



# **WOOD-SKIN: Designing with Nature – Translating Natural Complexity Through Computational Workflows and Material-Centered Fabrication**

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## **Abstract**

This paper presents a practice-based research approach that examines design-led applications and digital fabrication methods within the context of existing computational design theories. The paper explores the approach of WOOD-SKIN, a digital fabrication system that integrates nature-inspired geometries with standardized architectural production workflows. WOOD-SKIN facilitates the creation of flexible, three-dimensional panels from flat materials through a patented process and developability-driven computational workflow. These panels, fabricated via 3-axis CNC milling, incorporate a textile core that functions as a hinge, enabling spatial transformations from flat sheets to three-dimensional forms. Focusing on the 4300 Wilson project as a case study, developed by the authors and the team at WOOD-SKIN, the paper investigates how nature-inspired, algorithmically generated forms can be translated into buildable and sustainable solutions. The research positions WOOD-SKIN within the broader discourse of digital-material ecologies, drawing on theories of fractal geometry. (Mandelbrot, 1982), chaos theory (Gleick, 1987) and digital ontology (Bridle, 2022). By embedding fabrication intelligence directly into geometries and maintaining a feedback-oriented design-to-production process, WOOD-SKIN challenges conventional and linear workflows and proposes a recursive, adaptive methodology. The study demonstrates how this approach reduces material waste, enhances transportation efficiency, and supports sustainable construction practices. Ultimately, WOOD-SKIN is presented as both a technical innovation and a conceptual framework for rethinking the relationship between tools, materials, and form-making in architecture, offering a model for future workflows where digital precision and natural complexity converge.

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## **Keywords**

*Material design thinking; Nature-inspired complex geometry; Computational workflow; DfMA; WOOD-SKIN*

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## **1. Introduction: Digital, Computed, and Organic**

In the current epoch of design, a significant transformation is underway: a shift where the digital, the computational, and the organic converge into a continuous and dynamic dialogue. Design has moved from fixed patterns and repetition to embracing and fostering complexity. WOOD-SKIN operates within this approach, aiming to interpret the ingrained complexity of nature and translate its organic characteristics into architecture. As technology now allows

for more detailed analysis and reproduction of the intricate geometries found in nature, fabrication methods are being reimagined as dynamic and responsive.

This paper explores how WOOD-SKIN's computational workflows and material-centered design thinking bridge the gap between digital representation and physical construction. Focusing on the 4300 Wilson project, built in 2019 in Virginia, USA, as a case study, engineered and developed by the authors and the team at WOOD-SKIN, we examine how nature-inspired geometries are realized through feedback-driven design-to-fabrication workflows. Assembled during the pandemic, 4300 Wilson exemplifies how digital precision can produce innovative and sustainable solutions. The project was executed completely remotely, illustrating the strength and adaptability of the workflow.

Simon Winchester observed that “precision is the result of centuries of evolution, both natural and mechanical,” framing precision not as a technical feat but as an evolutionary continuum. (Winchester, 2019). This perspective underpins WOOD-SKIN's approach, where digital fabrication is not about replicating precision artificially, but about embedding evolutionary adaptability within the design system. Benoit Mandelbrot's Fractal Geometry of Nature reveals that the apparent irregularity of natural elements such as clouds, mountains, and lightning is not a flaw but, in fact, a manifestation of profound mathematical precision. (Mandelbrot, 1982). WOOD-SKIN's computational workflows adopt this principle by preserving geometric irregularities in fabrication, translating complexity into manufacturable, buildable surfaces. James Gleick furthers this discussion, illustrating that within the apparent disorder of the natural world lies an underlying order. (Gleick, 1987). A concept that drives WOOD-SKIN in the use of computational tools to harness complexity and render it into buildable designs.

WOOD-SKIN's design philosophy draws from these insights. Its panel system, composed of rigid layers bonded with a textile core, behaves like a living membrane: flexible, adaptable, and capable of deforming in response to site-specific conditions. This adaptability draws parallels to natural systems, as represented in Figure 1, where natural organisms deform or stretch in response to environmental conditions. WOOD-SKIN's panel system applies the same logic without requiring alterations between the design and fabrication phases. This research proposes that embedding fabrication intelligence into design geometries can dissolve the traditional boundary between representation and construction, enabling architecture to operate as a living and adaptive system.

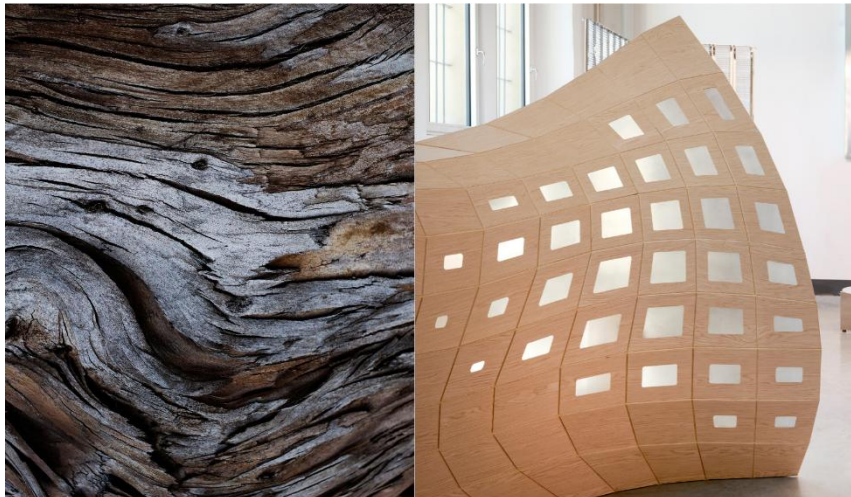


Figure 1. From natural complexity to architectural surface - translating organic forms into WOOD-SKIN's material systems. (2025, Tim Mossholder (left) and Andrea Segliani created by WOOD-SKIN® (right)).

## 2. Model Making as a Proxy for Natural Selection

In the process of transforming digital abstractions into physical realities, model-making serves not only as an essential intermediary but as a dynamic proxy that parallels the mechanisms of natural selection. In nature, only the fittest forms survive and evolve continuously to adapt to their environments. Similarly, digital models and physical prototypes are methods for designers to develop ideas, in which each iteration is reviewed for both aesthetic and functional viability.

Nikos Salingaros states that architectural forms evolve through a form of cultural selection, much like organisms evolve through environmental pressures. (Salingaros, 2013). According to Salingaros, the persistence of a form is not the result of aesthetic preference alone, but of deep structural logic; forms that work survive and are replicated. WOOD-SKIN treats each iteration as an adaptive structure shaped by environmental constraints. Rather than empowering a single ideal form, the system encourages generative variation and multiple possible solutions, selecting those that best integrate performance, constructability, and design intent.

Model-making within the WOOD-SKIN workflow functions not as a static act of representation, but as an iterative evolutionary system. Each prototype, mock-up, or parametric study is a step in an iterative feedback loop where material behavior, aesthetic feedback, and logistical constraints guide progressive adaptation. Whereas in nature, selection arises from random mutations and survival pressure, design adaptations are deliberate, but they similarly respond to environmental pressure such as budget, site constraints, and client demands, ultimately mirroring natural selection's ecological logic. In this sense, digital and physical models become more than tools of representation; they act as vehicles of knowledge and catalysts for transformation. What emerges is not a finalized object but a species of solutions, continuously optimized for resilience, cost, performance, and expression.

### **3. Representation and Loss of Information**

The transformation from digital conception to physical realization is inherently vulnerable to the loss of information. Every digital model, regardless of how meticulously crafted, carries with it a wealth of data that risks being lost in adaptation to physical format. The challenge is to preserve the delicate exchange of geometry and topology inherent in natural forms as they transition from digital designs to physical panels and structures. In this section, we analyze how WOOD-SKIN's workflow addresses this issue by embedding fabrication logic into geometry, reducing information loss, and rethinking the role of representation in architectural production.

#### **3.1. Embedding Logic into Geometry**

The Canadian Centre for Architecture proposes in *When is the Digital in Architecture?* that digitality is not a temporal event but a fundamental shift in perspective, an interrogation of how architecture is conceived, represented, and materialized (Goodhouse, 2017). Digital tools do not simply replace analog methods; they reframe the architect's role, turning representation into a process of action.

WOOD-SKIN builds on this framework by embedding fabrication intelligence directly into geometric data. Its algorithms encode fold angles, hinge tolerances, panel connections, and toolpath parameters, ensuring that material behavior reflects design intent without the need for extensive post-processing or manual interpretation.

In this sense, our analysis reveals that WOOD-SKIN's workflow acts as a computational ecology, where each design decision propagates through to fabrication, assembly, and performance, forming a closed loop of feedback. Unlike conventional workflows, where information is at risk of getting lost across phases, WOOD-SKIN strives to preserve geometric data within each step of the workflow. Each WOOD-SKIN panel carries embedded intelligence: information about curvature, fabrication sequence, hinge flexibility, and panel connection. As in ecological systems, these parts respond to local conditions while supporting a larger, more cohesive whole. Through strategies like adaptive panelization, flat-packing for transport, and embedded data for reassembly, the system optimizes not just performance but also sustainability, ultimately minimizing waste, carbon footprint, and logistical complexity. The 4300 Wilson project demonstrates how WOOD-SKIN's system shifts representation from a descriptive act to an active infrastructural agent, expanding upon Goodhouse's digitality thesis.

#### **3.2. From Model to Product**

Buckminster Fuller's concept of pattern thinking is equally important here. Patterns, according to Fuller, are not just visual representations but systems of relations (López-Pérez, 2020). For WOOD-SKIN, the pattern embedded within the digital model is spatial, geometric, and algorithmic. It doesn't only carry form but the instructions of its own fabrication. This aligns with Neri Oxman's framework of Material-based Design Computation (MDC), where material properties and fabrication constraints are embedded directly into computational workflows, ensuring that

design intent and material behavior co-evolve through the design-to-production process (Oxman, 2010). WOOD-SKIN operationalizes this approach by encoding fold logic, hinge behavior, and assembly constraints within its geometric patterns, making the digital model an active participant between design conception and physical output.

Our analysis of 4300 Wilson exemplifies this methodological application. The project showcases the seamless translation of digital modelling into physical structure, and with it, the embedded information needed for manufacturing and assembly. The result is a built surface that retains the vitality of the digital model, as shown in Figure 2. This transition demonstrates how embedding fabrication strategies directly into geometry reduces friction between design and realization.

This tension between the richness of digital design and the simplifications required for physical fabrication is a recurring theme in computational design discourse. Oxman addresses this topic, proposing that computational strategies must embed material behaviors and fabrication constraints from the outset to reconcile digital complexity with physical viability. (Oxman, 2010). Digital models are filled with complex data, but when they are translated into physical objects through fabrication techniques, whether it is through milling, laser cutting, or additive manufacturing, they require simplification and clarity. Rather than viewing simplification as an inevitable loss, WOOD-SKIN harnesses it as an adaptive filtering mechanism, ensuring that essential performance, assembly, and design-intent data are preserved across every phase, and ultimately to the final product.

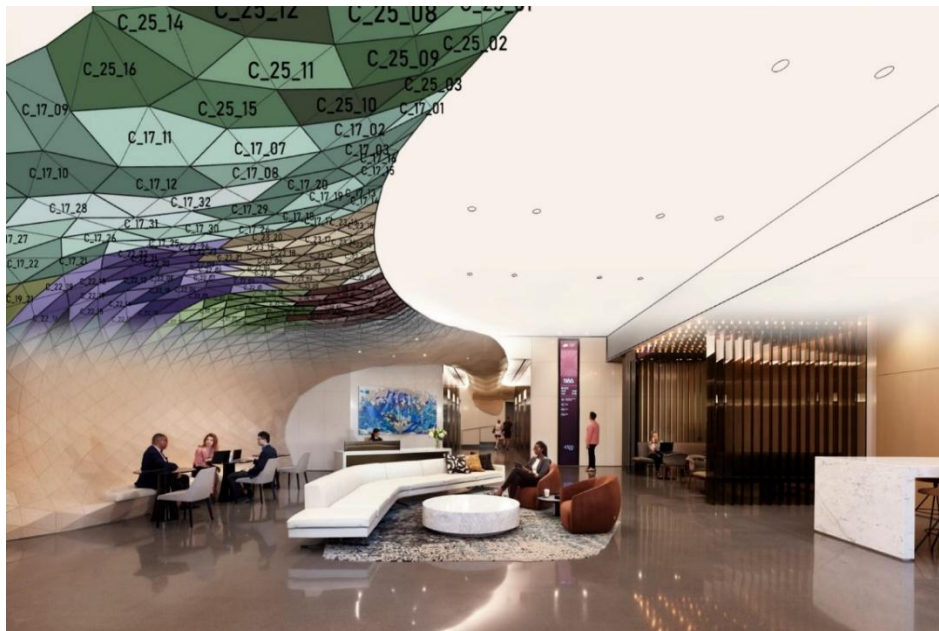


Figure 2. Physical and digital mixed representation of the 4300 Wilson project, figure reproduced from ACADIA 2024 Project Paper “Form Freed”. (2020, John Jetel and WOOD-SKIN®).

#### 4. Toward a Computational Ecology of Construction

Contemporary construction systems remain locked within rigid workflows: a linear progression from schematic design to construction drawings to construction. These workflows are optimized for speed and replication, but not for ecological integration or spatial complexity. The result is a built environment that often feels inert, sterile, and detached from the biological realities of the world it occupies. This critique is reflected in the growing body of research on computational ecology, which argues for a design approach that not only respects but also actively incorporates the dynamic processes of natural ecosystems through data analysis, mathematical modeling, and simulation. In this context, the need to break the current cycle is not simply a matter of technological upgrade; it is a call for fundamental reorientation of our construction philosophies.

WOOD-SKIN proposes this alternative: a computational ecology of construction in which design, material, fabrication, and environment form a responsive, co-evolving system. This approach is rooted in the belief that the logic of natural systems, variation, feedback, and adaptation, can inform the way we build. Instead of imposing

predefined shapes on static materials, WOOD-SKIN allows form to emerge through parametric constraints, material behaviors, and fabrication feedback loops.

This new approach is driven by the recognition that urban environments and the broader natural context are not isolated entities, but interrelated systems. Integrating these systems requires moving away from traditional workflows toward a more fluid, responsive method of construction, one that can adapt to changing environmental conditions and support sustainable practices over the long term.

This shift from linear workflow to recursive feedback loops reflects the transformation from industrial logic to ecological logic. Urban spaces become not just structured environments but synthetic ecosystems, in which architecture operates more like a living membrane than a static shell. The goal is not merely to imitate nature, but to design with it, incorporating lessons from its material economy, evolutionary intelligence, and tolerance for complexity.

## **5. Computational Design and Digital Fabrication**

As technological advancements redefine our approach to design, computational design and digital fabrication have emerged as powerful tools for understanding and replicating complex systems, such as the complexity of nature. These methods not only assist with the creation of intricate geometries but also serve as a bridge between abstract natural principles and physical manifestations in the built environment. This ultimately enables the creation of intricate geometries that retain both aesthetic appeal and functional integrity.

### **5.1. Designing with Feedback**

Where modernist architecture sought to rationalize the world, computational design seeks to engage its complexity. WOOD-SKIN operates at this intersection, where recursive systems, biomimetic principles, and mechanical precision converge. Its computational workflows decode the irregular but legible patterns of nature and re-encode them into buildable, adaptive structures.

James Bridle, in *Ways of Being*, suggests that digital life fundamentally redefines our interaction with the world. Bridle's observation underscores the transformative potential of digital tools, not as mere instruments, but as active agents in shaping our perceptual and material reality. (Bridle, 2022). In the framework of WOOD-SKIN, computational design is employed not only to mimic nature but also to understand and translate its underlying logic. The insights provided by Jussi Parikka in *Insect Media* further enrich this dialogue. Parikka's work emphasizes how digital media reveals hidden symmetries in natural chaos. (Parikka, 2010), an idea echoed in WOOD-SKIN's method.

In practice, WOOD-SKIN's computational design process begins with the conception of nature-inspired geometries. Advanced algorithms iterate over a multitude of design variables and incorporate key topological data to generate forms that are both expressive and buildable. The integration of digital fabrication techniques allows these complex geometries to be materialized. The fabrication process is not a mere replication of digital models; it is an act of translation in which the subtleties of natural forms are encoded into physical panels that maintain the flexibility and strength of their digital counterparts.

As shown in Figure 3 of 4300 Wilson, the digital workflow ensures constant visual updates of possible errors in the digital model. By incorporating feedback loops and automated adjustments based on design variables, the WOOD-SKIN workflow ensures that the final product remains faithful to its original design intent, while being optimized for buildability, efficiency, and sustainability.

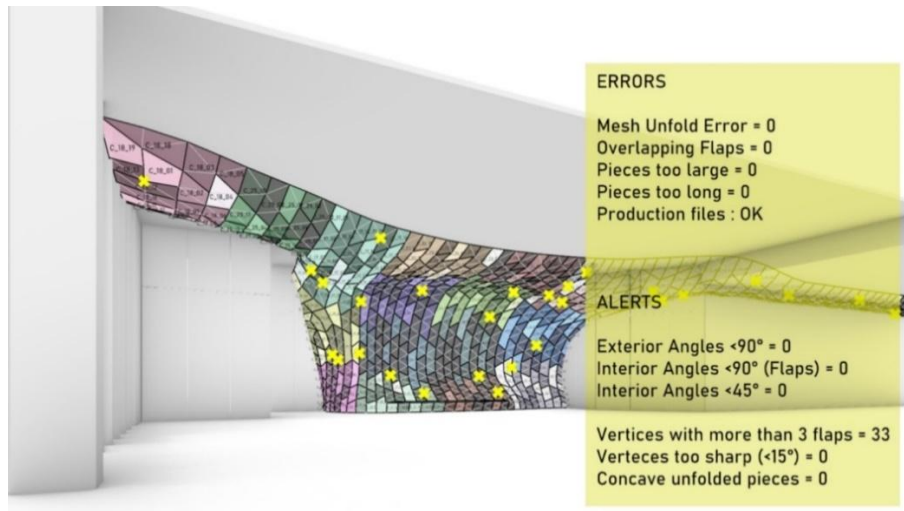


Figure 3. Visual feedback of possible errors, on screen and on 3D model for the 4300 Wilson project, figure reproduced from ACADIA 2024 Project Paper "Form Freed". (2020, WOOD-SKIN®).

## 6. Parametric Workflows and Design Intelligence

WOOD-SKIN uses visual programming tools such as Grasshopper in Rhino within the design process to quickly and seamlessly develop complex design iterations suitable for fabrication. The power that lies in using these digital tools is in the parameterization and ability to control certain design elements. Custom scripts can control everything from mesh subdivision and curvature analysis to panelization logic, hinge spacing, and milling constraints. The strength of the workflow lies in the parametric adaptability, where designers can alter one or more variables and watch the entire system adapt immediately. Principles of physics are used throughout the design stage for geometrical purposes, applying relaxation to the digital mesh to make it suitable for the next steps of the computational process.

Parametric validation ensures that complex forms remain fabricable, adjusting mesh vertices within feasibility constraints already embedded in the system. This allows the design to remain adaptable and constructable without compromising structural integrity. The digital design process of 4300 Wilson, as seen in Figure 4, shows the computational workflow of a 3D model analyzed and adapted for feasible manufacturing.

This workflow creates a sequence from abstract geometry to digital fabrication production files. It allows for the encoding of information directly from the digital mesh. These workable 3D mesh sets are then able to be modified into 2D fabricated flat panels. The final nesting of mesh panels, as shown in Figure 5, illustrates the embedded information needed for the milling process. When translating these geometries from 3D to 2D, the data structure is preserved, allowing for a continuous digital workflow. This enables precise tagging and tracking during assembly. As a result, the gap between drawing and making dissolves. The digital model becomes a scripted instruction set for the material world.

Structural elements that are hidden behind the panels provide necessary stiffness for complex geometries and simplify the assembly phase, as shown in Figure 6. These elements are optimized using evolutionary solvers and machine learning principles within the digital design phase. By testing the influence of structural elements in different locations, WOOD-SKIN minimizes surface deformations, allowing the partitions to adapt to various sites and scenarios. Evolutionary solvers mirror biological systems, where adaptive solutions often emerge through random variation, not just linear improvement. The evolutionary solvers used in the digital process work in the same way, finding interesting results by testing many combinations of variables, and sometimes striving towards solutions, far from the initial expectation, but more reliable for shape and fabricability, or structurally more efficient.

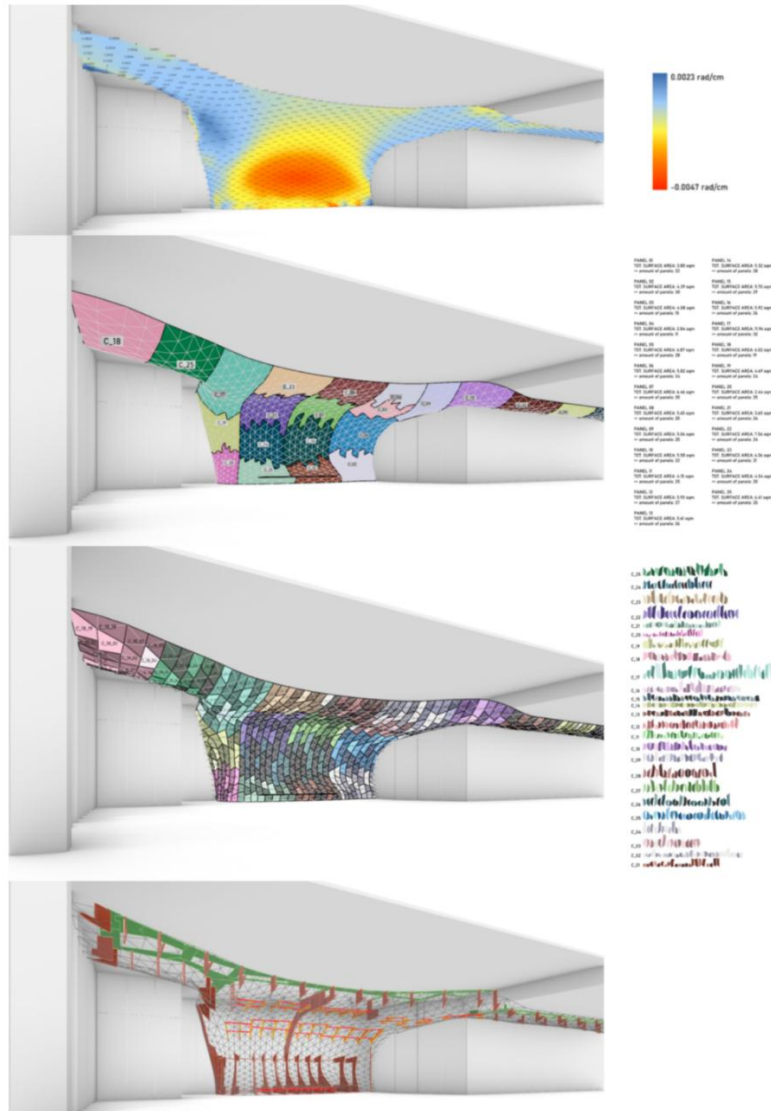


Figure 4. Digital process sequence of the *4300 Wilson* project, figure reproduced from ACADIA 2024 Project Paper “Form Freed”. (WOOD-SKIN®, 2020).

WOOD-SKIN’s computational workflows automate key fabrication parameters, adjusting material thickness, hardware integration, and pattern density to ensure constructability. CNC toolpaths are fully parameterized, including cut depth, typology, and angle. They are color-coded by type of manufacturing operations, which allows the translation into the G-code, tailored to specific milling tools. Though often invisible, this streamlined system reflects how a design experiment matured into an advanced fabrication platform, where architects and engineers converge to turn digital complexity into buildable form, bridging architecture, computation, and craft.

Our analysis of the case study demonstrates WOOD-SKIN’s use of parametric processes, exemplifying how computational platforms can move beyond mere form generation to become critical interfaces for material logic, feedback systems, and design intelligence.



Figure 5. Final nesting of the panels. Layer naming according to the typology of the milling process, figure reproduced from ACADIA 2024 Project Paper “Form Freed”. (2020, WOOD-SKIN®).

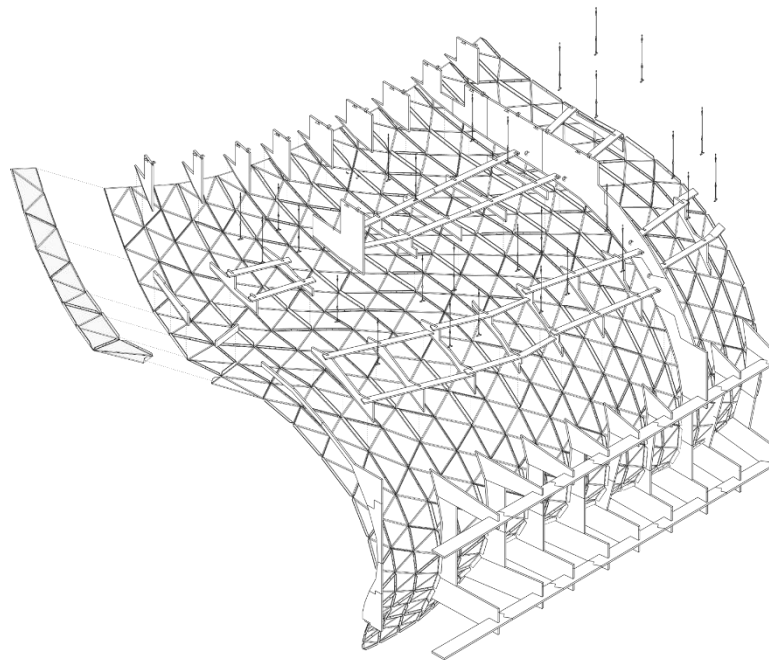


Figure 6. Exploded axonometric view of the back structure, figure reproduced from the ACADIA 2024 Project Paper “Form Freed”. (2020, WOOD-SKIN®).

## 7. Speculative Futures: Envisioning a New Paradigm of Architectural Practice

As WOOD-SKIN grows, it opens a path toward speculative futures. Design methodologies are not bound by present constraints but illuminated by what architecture could become when engaged fully with machine intelligence, ecological thought, and material influence. We propose that this evolution reposition architectural workflows as open systems, capable of responding to shifting aesthetic, environmental, and technological conditions.

Bridle urges us to reconsider digital tools not as sterile instruments, but as assistants in an ecological system of making. (Bridle, 2022). Parikka furthers this by likening designers to pollinators: agents within a network of transformation, where form is not drawn but grown. (Parikka, 2010). These theoretical frameworks support our view that architectural tools must be reframed as participants in co-evolutionary processes, responsive to both human and non-human agencies.

Building on this, we envision a semi-automated workflow that translates AI-generated 2D images into optimized 3D models, ready for manufacturing and assembly. This process harnesses the power of generative design, employing techniques such as latent code manipulation and adversarial learning to capture the subtleties of organic forms. The resulting models are not static representations; they are dynamic systems capable of adapting to various constraints, from material properties to environmental conditions.

Our proposal draws from our experience with WOOD-SKIN's fabrication-aware workflows, expanding them toward AI-assisted systems. The vision appears in recursive, data-rich workflows that map the journey from image to fabrication. Unlike traditional linear workflows, these workflows integrate feedback at every stage. Each node becomes a site of negotiation between desire and feasibility, between speculative vision and physical constraint.

In this speculative framework, architecture becomes a negotiation, not an imposition. WOOD-SKIN does not seek to impose order on the organic. Instead, it participates in its understanding. This is most evident in its ambition to create a semi-automated design-to-fabrication workflow; one that harnesses AI-generated imagery, as shown in Figure 7, and refines it through topological analysis and chaos theory, and outputs fabrication-ready data embedded with data for real-world assembly. Through this process, architecture becomes less a product and more a platform: an evolving system for responding to both human and non-human intelligence.



Figure 7. AI-generated renders depicting speculative futures of WOOD-SKIN Design (2025, WOOD-SKIN®).

### 7.1. Tensions and Limits in the System

Even as WOOD-SKIN advances toward semi-automated workflows and AI-integrated design processes, it does so within the friction of existing constraints. The bespoke nature of fabrication logic, reliant on tightly coupled workflows, high-resolution modeling, and subtractive manufacturing, challenges scalability, affordability, and adoption across broader architectural practices. While parametric systems allow for extraordinary adaptability, they also demand digital fluency and fabrication literacy, limiting access in contexts where such infrastructure is unavailable. These frictions are not failures, but feedback, pointing toward simpler tools, modular systems, biodegradable materials, and design methods that make complexity more accessible to people and machines.

This raises deeper questions: How will emerging technologies reshape our understanding of design and construction? What new roles will the architect and engineer adopt in a world where AI and digital technologies are normalized? What are the broader social and ecological implications of such a shift?

These questions form the core of WOOD-SKIN's forward-looking agenda. This speculative turn is not a detour from reality but an invitation to adapt to it. To imagine workflows that can accommodate unpredictability, material systems that encode responsiveness, and buildings that behave like ecosystems. By integrating image creation with an

automated, digital fabrication process, WOOD-SKIN envisions a future where architecture is not bound by traditional limitations, as shown in Figure 8.

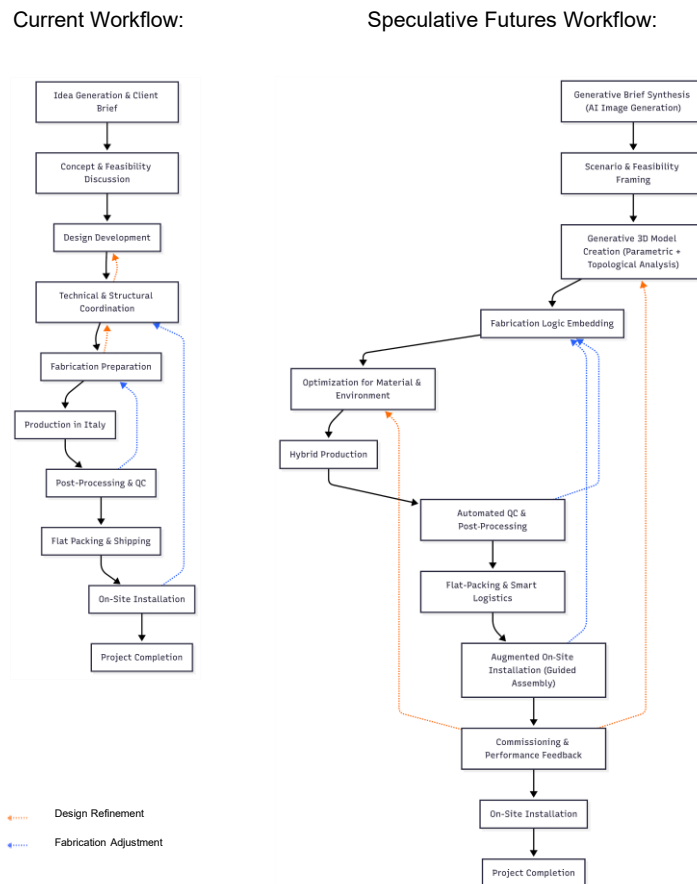


Figure 8. Diagrams showing the current and speculative futures design-to-production workflows of WOOD-SKIN (2025, WOOD-SKIN®).

## 8. Conclusion: Architecture as a Living Interface Between Nature and Code

WOOD-SKIN stands as a platform for redefining architectural practice, where digital precision and natural complexity meet to create new trajectories in design and fabrication. It reimagines the relationship between computational design and material systems, transcending the limitations of traditional workflows to facilitate responsive, adaptive, and speculative architectures.

This research has demonstrated how WOOD-SKIN integrates nature-inspired complexity into material workflows without compromising buildability or sustainability; dissolves the duality between digital and natural systems by embracing their interconnection as design logic; frames model-making as an evolutionary process shaped by constraints and feedback; embeds fabrication intelligence into geometries using computational tools; and proposes a future methodology where AI-generated imagery serves as input for semi-automated, fabrication-ready workflows.

This paper contributes to computational design literature by offering a practice-based framework for integrating fabrication logic into digital models. Through the analysis of the *4300 Wilson* case study, we have shown that WOOD-SKIN's developability-driven workflow is not merely an optimization technique but an embodiment of a material ecology, where geometries evolve through constraints, feedback loops, and the agency of materials themselves. By embedding fabrication intelligence directly into the design model, WOOD-SKIN establishes a recursive process where each step adapts and responds, echoing the ecological assemblages described by Parikka and the ontological frameworks of Bridle. This disrupts the rigid, linear workflows of conventional architectural production, proposing instead a symbiotic, co-evolutionary model where tools, materials, and algorithms participate in an ongoing dialogue.

WOOD-SKIN aligns with a wider shift in architectural design thinking: from process to product, from control to collaboration, from static forms to living systems. As such, it is both a technical innovation and a philosophical

proposition, a manifesto for an architectural future that merges the artificial with the organic, and the predictable with the emergent. It is a vision of a world where the precision of computational design meets the complexity of nature, creating a path toward a future that is as innovative as it is humane.

WOOD-SKIN challenges us to move beyond the constraints and limitations of current construction standards and to imagine a world where the rigid boundaries between digital and natural are dissolved. Through sophisticated computational workflows, innovative material-centered fabrication methods, and a commitment to preserving the organic complexity of nature, WOOD-SKIN offers a precedent for a future where architecture is as much an act of creation as it is an expression of aspirations.

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### **Ethics Approval**

Not applicable

### **Conflict of Interest**

The authors declare that there is no competing interest.

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