechanism for geometric formation. The study demonstrates that integrating natural laws into algorithms not only expands the horizons of geometric creativity but also contributes to the formation of architectural models that are both inherently familiar and increasingly diverse in the digital era.

KEYWORDS: Fibonacci, Grasshopper, Generative Design, Parametric Design.

TÓM TẮT: Sự phát triển của công nghệ số và các phương pháp thiết kế tạo sinh đang làm thay đổi sâu sắc tư duy kiến trúc đương đại. Hiện nay, việc đưa các quy luật tự nhiên vào thiết kế kiến trúc tạo sinh đã thu hút nhiều sự quan tâm trong học thuật và trở thành một xu hướng nổi bật. Những quy luật tự nhiên này không còn chỉ được dùng như nguồn tham khảo về hình thức, mà đã trở thành nền tảng logic cho các hệ thống thiết kế bằng thuật toán. Các tác giả đưa ra một khung phương pháp để áp dụng các quy luật tự nhiên — điển hình như dãy Fibonacci — vào kiến trúc tạo sinh theo ba hướng: như một bộ dữ liệu đầu vào cho các hệ thống thuật toán; như một quy luật tạo dữ liệu trong quá trình thiết kế; và như một cơ chế lặp lại để hình thành hình học. Nghiên cứu cho thấy rằng việc tích hợp các quy luật tự nhiên vào thuật toán không chỉ mở rộng khả năng sáng tạo hình học mà còn góp phần tạo nên những mô hình kiến trúc vừa mang cảm giác quen thuộc, vừa ngày càng đa dạng trong thời đại kỹ thuật số.

TỪ KHÓA: Fibonacci, Grasshopper, Kiến trúc tạo sinh, Thiết kế tham số.

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1. INTRODUCTION

The advancement of digital technology, artificial intelligence, and generative design methodologies is fundamentally reshaping contemporary architectural discourse. Within this context, architecture is no longer approached merely as a static formal composition, but is increasingly viewed as a dynamic system capable of adaptation, optimization, and evolution driven by data and algorithms. Concurrently, natural laws are emerging as a critical foundation for generative design. Among these, the Fibonacci sequence stands out as a prime mathematical rule due to its capacity to represent growth, spatial organization, and inherent order in nature. Today, this numerical sequence has been fully integrated into parametric design systems and generative algorithms. Building upon this foundation, this study proposes a framework to classify the roles of the Fibonacci sequence in generative architecture across three dimensions: input parameters, generative data rules, and recursive mechanisms for geometric formation. This serves as a theoretical framework to elucidate how natural laws are operationalized into computational structures within contemporary digital design.

2. LITERATURE REVIEW AND THEORETICAL FOUNDATION

2.1. The Intersection of Biology and Architecture

Recently, with the emergence of Generative Design, the role of the architect continues to be redefined. According to Wei Ma [1], generative design is a rule-based, iterative design

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process that leverages algorithmic and parametric models to automatically create, iterate, and optimize design possibilities by defining high-level constraints and objectives. Furthermore, modern architecture has witnessed a robust development in biomimetic trends. The advent of advanced computational tools has facilitated the simulation of complex natural mechanisms [2]. Consequently, in this new paradigm, the role and skill set of the architect are expanding significantly. Beyond traditional design capabilities, architects must acquire knowledge of algorithms and programming to construct generative design systems. Simultaneously, understanding and translating natural laws into computational models has become a vital competency, shaping the approach to architecture in the digital era.

2.2. Natural Laws: Order Within Apparent Randomness

Nature does not operate on pure randomness; rather, it adheres to intrinsic organizational laws manifested through structured and hierarchical morphologies. Decoding these laws provides crucial "parametric data" for generative design systems. The complexity of natural forms is frequently built upon simple, repetitive rules, such as the hierarchical order in snowflake and plant structures, or the self-similarity exhibited in morphologies ranging from coastlines to cloud formations [3]. Characteristics such as symmetry, branching, and hierarchy form the bedrock of many natural morphological systems. Among these established rules, the Fibonacci sequence is a well-known mathematical law that has been extensively explored and applied in architectural design:

$$F_n = F_{(n-1)} + F_{(n-2)}$$

The core attribute of this numerical sequence is the golden ratio of 1.618 the limit of the ratio between two consecutive numbers as the sequence approaches infinity. Consequently, the Fibonacci sequence can be utilized to construct the golden rectangle [4]. Extant literature indicates that numerous architectural works and designs, spanning from antiquity to the modern era, have been developed based on the golden rectangle or the Fibonacci rectangle [5]. In the future, as architecture becomes increasingly intertwined with automated computational systems, integrating natural laws—such as the Fibonacci sequence—into generative design algorithms will become an essential developmental trajectory. This represents not merely a continuation of the geometric and aesthetic values embedded in architectural history, but a paradigm shift from form-based design thinking to rule- and process-based design thinking. Through this approach, architecture can closely approximate the morphological organization and growth patterns found in nature.

2.3. Foundations for Translating Natural Laws into Parametric Data in Generative Design

The diversity of natural morphologies and organisms is the product of continuous evolution and development driven by natural selection. Thus, deriving architectural design solutions from natural laws equates to treating nature as a mentor for models and systems. In contemporary architectural design, extensive research has been conducted; notable examples include the interdisciplinary research on natural structures initiated by Frei Otto at the University of Stuttgart, and various collaborative projects by the Institute for Computational Design (ICD) that apply computational processes in architectural design using biological patterns. Furthermore, the dissertation by Niels Martin [6] presents a profound approach to translating biological laws—exemplified by L-systems, a mathematical model used to simulate plant growth—into an architectural language via mathematical techniques.

According to Vincent [7], there are three levels of transferring natural laws into architectural design: Copying (where attributes are replicated in their original form), Pattern Recognition (a generalized approach focusing on identifying patterns and principles), and the TRIZ level (based on the theory of inventive problem-solving). Biological patterns frequently serve as the foundational inspiration for generative systems in architectural design. These systems can exhibit order (aggregation, symmetry, trees, tessellations, numerical sequences, the golden ratio, spirals), chaos (randomness, probability), or complexity. A complex system represents a synthesis of order and chaos, mirroring biological systems [8]. The integration of simulation and parameterization in design has fostered a novel cognitive paradigm. The Fibonacci sequence is a prime example of natural laws that can be exploited in parametric design. The rules governing the sequence reflect an aspect of how biological structures form and develop. Consequently, the Fibonacci sequence can be utilized as a formal morphogenetic principle to generate organized and harmonious geometric variations within a generative design environment.

2.4. Research Gap

Although the theories of generative design and biomimicry have been firmly established through the seminal works of Wei Ma [1] and Kostas Terzidis [9], a significant gap persists in current literature between the mathematical theory of natural laws and concrete algorithmic practice. Specifically, despite the widespread application of the Fibonacci sequence, a systematic taxonomic framework defining its role within the parametric structure of generative architecture has yet to be clearly formulated. To address this research gap, this paper focuses on systematizing the roles of the Fibonacci sequence in the contemporary generative design workflow.

3. RESEARCH METHODOLOGY

This study employs an integrated methodology combining theoretical research, parametric modeling, and numerical simulation to analyze the role of the Fibonacci sequence in generative architecture. Literature was selected from specialized monographs and scientific papers concerning generative design, parametric design, biomimicry, and recursive algorithms in digital architecture. Computational experiments were executed within Rhinoceros 8 (trial version) and Grasshopper, incorporating a Python 3 script to establish recursive feedback loops. The Fibonacci sequence was constructed using input parameters including Seed A, Seed B, and the number of elements N. These Fibonacci values were utilized to control the scale, spacing, distribution density, and geometric growth rules within the generative system. The models were simulated through mesh subdivision, data filtering, and geometric iteration techniques.

4. RESULTS AND DISCUSSION

4.1. Morphological Classification Framework of the Fibonacci Sequence in Generative Design

To systematize the roles of the Fibonacci sequence within the generative design workflow, the authors propose a taxonomic framework categorized into three primary levels:

- **Data Level (Input):** The Fibonacci sequence serves as a set of control parameters for independent variables, directly determining physical attributes such as geometric radii, structural component thickness, or facade surface depth.

- **Structural Level (Generative Rule):** Establishing a numerical organizational logic to constrain the relationships between components, thereby dictating spatial positioning, density, and grid pattern configurations.

- **Algorithmic Level (Recursion):** Constructing a recursive script based on a feedback-loop mechanism (where the output of the preceding step acts as the input for the succeeding step) to simulate fractal-like morphological growth, generating complex structures from minimalist mathematical rules.

At these distinct levels, the Fibonacci sequence transitions from a traditional geometric motif into a direct, operational algorithmic component [9]. Particularly at the algorithmic level, the recursive principle operates by feeding the previous step's output into the subsequent iteration based on a predefined boundary condition (base element) [10]. This mechanism enables the system to generate continuously transforming structures capable of branching and self-similarity (fractals), mimicking natural growth processes. Within a generative design environment, recursive algorithms empower architects to automatically generate complex spatial grids or facade structures using minimalist code sequences, thereby transcending the limitations of conventional static geometry.

4.2. Algorithmic Implementation and Experiments

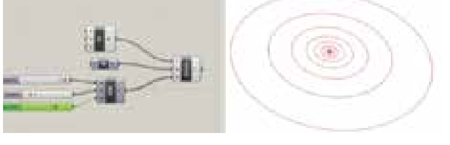

Figure 1: The Fibonacci sequence functioning as an operational input parameter

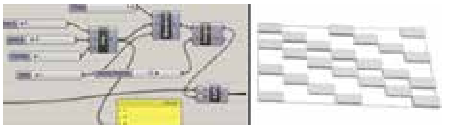

Figure 2: The Fibonacci sequence governing spatial positioning and organizational rules of surface apertures

Generative architecture enables computational systems to continuously simulate, iterate, and evaluate numerous design permutations by adjusting parameters based on the logic of the Fibonacci sequence. Consequently, the design process shifts from manual formal composition to the formulation of generative rule sets that govern the variance of design outcomes. Because the Fibonacci sequence facilitates the generation of structures characterized by growth and branching, the computational power of generative design liberates traditional geometric thinking. By proposing a vast array of design alternatives, it expands the decision-making horizon and optionality available to the architect. When functioning as an input parameter — the first role — the Fibonacci sequence operates as a parametric variable, directly feeding numerical values into the design algorithm. These values can control the scale, spacing, density, rotation, or proportion of architectural components. The proportional variance in scale generates a visual effect of movement and growth, which lies at the core of generative architecture. In this scenario, the Fibonacci sequence can be conceptualized as a parametric dataset designed to produce an ordered and organic variation [10]. The experiment illustrated in Figure 1 serves as a straightforward demonstration of the Fibonacci sequence acting as an input parameter, directly dictating the radii of the circles.

In addition, the experiment illustrated in Figure 2 explicitly demonstrates the sequence's role in determining spatial positioning and organizational rules, wherein the Fibonacci sequence is utilized as a rule for pseudo-random variation within the Cull Pattern component. Instead of conventional, uniform True/False filtering, executing data culling based on Fibonacci intervals generates surface apertures with naturally shifting densities. This process yields a diverse range of alternative design permutations, as detailed in Table 1.

Table 1: Generative outcomes resulting from parameter adjustments in the Fibonacci sequence

Seed A	Seed B	Number	Generative
0	1	2	
0	2	2	
0	3	2	
7	6	11	

As noted by Kostas Terzidis [9], employing the same algorithm with divergent parameters can precipitate entirely unexpected and unpredictable behaviors. The comparative experiment in Figure 3 clearly demonstrates this variability when the Number input of the Random component is driven by the Fibonacci sequence. Conversely, assigning a static integer to the Number input constrains the generative output of the Random parameter.

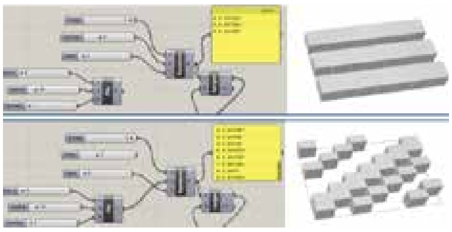

Figure 3: Comparative analysis of two parameter assignment methods for the Number input of the Random

Consequently, the paradigm of embedding mathematical sequences derived from natural laws into parametric frameworks is further validated by its demonstrated capacity to maximize solution diversity in generative architecture. It can be argued that within generative design, the Fibonacci sequence transcends its role as a mere geometric proportion, evolving into an computational driver that catalyzes alternative solutions. It is precisely this synergy between natural laws and computational power that facilitates the formulation of highly flexible architectural permutations, effectively pushing the boundaries of traditional design methodologies.

Figure 4: The Fibonacci sequence and recursive algorithms

The generation of circular-arc patterns driven by the Fibonacci sequence, illustrated in Figure 4, serves as a prime demonstration of recursiveness in generative design. Fundamentally, the Fibonacci sequence is an inherent natural recursive law, where each subsequent value is determined by the sum of its preceding predecessors. Because Grasshopper operates on a linear, left-to-right dataflow logic and lacks native support for direct feedback loops, integrating a Python 3 script component becomes a prerequisite. This script governs the underlying execution logic, enabling the definition of self-calling functions to construct infinite nested geometries. Consequently, from a minimalist rule set defined within the Python 3 script, an architectural morphology characterized by structured complexity and self-similarity is effectively established.

4.3. Discussion

This study demonstrates that the evolution of generative architecture has fundamentally transformed how natural laws are approached within architectural design. However, the application of the Fibonacci sequence in generative architectural design also presents certain considerations that warrant attention. First, an over-reliance on algorithms carries the risk of superficial formalization if it lacks the oversight of architectural intent and the constraints of the physical context. Furthermore, the deployment of this numerical sequence should be contextualized merely as a representative parametric organizational model.

From a pedagogical perspective, the growth of generative design is reshaping architectural curricula at numerous universities globally. Within this framework, researching and applying natural laws like the Fibonacci sequence can be considered a foundational curriculum item, assisting students in navigating the relationships between mathematics, natural geometry, and digital generative systems. This contributes to fostering interdisciplinary competencies across architecture, mathematics, programming, and data science—skills that are becoming increasingly vital for architects in the digital era.

5. CONCLUSION

Digital technology and generative design open up novel approaches by translating natural laws into the operational foundations of design algorithms. Within this paradigm, the Fibonacci sequence participates directly in architectural morphogenesis through three distinct roles: as an input parameter, a data generative rule, and a recursive mechanism. The results indicate that this integration not only expands the horizons of geometric creativity but also facilitates the formation of architectural models characterized by natural growth and variation. Nonetheless, the current study remains primarily at a theoretical stage, necessitating further validation through design experiments, performance simulations, and real-world applications. This defines the trajectory for future research, aimed at further elucidating the relationship between generative algorithms and the adaptive capacity of architecture in the digital era.

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