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Research Article

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Biosimulation in Architecture: An AI-Supported Approach to Living Architectural Systems

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Abstract

This study goes beyond biophilic and biomimetic approaches that limit the relationship with nature in architecture to merely aesthetic or structural representations, presenting a new theoretical proposal that centers on the behavioral patterns of nature: Biosimulation. Supported by interdisciplinary theoretical foundations such as systems theory, autopoiesis, and evolutionary algorithms, this approach is based on the analysis of speculative prototypes developed with AI-supported visual production tools. Prototypes developed within the study, such as Myco-Habitat, Photosynthetic Pavilion, and Coral Shelter, have been evaluated comparatively with structures selected from the real world, and the potential of biosimulation to produce behavioral intelligence, environmental adaptation, and organizational dynamism in architectural design has been questioned. The study contributes to the redefinition of the structure not merely as a form resembling nature, but as a system that responds like nature and can reorganize itself.

Keywords: AI-Supported Design, Behavioral Architecture, Biophilic and Biomimetic Design, Biosimulation, Environmental Adaptation, System Theory.

1. Introduction

Throughout the history of architecture, nature has been the primary source of formal, structural, and functional inspiration. Architectural strategies that imitate nature's forms, cyclicality, and organizational patterns have been integrated into design with different motivations in different periods [1]. In this process, especially towards the end of the 20th century, biophilic and biomimetic approaches emerged as efforts to re-establish a connection between nature and the built environment. Biophilic design has developed a design strategy focusing on the innate connection between humans and nature, emphasizing environmental psychology, user experience, and health [2]. In contrast, biomimetic design is a strong approach that models not only the aesthetic but also the structural, performative, and systemic aspects of nature, with a strong technological and computational focus [3-4].

However, both approaches are generally limited to formal tools representing nature and fail to establish a deep relationship with nature's behavioral intelligence and environmental adaptation capacity [5]. In today's conditions, where the impacts of the climate crisis are deepening, resources are rapidly depleting, and cities are evolving under extreme pressure, architecture needs to establish systems that think, respond, and reorganize themselves like nature, rather than merely producing forms that resemble nature [6-7]. In this context, it is not enough to have merely an aesthetic or symbolic representation of nature; the principles of organization, behavioral patterns, and adaptive abilities of nature should be at the center of architectural design.

This study proposes a new concept to the literature by bridging architectural theory and computational design practices: Biosimulative Architecture. Unlike biomimetic design, which models nature's forms and systems for structural or performance benefits, and biophilic design, which integrates natural elements to enrich human experience, the biosimulation approach centers on harnessing nature's dynamic behaviors and organizational logic in architecture. In essence, this concept posits the creation of 'living' architectural systems through AI support; for example, the Coral Shelter prototype developed in this study illustrates how an AI-generated architectural form can adapt and evolve in response to environmental inputs, much like a coral reef growing and responding to ocean currents. This concept aims to simulate biological systems in the spatial

realm through AI-supported tools, thereby producing living structures that can respond to environmental stimuli, establish symbiotic relationships, and transform themselves. Biosimulation not only envisions integrating the appearance of nature but also its processes, such as learning, evolving, and symbiotic existence, into the built environment. In this aspect, it transforms architectural design from a static object into a system that can evolve behaviorally.

While the term “biosimulation” has previously been used in disciplines such as computer science and medical sciences to describe the technical modeling of biological systems, in this study it is redefined within a speculative architectural framework. Although earlier uses of the term exist in biodigital design discourse[1], the concept is expanded here to emphasize behavior-driven, adaptive architectural systems supported by artificial intelligence. This interpretation moves beyond formal biomimicry by aligning architectural design with the systemic, responsive, and evolving characteristics of natural organisms.

Biosimulation in architecture seeks to redefine the relationship between design and nature by enabling buildings to behave, adapt, and evolve like living systems. Supported by artificial intelligence, this approach translates biological logics into spatial patterns through computational processes. It proposes a shift from static, representational design toward architecture that learns, responds, and reorganizes itself in real-time. This study investigates the potential of an AI-supported biosimulation framework to generate adaptive and behaviorally responsive architectural systems.

In this study, the concept of "biosimulation in architecture" is theoretically defined; subsequently, its design potential is examined through spatial prototypes generated using artificial intelligence. Biophilic and biomimetic structures drawn from the real world are being compared with biosimulation spaces generated by artificial intelligence; the boundaries, potentials, and risks of this new approach are being discussed. The research flowchart is shown in Figure 1. Figure 1 illustrates the logical flow of the research, which begins with the theoretical framing of biosimulation, followed by the selection of both real-world and AI-generated architectural cases, the visual comparative analysis based on defined criteria, and the interpretative evaluation of results. Each step is aligned with the objective of exploring AI-supported biosimulation as a speculative design methodology.

The concept of biosimulation, as proposed in this study, positions itself within architectural theory as a novel synthesis of these interdisciplinary foundations. By combining insights from systems theory, autopoiesis, evolutionary computation, and behavioral architecture, biosimulation provides an original framework that extends beyond existing nature-inspired design paradigms. This approach represents the study’s unique contribution by reframing the design process as a ‘living system’ paradigm, in which architecture not only emulates natural forms or aesthetics but also operates with nature’s adaptive and evolutionary logic through AI support. In summary, biosimulation bridges the gap between nature’s intrinsic behaviors and architectural creation, offering a cohesive theoretical lens that underpins the design explorations in the following sections.

[1] For example, see Dennis Dollens (2009), “Architecture as Nature: A Biodigital Hypothesis,” *Leonardo*, 42(5), 412–420.

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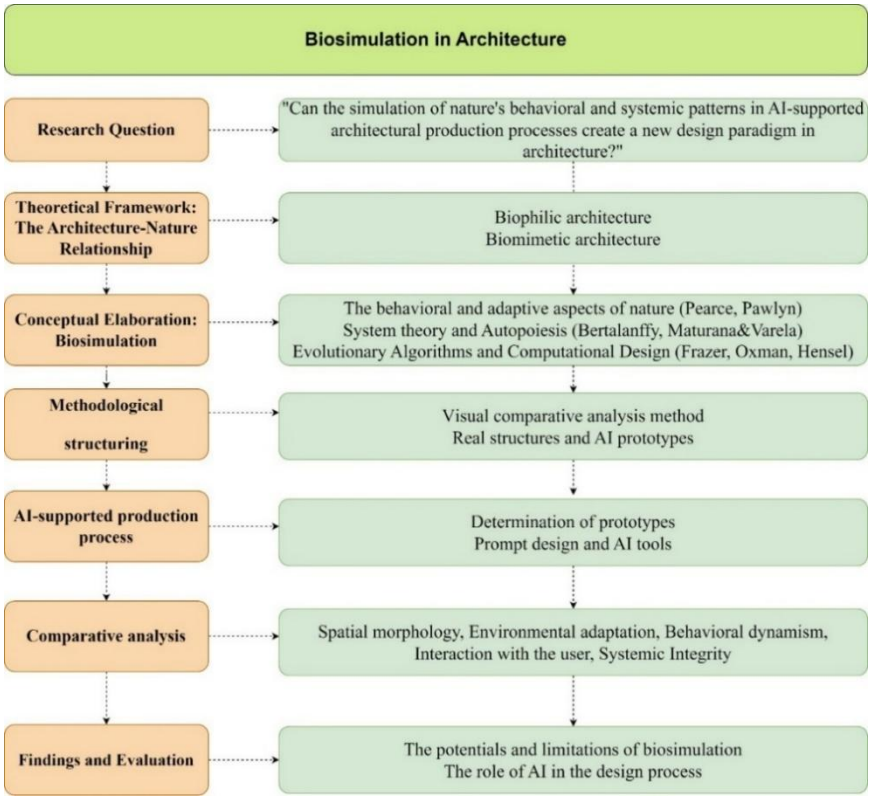


Figure 1. Flowchart of the research

2. Theoretical Foundations of Biosimulation

Nature-based design approaches have produced numerous applications and theoretical developments within modern architectural thought at both formal and conceptual levels. Since the 1980s, biophilic and biomimetic design paradigms have aimed to integrate nature's aesthetic and structural characteristics into the built environment in various dimensions [2-3]. However, most of these approaches remain on a plane that represents and imitates nature; they are limited in directly transferring nature's systemic, behavioral, and evolutionary characteristics to architectural organization [5].

This section first addresses the fundamental principles and limitations of biophilic and biomimetic approaches; then, it discusses how AI-supported computational design processes can intersect with nature-based behavioral modeling. Ultimately, the theoretical

The foundations of the concept of "biosimulation," the study's unique contribution, are presented, and its place within architectural theory is discussed.

2.1. Biophilic Foundations

Biophilic design is an architectural approach that aims to reproduce the innate closeness and tendency to bond with nature in the built environment. The concept of biophilia, proposed by Edward O. Wilson suggests that the relationships humans have established with nature throughout their evolutionary history have shaped today's behavioral patterns at psychological, physiological, and cognitive levels [8]. In this context, biophilic design does not only focus on the visual representation of nature; it also aims to reimagine the individual's relationship with nature in a multidimensional way.

The biophilic design model developed by Stephen Kellert [2] classifies this approach into three fundamental dimensions: direct contact with nature (e.g., sunlight, water, vegetation), indirect representation (nature motifs, use of natural materials, biological form analogies), and spatial experience (organic organizations, rhythmic transitions, circulation patterns) [2]. This theoretical framework not only emphasizes the relationship between environmental psychology and architecture but also supports a user-centered approach in spatial design.

The beneficial effects of biophilic design on user well-being, particularly in healthcare facilities, educational spaces, and office environments, have been well documented. Numerous empirical studies have shown that environments incorporating natural elements can reduce stress levels, enhance cognitive performance, and improve overall well-being [9–10–11]. However, biophilic design tends to treat nature primarily as an aesthetic or symbolic component, often lacking a deeper engagement with nature’s behavioral and systemic logic [12]. While these approaches remain valuable, they largely operate within a representational or static design

paradigm. In contrast, biosimulation seeks to establish a dynamic framework that enables architecture to behave, adapt, and evolve, drawing on AI-supported computational processes to simulate natural systems. This conceptual shift responds to a broader need in architectural theory: a move toward frameworks that go beyond symbolic imitation to actively engage with nature's evolutionary and organizational intelligence. In this context, biosimulation builds upon the psychological and sensory dimensions emphasized in biophilic design, extending them into a behavioral and systemic architectural logic. It enables the development of spatial systems that not only evoke nature but also learn from it, transform over time, and establish symbiotic relationships with their environment. Biophilic design thus serves as an intuitive threshold for biosimulation, from which architecture can transition into a more interactive and life-like design paradigm.

2.2. Biomimetic Strategies

Biomimetic architecture is an approach that produces designs inspired not only by the aesthetic values of nature but also by its structural, functional, and systemic logic. Derived from the Greek words bios (life) and mimesis (imitation), biomimetic aims to integrate the problem-solving methods of organisms in nature into fields such as engineering, materials science, and architecture [4]. This approach does not view nature as a fixed model. Instead, it sees nature as a network of systems; interactive, energy-efficient, adaptable, and sustainable [13].

Janine Benyus's [3] three-tiered biomimetic classification elaborates on this approach: the form level (imitation of natural forms), the process level (reproduction of biological processes), and the ecosystem level (modeling the functioning of natural systems). These three levels reveal that the approach to nature is visual and varies in structural, organizational, and behavioral aspects. For example, the Eastgate Centre building, inspired by the ventilation mechanisms of termite mounds, offers a passive climate-control solution that uses natural airflow as an alternative to artificial energy systems [14] (Figure 2). Similarly, in structures like the Eden Project, ETFE domes, inspired by natural cellular structures, embody biomimetic principles in both structural efficiency and energy permeability (Figure 3).

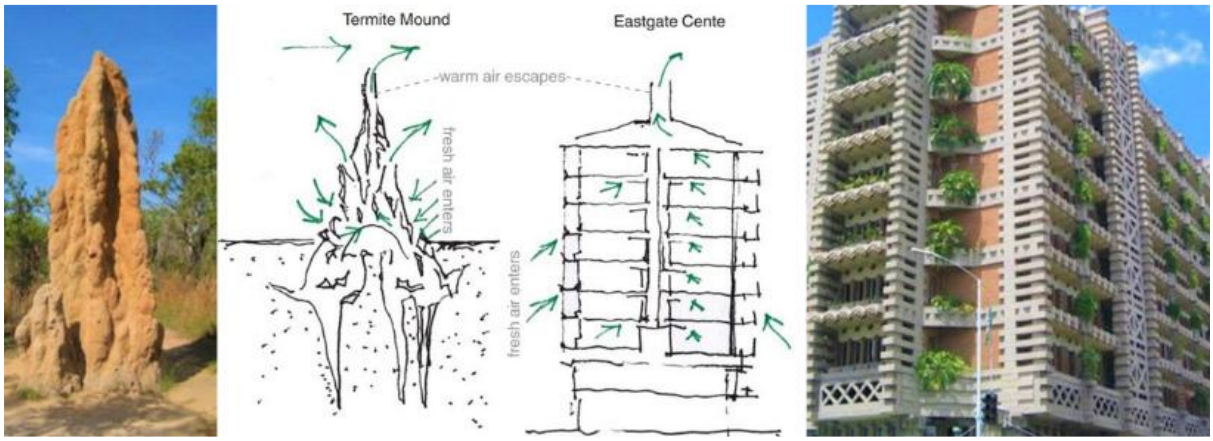


Figure 2. Ventilation systems in a termite mound and the Eastgate Centre building [15].

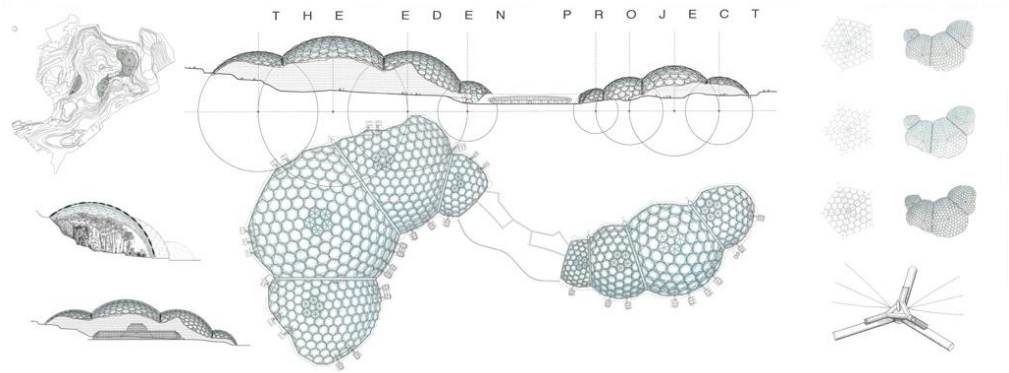


Figure 3. The Eden Project: Architectural design principles of The Biomes [16].

Biomimetic architectural practices are deeply related to sustainability-focused thinking. Nature's waste-free, circular organizational principles, carbon-neutral building technologies, and adaptive building shells yield innovative solutions [5]. However, most biomimetic applications are limited to integrating specific principles derived from nature into the building system at the initial design stage. This situation severely limits the ability to dynamically respond to environmental variables in later design stages.

In this context, the concept of biosimulation proposed by this study claims to advance the biomimetic approach to a higher level. Although biomimetic design provides a strong foundation for understanding nature, it generally remains at a static level of imitation. However, biosimulation focuses on simulating biological behaviors using artificial intelligence and computational design; in other words, it aims to produce spatial systems that operate like nature rather than resembling it. In this respect, biosimulation heralds a new way of relationship that architecture will establish with biological systems at both behavioral and cognitive levels.

2.3. Beyond Representation: Systems Theory, Evolutionary Algorithms, and Behavioral Spaces

Nature-based approaches in architecture have long focused on representing the formal and aesthetic qualities of nature. However, in today's world, nature needs to be considered not only as a visual resource but also as a behavioral and systemic model. In this context, interdisciplinary theories such as systems theory, organic design, and evolutionary algorithms offer a new paradigm for the relationship between architecture and nature.

Various interdisciplinary theories offer a shift in architectural thinking from static representations toward dynamic, responsive systems. General systems theory, particularly through the work of Ludwig von Bertalanffy, introduced the concept of open systems interacting with their environment [17], laying the foundation for conceiving architectural structures as adaptable rather than fixed entities. The theory of autopoiesis, developed by Maturana and Varela, which describes organisms as self-producing and self-maintaining systems, further reinforces this biological analogy [18]. When integrated with computational design tools such as evolutionary algorithms, genetic encoding, artificial neural networks, and agent-based modeling, these theoretical frameworks enable the simulation of nature's organizational behaviors within the architectural domain [6,19]. Rather than optimizing predefined outputs, these models promote learning, adaptation, and interaction—offering a methodological basis for biosimulation to emerge as a behavior-driven, system-oriented design paradigm.

In this context, behavioral spaces can be designed as systems that can respond to environmental variables, self-structure, and transform through user interaction. In these systems, nature does not merely serve as a metaphor but operates directly as a model. Thus, the design process can involve continuity and adaptation, much as the development of an organism. The theoretical gap that arises at the intersection of systems theory and computational design is filled in this study with the concept of biosimulation (Table 1). Biosimulation aims not only to mimic nature in design by simulating nature's behavioral patterns but also to think and act like nature.

Table 1. The Theoretical Foundations of Biosimulation

Theoretical approach	Basic Concepts	Relationship with architecture	Interaction with Biosimulation
System theory [17].	Open system, environmental interaction, dynamic structure	It considers structures as interactive systems with the environment.	It forms the systemic basis of biosimulation.
Autopoiesis theory [18].	Self-reproducing organisms, continuously updating	Architecture is seen as a self-renewing organism	An organic logic supports biosimulation
Evolutionary algorithms and computational design [19].	Genetic coding, artificial neural networks, agent-based modeling	It guides design processes with algorithms derived from nature	It enables biosimulation to operate with computational methods
Organizational thinking and behavioral architecture [6].	Response to environmental data, interaction with users, and adaptation	Defines spaces as systems that change, transform, and behave	It translates the behavioral system theory into spatial form
Biosimulation (Author)	Thinking, behaving, and reorganizing like nature	It simulates nature not as a metaphor, but directly as a model	The concept of biosimulation is formed by the combination of these (above) theoretical foundations

Beyond the computational and systems-oriented lineage discussed above, biosimulation can also be contextualized through new materialist accounts of material agency. From this perspective, architectural matter and environments are not treated as passive substrates but as active participants in the emergence of spatial organization. Concepts such as agential relations and distributed vitality offer a useful meta-level lens for interpreting biosimulation as a framework that foregrounds interaction, responsiveness, and co-constitution between spatial systems and their

contexts. This alignment strengthens the theoretical positioning of biosimulation as a speculative paradigm that shifts architectural thinking from representation toward agency-oriented design logics [30,31].

While the architectural discourse has long explored computational design, parametric modeling, and artificial life simulations, these approaches often emphasize optimization or formal generation rather than behavioral adaptation. Biosimulation contributes to this lineage by proposing an AI-supported design logic focused on responsiveness, interaction, and systemic learning. In this respect, it situates itself at the intersection of behavioral architecture, cybernetic systems, and speculative AI-generated design, forming a unique paradigm for developing spatial systems that simulate natural behavior.

2.4. AI-Supported Design Processes and Speculative Architectural Applications

The increasing presence of artificial intelligence technologies in architecture theoretically allows for the redefinition of design processes as both automation and learning, adapting, and responsive systems. Traditional design methodologies often establish linear structures shaped by specific inputs and focused on fixed outputs, while AI-supported computational design processes create open systems that are fed by data, capable of generating variations, and possessing evolutionary qualities [20]. This transformation holds great potential in shifting architecture's relationship with nature from the representational plane to the behavioral plane.

Computational design tools and artificial intelligence techniques (genetic algorithms, artificial neural networks, diffusion models, large language models) enable architecture not only to produce formal diversity but also to create systems sensitive to environmental, social, and functional contexts by processing environmental data [21]. For example, while visual variations inspired by nature can be obtained in form generation using diffusion-based AI models like Midjourney or DALL·E, behavioral performances related to climate data, user movements, or energy consumption data can be simulated with AI plugins based on Rhino/Grasshopper [7].

Speculative architectural applications use the possibilities offered by these tools not only as technical optimization methods but also as critical and visionary design tools. In this context, Theodore Spyropoulos's concept of "behavioral design agency" argues for positioning the designer not merely as a form-giver but as an entity that writes the system's rules and defines autonomy [22]. In this process, artificial intelligence is not just a tool; it becomes a partner in co-constructing the development of architectural thought.

Architecture practices working with artificial intelligence have begun to create living spatial constructs through methods such as digital prototyping, parametric morphogenesis, synthesized nature models, and agent-based simulations. Especially in the context of posthuman architectural thought, these approaches aim to place a logic beyond humanity and a symbiotic interaction with nature at the center of the structure. Thus, the design process aims to produce not only responses to human needs but also spatial organisms with ecological intelligence, constantly evolving and intuitive.

The concept of biosimulation proposed in this study aims to integrate these new design paradigms supported by artificial intelligence with the behavioral patterns of nature in architecture. Artificial intelligence is not just a form generator; it is a design actor that simulates nature, makes data-based decisions, and forms the algorithmic core of living spaces. Recent reviews also highlight that while generative AI models have rapidly expanded their role in early-stage architectural design, their integration remains primarily representational rather than performative or system-based [32, 33].

2.5. Conceptual Positioning of Biosimulation

Nature-based design approaches in architecture have generally developed around two main axes: biophilic design, which represents emotional and psychological orientations aimed at bringing the intrinsic human connection to nature into space; and biomimetic design, which aims to technically integrate nature's formal and systemic patterns into the built environment [2-3]. Although both approaches aim to establish a strong connection between nature and architecture, the paradigms they represent are largely fixed, predetermined, and limited to one-way relationships. Nature has been incorporated into the field of architecture either as an aesthetic motif or a technical solution. However, the most fundamental characteristic of nature is not stability, but continuous change, adaptation, and evolution.

This study defines the concept of biosimulation, which it presents as a new conceptual proposal in the field of architecture, as a new paradigm that combines these evolutionary and behavioral characteristics of nature with AI-supported design processes. Biosimulation describes an architectural thought that not only represents or imitates nature but also computationally simulates behavioral patterns, responds to environmental and social inputs, and produces living spatial systems (Table 2). In this context, biosimulation transcends biophilic and biomimetic approaches and offers a conceptual framework that reorganizes them.

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Table 2. Comparison of Biophilic, Biomimetic, and Biosimulative Architecture

Criterion	Biophilic architecture	Biomimetic architecture	Biosimulative architecture (Biosimulation)
The "*nature*" of the relationship with nature	Emotional and symbolic (establishes an experiential connection with nature)	Formal and systematic (imitates nature from a technical perspective)	Behavioral and adaptive (systems that think and respond like nature)
Formal design approach	Aesthetic and sensory solutions inspired by nature	Reproduces forms and structures in nature using technical tools	Simulates the processes, behaviors, and adaptation abilities of nature
Behavioral and adaptive capacity	Limited; generally static and passive	Medium; environmental response may be present in some systems	High; active and adaptive, real-time environmental and user interaction
Environmental adaptation abilities	Passive, limited level of environmental response	Generally offers fixed solutions, with limited environmental response capacity	Active; real-time responses to the environment and adaptive solutions
Role in the design process	A helper that enhances aesthetic and sensory quality	The role of improving structural and technical solutions	The fundamental paradigm shaping design processes
Spatial intelligence level	Low; systems that resemble nature but do not behave like nature	Medium; structures that imitate technical systems and models from nature	High; learning systems that simulate nature's adaptive intelligence
Main focus point	Strengthening the human-nature connection, improving user experience	Energy efficiency, structural optimization, and technical performance	Responding to environmental crises, creating adaptive and learning spaces
Use of technology in design	Limited; mostly the use of natural materials and landscaping	High; advanced technologies and digital tools are common in form production	Very high; artificial intelligence, simulation tools, and adaptive technologies

The foundation of biosimulation is the application of the self-replicating, environmentally interacting, and learning structural behaviors of organisms in nature to space through artificial intelligence algorithms [6, 7]. In this approach, artificial intelligence serves not only as a production tool but also as an intelligence layer that interprets and reconfigures the behaviors of natural systems. Thus, the design process evolves into spatial organisms that not only respond to human needs but also react to environmental variables, develop their own organizational logic, learn, and transform.

This theoretical positioning intersects particularly with fields such as systems theory, new materialism, posthuman architecture, and cybernetic thought [8, 17, 23]. The architectural understanding proposed by biosimulation suggests a behavioral, relational, and process-based existence instead of a fixed design object. In this respect, biosimulation is not just a technical strategy but a new architectural ontology: the ontology of architectural systems that live within nature, think with it, and act like it.

3. Method

3.1. Positioning Biosimulation in Architectural Thinking

The theoretical framework presented in the previous sections of this study has addressed the representative, mimetic, and behavioral orientations of architecture towards nature in a layered manner. While biophilic and biomimetic approaches offer aesthetic, functional, and structural representations of nature in architectural production, the concept of biosimulation, which is the unique contribution of this study, proposes transferring nature's behavioral and systemic patterns to the architectural plane through AI-supported processes (Figure 4).

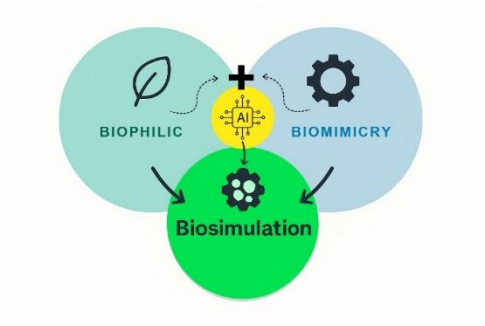


Figure 4. Combining biophilic and biomimetic design approaches with AI-supported processes gives rise to the concept of biosimulation in architecture (Figure created by the author).

To demonstrate the applicability of this proposal developed at the theoretical level, the research continues with a comparative analysis of both biophilic/biomimetic architectural examples selected from the real world and speculative prototypes produced by artificial intelligence. This comparison is conducted through multiple criteria such as form-morphology, organizational logic, environmental adaptation potential, level of user interaction, and behavioral capacity.

The study's methodological approach aims not only to present a speculative theory but also to evaluate the structural and conceptual correspondences of the spatial

outputs of this theory. Thus, it is debated whether biosimulation in architecture is theoretical and a tool that can be designed, evaluated, and developed.

3.2 Methodological Approach and Rationale

In architectural research, evaluating the spatial correspondences of theoretical proposals requires concrete tools not only on an intellectual level but also in terms of applicability to design. In this context, the visual comparative analysis method has been adopted in this study to analyze how the proposed concept of biosimulation can find its place in architectural production. This method allows for simultaneous comparisons between physically constructed, real-world structures and speculative prototypes produced by artificial intelligence, enabling the multidimensional testing of the conceptual framework [24].

Visual comparative analysis, especially in contemporary architecture, allows for the multilayered reading of parameters such as form, organization, context, and user experience. Going beyond traditional verbal or numerical analyses enables the evaluation of more intuitive yet conceptually meaningful elements, such as form, morphology, spatial hierarchy, and relationships with the user [25]. Therefore, visual analysis is methodologically appropriate and conceptually integrative in evaluating a concept like biosimulation, which is both formal and behavioral.

Additionally, in the history of architecture, approaches referencing nature have often been evaluated through retrospective readings. However, the production methods offered by AI-supported design tools enable the development of speculative models that look towards the future [20]. In this context, the method used in the study not only examines existing structures but also provides projections of what potential future spaces might look like. Comparing real structures and AI-supported prototypes is meaningful for questioning what architecture can achieve in nature-based design processes and how biosimulation can expand these boundaries.

Additionally, the visual and behavioral comparison of prototypes produced by artificial intelligence with real structures has the potential to demonstrate that the concept of biosimulation is not merely an abstract idea; it offers a designable, measurable, and developable architectural approach. Thus, the methodological preference enables the establishment of a strong bridge between the theoretical and the experimental. Thanks to this bridge, structures that think and react like nature are not just speculative imaginations, but architectural systems that can be comparatively assessed.

3.3 Case Study Selection Criteria

Within the framework of the comparative analysis method used in this study, three biophilic/biomimetic architectural structures are selected from the real world, and three speculative prototype examples are produced through artificial intelligence.
The selected real-world cases were chosen to represent distinct tendencies within biophilic and biomimetic design: Eastgate Centre exemplifies biomimetic climate control through passive systems, Eden Project represents structural biomimicry inspired by cellular forms, and Bosco Verticale illustrates biophilic integration of vegetation within high-density urban architecture. Together, these cases offer a diverse foundation for comparative evaluation against the speculative biosimulation prototypes.

The main purpose of selecting these examples is to demonstrate how the concept of biosimulation can manifest in different types of spatial systems in formal, organizational, and behavioral dimensions. In this context, the case selection has been designed with a dual approach: on one hand, analyzing fixed structures inspired by nature, and on the other hand, conducting a conceptual test with artificial productions assumed to possess behavioral and transformable characteristics.

Among the real structures, the Eastgate Centre, which stands out for its natural ventilation system inspired by termite mounds, the Eden Project, designed with a cellular structural organization, and The Bosco Verticale, which is intertwined with urban nature (Figure 5), are included. Each structure embodies biomimetic or biophilic approaches and is considered a reference in the architectural literature [1, 14, 26].

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Figure 5. The Bosco Verticale acts as a vertical forest system that regulates temperature, allows light penetration, shields from wind, releases humidity, captures fine dust particles, produces oxygen, and mitigates both CO_2 emissions and acoustic pollution [27].

In the examples produced with artificial intelligence, three different scenarios inspired by behavioral patterns in nature have been proposed: Myco-Habitat is a spatial concept inspired by mycorrhizal networks and based on the simulation of information flow between structures; Photosynthetic Pavilion represents a semi-organic structural system that grows and opens and closes in response to light; Coral Shelter, on the other hand, is a porous and permeable structure that develops according to the growth logic of sea corals.

Each example has been evaluated against five fundamental criteria that enable the analysis of the spatial potential of biosimulation: formal organization, environmental adaptation, behavioral capacity, systemic integrity, and interaction with the user. According to these criteria, the extent to which the structures "biosimulate" will be interpreted (Table 3).

Table 3. Constructed Biophilic-Biomimetic Examples and Biosimulation Prototypes

Name	Type	Inspiration	Main Feature	Relationship with Biosimulation
Eastgate Centre	Built structure	Termite mounds	Passive climate control	Technical imitation of behavioral organization
Eden Project	Built structure	Cellular structures	Lightweight and permeable structure	Structural biomimetics
Bosco Verticale	Built structure	Urban ecosystem/vegetation	Vertical afforestation	Biophilic experiential intensity
Myco-Habitat	AI prototype	Mycorrhizal communication network	Distributed organization	Knowledge-based simulation
Photosynthetic Pavilion	AI prototype	Plant photosynthesis	Light-sensitive shell	Stimulus-based growth model
Coral Shelter	AI prototype	Coral formations	Porous biological shell	Organic evolutionary organization

3.4 AI-Based Prototype Development Process

In this study, three speculative prototypes were developed to evaluate the architectural potential of the concept of biosimulation, using AI-supported visual production tools. The produced prototypes (Myco-Habitat, Photosynthetic Pavilion, and Coral Shelter) are inspired by natural organism systems.

However, they are unique artificial creations that aim to represent these systems not only at a formal level but also at a behavioral level. In the present study, AI is employed specifically for concept visualization and speculative prototyping; therefore, the generated outputs should be read as representational design hypotheses rather than operational architectural systems. Each AI-generated prototype was developed through a carefully designed prompt that translated a specific natural system into architectural language. Tools such as Midjourney, DALL·E, Leonardo AI, and Microsoft Designer were used to generate form variants from prompts. The conceptual depth of these prompts was aligned with the core principles of biosimulation: growth, responsiveness, and distributed intelligence. Table 4 summarizes the biological reference, prompt used, and conceptual keywords for each prototype.

The success of architectural visuals produced with artificial intelligence largely depends on the design of the prompts used. In this context, detailed and conceptually deepened text inputs were used for each prototype; concepts such as spatial behavior, nature-based principles, and environmental interaction were meticulously defined in these inputs [28]. In the training experiments conducted by Yaşar et al. [29], it has been demonstrated that the concreteness of the prompt content, language proficiency, and the quality of the AI tool used directly affect visual production quality. Prompts have been structured to include behavioral logics such as the responses of organisms in nature to environmental stimuli, network-based relationships, or growth algorithms.

The prompt developed for Myco-Habitat is designed to reflect the signaling, resource sharing, and network-based structural organization of mycorrhizal networks in forest ecosystems.

"Design a decentralized architectural building inspired by underground mycorrhizal networks, enabling inter-structural communication, organic growth, and environmental responsiveness. Aesthetic reference: forest soil, roots, mist."

The prompt developed for the Photosynthetic Pavilion focuses on the opening and closing movements of plant leaves in response to the photosynthesis process and sunlight. As an architectural counterpart of this system, a semi-organic, permeable structure that can respond to environmental variables has been conceived:

"Create a photosynthetic architectural shell that opens and closes in response to sunlight intensity, inspired by plant leaf structures. Semi-transparent, organic, responsive."

Finally, the prompt developed for the Coral Shelter prototype envisioned an architectural system that evolves form-wise based on the layered, porous, and branched structural formations of sea corals and can adapt to environmental inputs like currents.

"Generate a porous, coral-inspired architectural shelter that grows in response to ocean current simulations. Emphasis on calcified texture, branching structures, and adaptive layering."

These visuals go beyond classical AI-generated imagery because they are designed not only for form production but also based on behavioral potential. The aim here is to transform the behavioral principles of natural organisms into architectural representation.

To more clearly showcase the critical role of prompts in the production process and their conceptual depth, Table 4 below presents the natural source of inspiration for each prototype, the prompt used, and the conceptual axes holistically represented by that prompt.

Table 4. AI Prompt Details and Conceptual Matches

Prototype Name	Natural Source of Inspiration	Prompt	Conceptual keywords
Myco-Habitat	Mycorrhizal networks (fungal root systems)	*Design a decentralized architectural building inspired by underground mycorrhizal networks, enabling inter-structural communication, organic growth, and environmental responsiveness. Aesthetic reference: forest soil, roots, mist.*	network structure, symbiotic communication, growth organization
Photosynthetic Pavilion	The opening and closing mechanisms of plant leaves based on photosynthesis	*Create a photosynthetic architectural shell that opens and closes in response to sunlight intensity, inspired by plant leaf structures. Semi-transparent, organic, responsive.*	interaction with light, spatial flexibility, photosynthetic shell
Coral Shelter	Coral formations and growth patterns compatible with underwater ecosystems	*Generate a porous, coral-inspired architectural shelter that grows in response to ocean current simulations. Emphasis on calcified texture, branching structures, and adaptive layering.*	porosity, environmental evolution, sensitivity to flow

The role of AI tools in this process is not limited to being merely a creative assistant. AI functions here as the visual modeler of biosimulation; that is, it becomes a design actor that simulates the potential organizational forms, behavioral patterns, and contextual responses of natural systems. Therefore, the production process carries both technical and conceptual depth, and the resulting visuals are artificial architectural organisms that present aesthetic and behavioral hypotheses (Table 5).

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Table 5. AI-Generated Biosimulative Architecture Systems

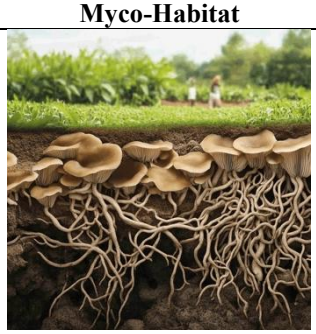
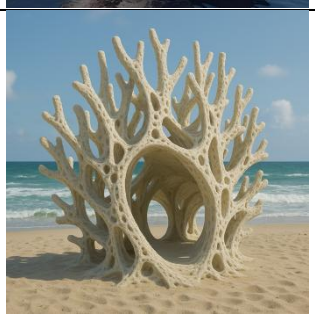
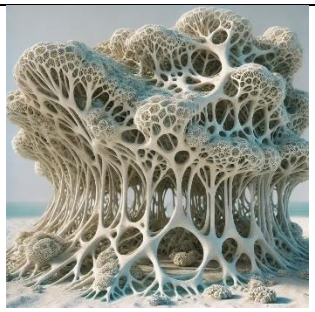
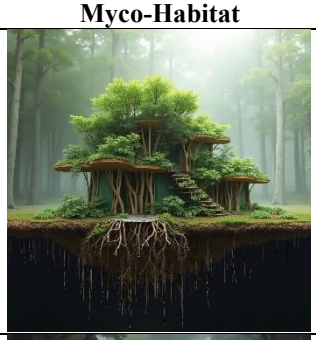
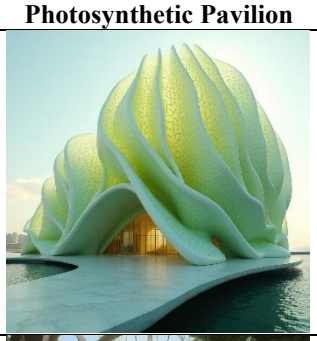
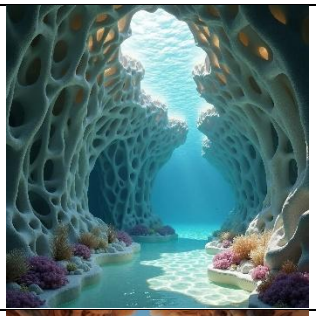
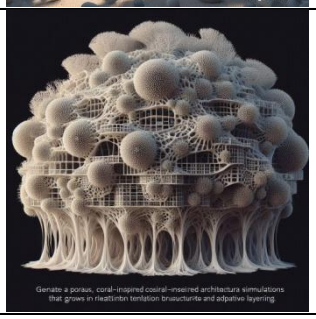
Tool	Myco-Habitat	Photosynthetic Pavilion	Coral Shelter
Real world ref. image			
Canva			
ChatGpt-4.0			
Dall-e			
DeepAi			

Table 5. (continued)

Tool	Myco-Habitat	Photosynthetic Pavilion	Coral Shelter
Leonardo-AI			
MagicStudio			
Microsoft-Designer			

These three prototypes will be analyzed in the next phase by visually and functionally comparing them with selected real structures, thereby examining the conceptual capacity of biosimulation. Thus, it will be demonstrated that AI-supported production is a creative tool and offers an architectural experimental environment with conceptual validity.

3.5. Comparative Evaluation Framework and Criteria

To evaluate the extent to which the concept of biosimulation is reflected in the architectural context, six structural examples (three real and three generated by artificial intelligence) have been compared using specific analysis criteria. These criteria aim to examine the difference between "resembling nature" and "acting like nature," which lies at the center of the conceptual framework.

- These criteria are defined as follows to clarify the analytical framework:
- Spatial Morphology refers to the formal complexity and biomorphic organization of a structure, particularly its relationship to natural geometries such as fractals, networks, and cellular patterns.
- Environmental Adaptation evaluates the structure's capacity to interact with environmental factors—whether through passive strategies (e.g., natural ventilation) or active responsiveness to stimuli like light or humidity.
- Behavioral Dynamism considers the degree to which a design can transform, evolve, or respond autonomously over time, reflecting a system's ability to exhibit lifelike adaptation.
- User Interaction assesses how effectively the design engages users on sensory, emotional, and behavioral levels, including responsiveness and feedback mechanisms.
- Systemic Integrity measures the coherence and interrelation between the system's components (form, function, material, environment, and user experience) operating together as a unified, adaptive whole.

These criteria serve as technical parameters and theoretical tools for assessing whether biosimulation can become an ontology in architecture. During the analysis,

the structures were evaluated against these five criteria to determine whether they possess a high, medium, or low level of biosimulation potential. This evaluation used a qualitative content analysis based on the relevant literature on biosimulation, behavior-oriented architectural analysis, and nature-inspired design approaches [6, 14, 31], as well as information on the designs, visuals, and conceptual definitions (Table 5). Table 6 presents the expanded definitions of the biosimulation criteria and the approaches used for determining low, medium, and high ratings.

As shown in Table 6, AI-generated prototypes, particularly Myco-Habitat and Coral Shelter, exhibit strong potential for behavioral dynamism and systemic integration, whereas real-world cases tend to perform better in environmental adaptation and user interaction. This contrast underlines the speculative strengths of biosimulation, while also revealing its current limitations in applied architectural contexts.

Table 6. Case Typology and Biosimulation Potential Matrix

Structure / Prototype	Spatial Morphology	Environmental Adaptation	Behavioral Dynamism	User Interaction	Systemic Integrity
Eastgate Centre	Medium	High	Low	Medium	Medium
Eden Project	High	Medium	Low	Medium	High
Bosco Verticale	Medium	Medium	Low	High	Medium
Myco-Habitat (AI)	High	High	High	Medium	High
Photosynthetic Pavilion (AI)	High	High	Medium	High	Medium
Coral Shelter (AI)	High	Medium	High	Medium	High

Table 7. Explanation Table of Evaluation Criteria

1. Spatial Morphology
• High: Structures or prototypes that intensely and distinctly display the structural patterns of nature (for example, fractal or biomorphic forms). For example, the cellular and biomorphic structures of the Eden Project [1].
• Intermediate: Structures resembling natural formations but whose organization and shaping are close to classical architecture. For example, Eastgate Centre [14].
• Low: Structures that are distinctly distant from natural forms or patterns, following more conventional architectural forms.
2. Environmental Adaptation
• High: Structures with high energy efficiency systems that respond directly and actively/passively to environmental data. The natural ventilation system of the Eastgate Centre is a good example of this [14].
• Medium: Structures designed to be compatible with environmental factors but with a limited level of interaction. Like the Eden Project [1].
• Low: These are classic closed system designs that do not provide active or passive interaction with the environment.
3. Behavioral Dynamism
• High: Systems that change over time, can adapt, or respond in real-time to environmental factors. For example, systems like the AI prototype Myco-Habitat have the capacity for dynamic interaction with the environment.
• Medium: Prototypes with some fictional or partial mobility/reaction characteristics.
• Low: Structures with fixed form and fixed structural characteristics, lacking behavioral flexibility or mobility (for example, real building examples like Eastgate, Eden, and Bosco Verticale).
4. User Interaction
• High: Structures that directly enrich users' experiences and create sensory and emotional interactions. Bosco Verticale is an example of this with its biophilic design that allows users to establish intense emotional connections with nature [26].
• Medium: Structures that partially support user experience but have limited direct interaction (for example, systems like Eastgate Centre that offer indirect interaction).
• Low: Designs that do not prioritize user interaction, focusing solely on functionality.
5. Systemic Integrity
• High: Structures that establish a strong, organic bond and integrated system among all structure components (form, function, environmental interaction, user experience, etc.) (for example, Coral Shelter and Eden Project).
• Intermediate: Structures that connect components but provide more fragmented and partial integration (like Bosco Verticale or Photosynthetic Pavilion).
• Low: Structures with weak inter-component connections that do not ensure system integrity.

The evaluation criteria presented in Table 7 were developed by the author as an analytical framework derived from the theoretical foundations of biosimulation discussed in the literature. The criteria are conceptually grounded in prior studies on performance-oriented architecture, behavioral architecture, biomimetic design, and systems-based architectural analysis (e.g., Hensel, 2013; Frazer, 1995; Oxman, 2010; Groat & Wang, 2013).

The evaluation was conducted by the author through a qualitative visual–conceptual content analysis. Each architectural case and AI-generated prototype was

assessed individually based on visual material, documented design descriptions, and the conceptual intentions defined within the study.

The ratings (low, medium, high) do not represent quantitative performance measurements; rather, they indicate the relative degree to which each case aligns with the biosimulation criteria, particularly in terms of behavioral potential, environmental responsiveness, and systemic integration.

During the analysis, no numerical scoring or statistical processing was applied. Instead, the assessment followed an interpretative-comparative logic, enabling the positioning of each case within the proposed biosimulation framework. This approach is consistent with qualitative architectural research methodologies that emphasize conceptual interpretation over empirical measurement.

The comparative findings based on the five evaluation criteria reveal notable distinctions between AI-generated prototypes and real-world architectural examples. These findings do not constitute performance-based claims; rather, they represent a conceptual positioning supported by a visual-analytical comparative evaluation.

– Spatial Morphology: All six cases display nature-inspired formal complexity, but the AI-generated forms (especially Coral Shelter) demonstrate more experimental and biomorphic geometry.
– Environmental Adaptation: Real-world projects such as Eastgate Centre perform better in practical environmental response due to their integration of passive systems.
– Behavioral Dynamism: Myco-Habitat and Coral Shelter exhibit higher potential for transformation and responsiveness, reflecting speculative behavior-driven design logic.
– User Interaction: Bosco Verticale achieves strong emotional engagement through its biophilic integration, while AI prototypes offer only representational interaction.
– Systemic Integrity: AI prototypes achieve conceptual coherence across their form, function, and environmental logics, though this is not yet realized in physical practice.
While the AI-generated prototypes show high conceptual potential in terms of system integration and behavioral logic, their physical realization remains constrained by current construction technologies. These limitations, however, do not undermine their value; rather, they highlight the speculative and theoretical strength of biosimulation as a forward-looking design paradigm.

4. Findings and Theoretical Implications

The comparative analysis conducted in this study suggests that the concept of biosimulation is not only a theoretical proposition but also has meaningful counterparts in the formal, organizational, and behavioral dimensions of architectural design. Evaluations of real structures and speculative prototypes generated by artificial intelligence have shown that the relationship with nature in architecture is not merely an aesthetic metaphor or a passive system integration; rather, it carries an active transformational potential through structures that generate behavior and are reshaped by environmental data.

Although many real structures are defined as systems inspired by nature or that interact with nature, these examples generally involve a static representation of nature. Natural processes have been transferred to architecture either as a formal model (for example, cellular domes) or as a functional metaphor (for example, passive ventilation). In this respect, architecture has produced a language that "resembles" nature but does not act like it.

In contrast, prototypes produced with artificial intelligence are designed not only to simulate the formal characteristics of nature but also its organizational logic and behavioral responses. These prototypes propose systems that go beyond classical parametric design, designed to suggest responsiveness to environmental data, growth, networking, and reorganization of their internal logic. In this respect, artificial intelligence should not be considered merely an assistant in the design process; it should be regarded as a level of intelligence that establishes the epistemic infrastructure of biosimulation.

One of the most important findings of this study is that biosimulation offers a paradigmatic change not only at the level of design objects but also at the level of design thinking. Most biophilic or biomimetic designs establish their relationship with nature as fixed and human-centered; however, biosimulation argues that this relationship can be reconstructed behaviorally, procedurally, and organismically. This approach suggests rethinking not only the design of spaces but also the act of designing itself, as a process closely aligned with the logic of nature.

However, some limitations regarding the applicability of AI-supported prototypes in the physical world should not be overlooked. Current construction technologies, material intelligence, and building capabilities are still in the early stages of producing behavioral structures. However, this limitation does not diminish the conceptual power of biosimulation; rather, it creates an intellectual leap into the future of architectural thought. This leap does not merely involve producing form; it opens up a discussion on how form can learn, evolve, and co-evolve with nature.

This assessment suggests that biosimulation offers an alternative design ontology in architecture. This ontology proposes changing systems rather than fixed structures,

behavior rather than form, and nature-based communication rather than human-centered control. Architecture can now become not just a representation of nature, but a network of intelligence living with it.

5. Conclusion

This study proposes the concept of biosimulation as an approach to rethink the relationship with nature in architecture, and to reconstruct it not only through aesthetic or technical representations but also at the behavioral and systemic levels. While the contributions of biophilic and biomimetic design paradigms are appreciated, it has been determined that these approaches are largely based on fixed, one-dimensional, and representation-focused systems. In contrast, biosimulation represents a more dynamic and multilayered approach that aims to incorporate nature's moving, responsive, and evolving organizational forms into AI-supported architectural processes.

The concept of biosimulation, developed within a theoretical framework, has been tested at the methodological level using a visual comparative analysis of six selected cases. Comparisons between biophilic/biomimetic building examples drawn from the real world and speculative prototypes generated by artificial intelligence argue that biosimulation can offer not only speculative but also a meaningful design epistemology in architecture. The prototypes developed with artificial intelligence tools, as systems capable of responding to environmental data and establishing structures at the behavioral and organizational levels, have the potential to deepen the relationship between architecture and nature.

Among the limitations of the study, the limited applicability of prototypes produced with artificial intelligence in the physical world and the fact that artificial intelligence simulates behaviors only visually can be mentioned. However, these limitations do not weaken the conceptual validity of biosimulation; rather, they open a new speculative field for architectural thought, issuing a strong call to explore ways of producing designs that behave like nature rather than merely resembling it.

Biosimulation represents an emerging design paradigm that repositions architecture as an adaptive, evolving, and systemically intelligent entity. While still speculative in application, it offers a valuable lens for rethinking the relationship between design, nature, and technology.

In summary, the findings indicate that AI-supported biosimulation holds strong potential for rethinking architecture as an adaptive, learning, and systemic practice, even though its application remains conceptual at this stage.

Future research

This research presents the theoretical foundations and application potential of biosimulation, proposed as a new paradigm among nature-based approaches in architecture. However, since the study focuses on evaluating speculative prototypes through AI-supported visual representations, aspects such as material reality, physical feasibility, and user experience have been excluded from the concept's scope. This situation, while limiting the scope of the research, also offers new avenues for future studies.

Future studies could involve the physical prototyping of biosimulative concepts, potentially incorporating responsive materials or robotic components to assess real-world adaptability.

Research may also explore biosimulation at the urban scale, particularly in relation to adaptive public space design.

In architectural education, biosimulation could be integrated into design studios to encourage critical thinking around AI-supported speculative processes.
This study presents the theoretical foundation of the concept of biosimulation, along with initial application examples; it also emphasizes that the concept is open to further research across spatial, technological, and pedagogical dimensions.

Author's Contributions

Fazıl Akdağ: Conceived and designed the study, developed the theoretical framework, generated the AI-supported prototypes, performed the comparative analysis, and drafted and wrote the manuscript.

Ethics

There are no ethical issues after the publication of this manuscript.

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