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A BIOMIMETIC GENERATIVE DESIGN FRAMEWORK: SIMULATING SILKWORM SILK TAPESTRY IN HOUDINI FOR PRODUCT AND EDUCATIONAL APPLICATIONS

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ABSTRACT

Nature has long inspired design innovation by revealing sustainable, meaningful structures and processes. This research presents a novel framework that mimics the flat tapestry weaving behaviour of Bombyx mori silkworms to inform generative design workflows, product renderings, and interdisciplinary education. When placed on flat surfaces, silkworms produce intricate, non-woven, flat silk tapestries that deviate from their natural cocoon structures. In Phase 1, silkworms were raised on square, flat pedestals, and their silk-spinning behaviour was recorded, yielding insights into filament layering, randomised path selection, and natural boundary constraints. These observations informed Phase 2, where computational tools, specifically Houdini software, were employed to simulate the natural flat spinning patterns of the silkworms to create a geometry node for application on rendered product design surfaces. Phase 3 applied the node on a digitally rendered Isamu Noguchi lamp, which expressed the silk's structural resilience and visual richness. Results include successfully using silkworms to produce a flat woven silk sheet, developing a Houdini geometry node, and applying its pattern in a Noguchi-style lamp rendering. Pedagogically, this approach forms an engaging curriculum that blends ethnographic observation, material experimentation, and computational modelling. This study highlights the transformative potential of biomimicry and treating natural agents and computational modelling tools as co-creative partners to bridge nature and digital fabrication.

Keywords: Computational biomimicry, computational creativity, biomimetic algorithms, organic pattern simulation, industrial design education

1 INTRODUCTION

Nature has commonly served as a source of inspiration in product development and architecture, offering both aesthetic and functional insights [1]. It has been perfecting its methods for millions of years, offering a vast collection of design inspirations. Nature-inspired design has long provided inspiration, driving the integration of modern technology to understand and emulate nature's timeless solutions. This biomimetic approach enriches the creative process and yields work that reflects the efficiency and beauty inherent in natural systems.

Bombyx mori silkworms have garnered attention due to their ability to produce silk fibres traditionally used in textiles. While silkworms naturally spin cocoons in preparation for metamorphosis, they can generate non-woven, tapestry-like flat sheets when limited to spinning on flat surfaces. In a notable exploration of silk's potential beyond traditional textiles, Oxman and her colleagues pioneered an innovative fabrication process by integrating living silkworms directly into the assembly of a large pavilion structure [2]. Rather than relying solely on traditional manufacturing methods to create the facade, they placed silkworms onto a carefully engineered scaffold, allowing the insects to spin their silk in place. This organic process enabled the silkworms to deposit silk fibres directly onto the structure, creating a self-assembled network that formed the pavilion's envelope. The resulting formation highlighted the strength and intricacy of natural silk and demonstrated that biological processes can be harnessed in real time to fabricate large-scale, functional forms. This method has opened new pathways for bio-fabrication, illustrating the potential of combining living systems with design to achieve nature-inspired and aesthetically unique constructions [2]. Mimicking these complex silk patterns to simulate design situations such as Oxman's Silk Pavilion, which replicates nature's organic, self-assembling process in a controlled manner, is increasingly feasible with computational design tools. Computational design, distinct from traditional computer-aided design, utilises generative, constraint-driven, and algorithmic-oriented approaches to simulate the inherent complexity of natural processes on a larger scale. This technology allows designers to capture the dynamic qualities of nature, such as variability, adaptability, and emergence, to translate them into innovative frameworks for both architectural and product design [3]. Moreover, this bio-computational workflow lends itself to a novel design approach for educational settings. For example, students can observe silkworm behaviour firsthand, document pattern formation, and then translate those observations into a computational modelling programme, such as Houdini, as part of a studio project. Embedding such exercises in design curricula fosters interdisciplinary skills like ethnographic research, material experimentation, and computational design while collaborating directly with natural systems.

Within this study, Houdini, a computational design programme known for its robust, node-based procedural workflow, was chosen for its capacity to recreate complex, organic structures dynamically. Its ability to generate and modify intricate patterns makes it particularly effective for simulating silkworms' unpredictable yet cohesive silk-spinning behaviours [4]. By leveraging Houdini, the project could digitally emulate the natural deposition of silk fibres and adapt them into a controlled design framework, effectively bridging the gap between biological processes and tangible product design. This approach facilitates rapid iteration and experimentation and enables a deeper exploration of how natural structures can be augmented and integrated into modern design practices.

This study investigates the simulation of biological silkworm pattern-making through computational design and its application to product design rendering. The research was structured into three distinct phases:

- Phase 1: Observe and document silkworm spinning behaviours on flat pedestals under controlled conditions, focusing on how the worms produce flat silk tapestries and study the patterns created.
- Phase 2: Employ computational design techniques, explicitly using Houdini software, to digitally replicate and simulate these silk patterns.
- Phase 3: The resulting geometry node network was then applied to the design of an Isamu Noguchi-style lamp, illustrating how biologically inspired patterns can inform product aesthetics.

This research demonstrates how combining biological processes and computational tools can be used for product design, emphasising co-creation and collaboration with natural agents.

2 METHOD

2.1 Phase 1 – Silkworm Study

The study began by observing the spinning behaviours of Bombyx mori silkworms on a square flat 3d-printed PLA (polylactic acid) pedestal. The silkworm's silk deposition was meticulously documented through photography and detailed field notes, capturing the nuances of their organic and layered patternmaking. Silkworms produce silk thread during their final larval phase, culminating in cocoon formation and eventual metamorphosis into moths. Silkworms seek out locations where their cocoon can be suspended between vertical pillars. Four Bombyx mori silkworms were raised and placed on two flat pedestals (i.e. two worms per pedestal) to observe their natural silk-spinning behaviours and silk-forming patterns. This setup was informed by prior research [2], which indicated that silkworms, in the absence of vertical supports, produce expansive, flat silk tapestries rather than the typical cocoon structures. Figure 1 shows a silkworm in the process of spinning its tapestry.

2.2 Phase 2 – Computational Design

Insights from Phase 1 informed the digital recreation of silkworm weaving patterns. Using Houdini, a custom geometry node was developed to simulate layered and randomised silkworm filament paths constrained by the pedestals' outer edges, on which they were weaving. Filament parameters were manually tuned to capture the organic complexity of real silkworm patterns. This iterative process is labour-intensive and could benefit from a more automated approach in future research. For example, in 2021, Google researchers demonstrated how differentiable reaction-diffusion networks can reproduce natural textures via gradient-based learning [5], illustrating algorithmic systems that learn directly from biological patterns. More broadly, these efforts exemplify a shift toward treating software tools and AI as creative partners. From ChatGPT-facilitated ideation [6] to AI-driven visual design workflows [7], co-design with non-human collaborators is reshaping both professional practice and design education.

Figure 1. Bear and Wolf, the silkworm co-designers, are spinning tapestry on a pedestal

2.3 Phase 3 – Rendering Application

The simulated silk pattern geometry was then applied to a Noguchi-style lamp design. After modelling the lamp's framework, the typical paper lampshade was replaced with a geometry node network, envisioning the envelope as if a swarm of silkworms collectively spun it. The design was fine-tuned by adjusting density and connection points, ensuring visual accuracy through references to physically spun squares of silk and related imagery collected through the study of Phase 1. Once the model was aligned with the reference materials, the lamp was rendered. The successful application of the geometry node network demonstrates how digital tools can translate organic patterns into a three-dimensional form [8].

3 RESULTS

3.1 Phase 1 – Silkworm Spinning Results

During the spinning phase, two silkworm teams produced distinct flat silk sheets. The silk is deposited randomly, creating an intricate network of intersecting threads that overlap and layer unpredictably. These sheets measured approximately 3 × 3 inches (76.2 mm x 76.2 mm), equal to the size of the surface of the pedestal itself. While the worms generally spun in circular or looping paths, variations in density and direction were observed among individual specimens. The silk tapestries were extremely thin yet durable, anchoring to the pedestal surface at multiple contact points. Figure 2 displays completed silk sheets removed from their pedestals, each created by two silkworms. These insights provide the basis for simulated patterns to be used in product design concepts.

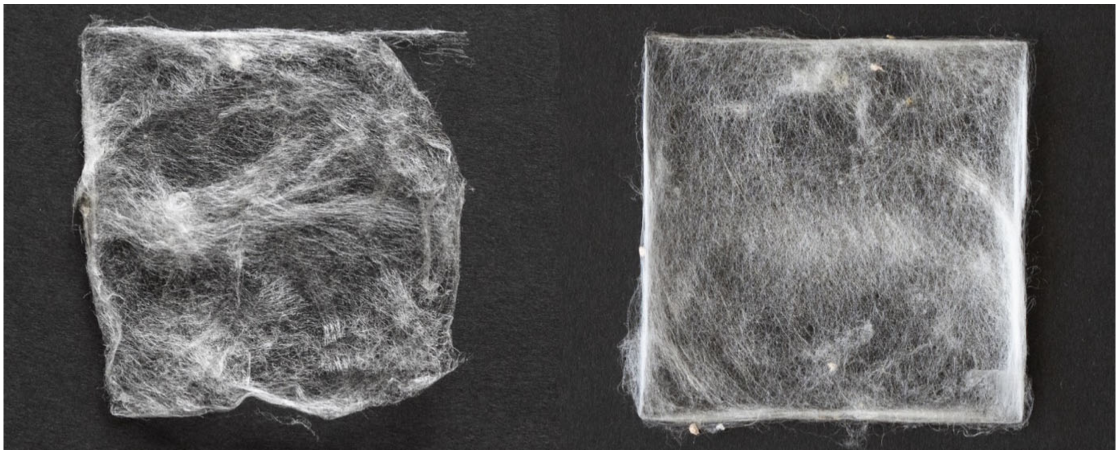

Figure 2. The silkworms created two silk sheets

3.2 Phase 2 – Computational Design Results

The silk-thread simulation was created through a custom geometry node in Houdini that replicates organic branching and connectivity. First, points were scattered randomly across the desired surface, adjusting the density and randomness to establish an initial distribution. These points were then connected by proximity to form line segments, which were resampled to introduce additional points for a more fluid, natural appearance. Redundant or overlapping points were fused to streamline the mesh, and a smoothing operation was applied to refine the overall flow of the pathways into an organic, silk-like pattern. Finally, a polywire node was used to convert these pathways into a solid mesh, producing a structure resembling a network of silk threads suitable for integration into product design. Figure 3 shows the node chain in Houdini used to simulate silk patterns for textiles. Figure 4 visually compares the authentic silk artefacts on the left and the computer-simulated silk on the right. These images show the similarities in the overall pattern, interconnected network, and layering of silk threads between the authentic and digital artefacts.

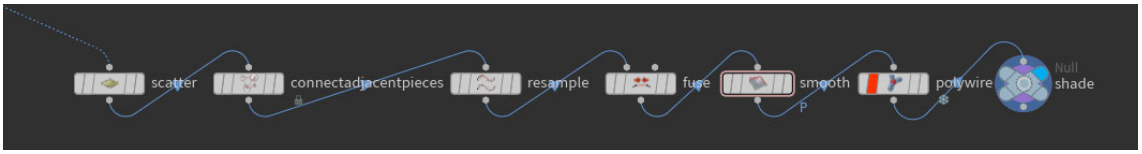

Figure 3. A screenshot of the Houdini software geometry node network for patternmaking

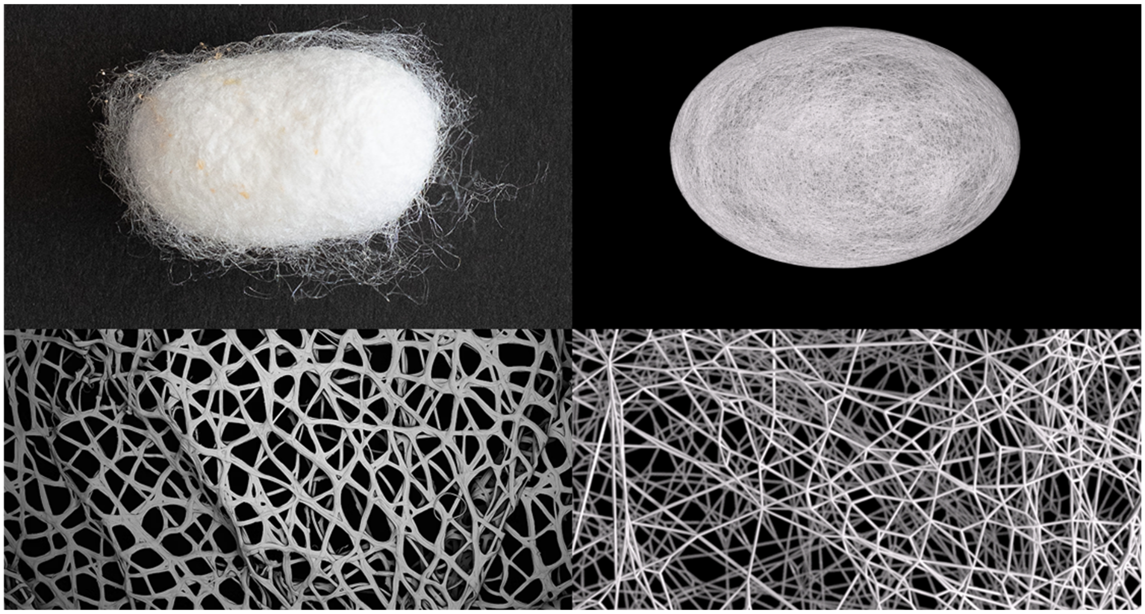

Figure 4. A comparison of authentic (left side) and digital (right side) silk patterns. The microscopic image on the bottom left is used with permission from Oxman. The close-up image on the right is a screen capture of a zoomed-in image of the software outcome

3.3 Phase 3 – Rendering Application Results

With the digital silk patterns generated, the geometry was mapped onto a Noguchi-style lamp, using the organic silkworm tapestry as the lamp's exterior "skin." The translucency and delicate layering characteristic of actual silk convey a natural visual appeal to the design's surface as shown in Fig. 5.

4 DISCUSSIONS

4.1 Phase 1 – Silkworm Spinning

Observations of silkworms spinning on flat pedestals provided insights into alternative silk structures and their potential applications in industrial design. The non-woven textiles demonstrated how silkworms adapt their spinning process in the absence of vertical structures, highlighting silk's versatility in design contexts. The study confirms silk's renowned balance of delicacy and strength. It's fine fibres, when layered, create surprisingly resilient tapestry-like structures.

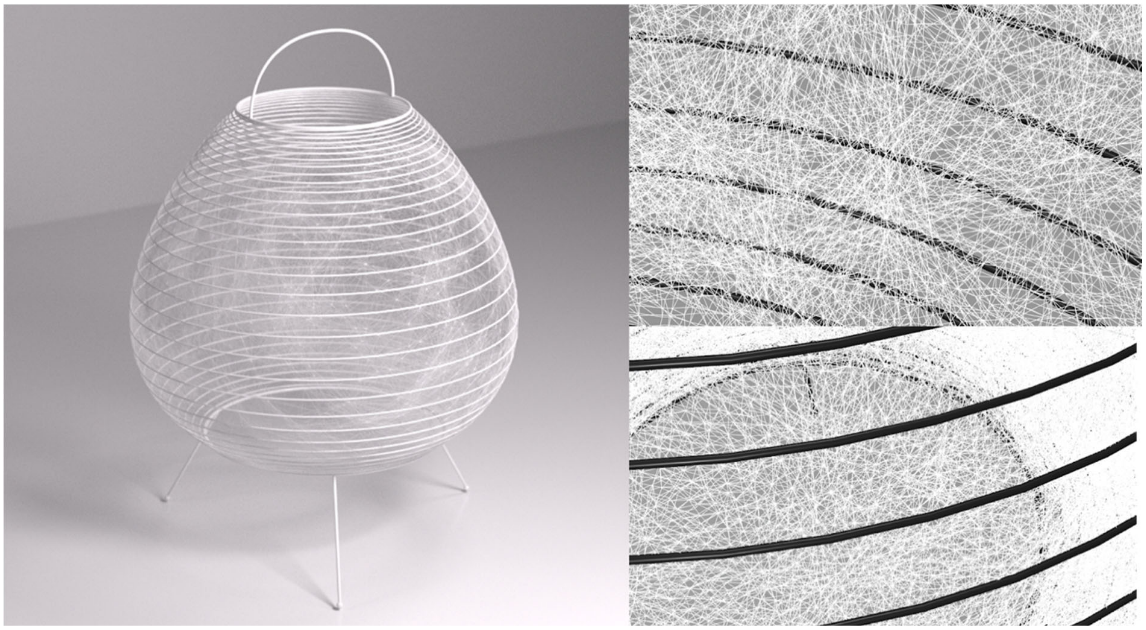

Figure 5. An Isamu Noguchi lamp rendering with the digital silkworm textile pattern. The product view is on the left, and two close-up views are on the right

4.2 Phase 2 – Computational Design

Phase 2 provided the discovery of the remarkable capacity of computational design to replicate and simulate nature's intricate patterns and processes. Seemingly random behaviours and natural phenomena can be deconstructed into algorithmic sequences that modern technology can reconstruct. By studying these biological algorithms, nature's design principles can be harnessed and integrated into real-world design applications [9]. Ultimately, this approach paves the way for innovative solutions that bridge the gap between the digital and the organic.

4.3 Phase 3 – Rendering Application

In Phase 3, the study moved from theoretical hypothesis to practical validation. Rather than merely crafting a geometry network that mimics the spinning patterns of silkworms, an algorithm was developed that is ready for diverse real-world applications. An Isamu Noguchi style lamp was chosen for its thin shade and network of repeating wires spiralling up its gradual curved form, a perfect scaffolding for a group of silkworms to deposit their silk the same way they did in Phase 1. The success of this computational simulation confirms that the node network can be adapted to nearly any form, consistently producing the desired effect.

4.4 Educational Application

Integrating this research into industrial design curricula can provide students with a rich, interdisciplinary learning experience. For example, a studio course might include a module where students rear Bombyx mori silkworms on tailored, open-framework pedestals, document the resulting flat silk tapestries, and reverse-engineer those patterns into custom Houdini geometry nodes. Such a project reinforces core competencies of ethnographic observation, material experimentation, and computational modelling while encouraging co-design with non-human collaborators, a growing focus in contemporary design pedagogy. By embedding these activities into project-based assignments, educators can foster critical reflection on sustainable design processes, promote collaborative problem-solving across biology and computation, and inspire product aesthetics grounded in natural systems.

4.5 Future Work

Future studies might include using a small Noguchi lamp with the shade surface removed, leaving only the rib structure and placing silkworms on it to discover if they would spin silk between the ribs and complete the lamp shade. Projects could require researchers to design open-frame structures to encourage silkworm spinning and inform the product's aesthetic and functional qualities. This project encourages alternative design explorations and exposure to new perspectives in design practice.

4.6 Limitations

The study was limited by a small sample size of only four silkworms, suggesting that more extensive studies could reveal additional differences in spinning behaviour. This study was also limited by computationally demanding high-fidelity simulations capturing micro-level thread interactions. Computational modelling of silkworm behaviour can reveal new opportunities for procedural simulation and design applications. Additionally, consideration and development of manufacturing techniques would be required to use these patterns for larger commercial products or industrial design applications.

5 CONCLUSIONS

This research demonstrates that integrating biological processes with procedural computation offers a powerful new paradigm for product-design pattern generation. By observing Bombyx mori silkworms spinning flat silk tapestries, encoding their behaviour into a custom Houdini geometry node, and applying the resulting node network to an Isamu Noguchi-style lamp, the study validated both the aesthetic fidelity and practical feasibility of this bio-inspired approach. The digitally rendered lamp expresses the natural silk’s intricate layering, randomness, and structural resilience, underscoring how organic networks can be translated into robust digital meshes. Beyond its design applications, the methodology establishes a replicable educational framework to engage students in a hands-on design project that includes ethnographic research of silkworms, new material experimentation, and computational simulation. Findings highlight the potential of using computational biomimicry in design workflows, pedagogical enrichment, and co-creative collaborations with non-human agents.

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