

The Role of **ARTIFICIAL INTELLIGENCE IN LANDSCAPE ARCHITECTURAL BIOMIMICRY**



Benjamin Chemarum



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#Artificial intelligence
#Biomimicry
#Climate adaptation
#Urban heat island
#Landscape architecture
#Helianthus annuus L.

Abstract

The accelerating impacts of climate change have made urban heat mitigation a critical design priority. Record-breaking heat waves across Europe, Asia, North Africa, and North America in 2025 reaffirmed the urgency of rethinking shading systems within dense urban environments. This research explores how artificial intelligence can augment biodesign thinking to develop responsive, ecologically integrated shading structures for climate-adaptive cities. The Sunflower Parasol represents a speculative AI-assisted design concept that transforms the conventional polyester parasol — typically non-biodegradable and environmentally detrimental — into a living canopy covered with vegetation. Drawing inspiration from the morphology and heliotropic behavior of *Helianthus annuus* L. (the common sunflower), the project employs AI-driven generative modeling and visualization to simulate biomimetic forms and environmental performance. Through iterative

digital experimentation in ArchiCAD and rendering with the Nano Banana AI tool, the design explores how computational intelligence can replicate natural logics such as evapotranspiration, solar orientation, and dew collection to regulate microclimates.

By integrating AI methods with principles of landscape architecture and biomimicry, the Sunflower Parasol demonstrates the potential of machine intelligence to mediate between natural and synthetic systems. The concept challenges traditional boundaries between digital design and living materials, positioning AI not merely as a visualization tool but as a collaborative design partner in ecological innovation. Ultimately, this study highlights how AI-assisted biodesign can inform new forms of climate-responsive infrastructure, promoting regenerative, adaptive, and symbiotic urban environments.

Introduction

Background and motivation

Rapid urbanization and intensifying climate change have amplified the urban heat island effect, posing serious risks to public health, ecological balance, and urban livability [1, 2]. Record-breaking heat waves across multiple continents in 2025 have underscored the urgency of developing adaptive and sustainable shading systems within dense urban environments [3]. Traditional shading structures — often composed of synthetic and non-biodegradable materials — offer limited ecological benefits and fail to contribute to microclimate regulation.

Biomimicry, the practice of emulating nature's strategies in design, offers promising pathways toward sustainable and adaptive solutions in landscape

architecture. Research demonstrates that biomimetic approaches can enhance environmental resilience and performance. For instance, light-responsive kinetic systems inspired by the *Gazania* flower illustrate how natural forms can inform functional design innovations [4]. Such principles highlight the potential for living and dynamic structures that respond intelligently to climatic stimuli.

In parallel, recent advancements in artificial intelligence (AI) have expanded the possibilities of computational design. AI tools facilitate rapid prototyping, simulate environmental conditions, and optimize spatial configurations, enabling designers to generate photorealistic renderings

and evaluate performance in real time [5]. This technological shift allows for efficient exploration of design alternatives while enhancing communication with stakeholders. AI-driven modeling and visualization also enable the generation of biomimetic forms aligned with natural processes [6, 7], though their application in climate-responsive urban infrastructure remains underexplored [8].

Emerging platforms such as Nano Banana – an AI-powered image generation and editing tool developed by Google – are redefining digital design workflows [9]. By transforming text or images into high-fidelity 3D models, Nano Banana supports diverse visualization modes, including blueprints and 3D-printed models. Comparative studies have shown its precision in interpreting prompts and producing visually compelling results, making it a valuable tool for landscape and architectural designers [10].

This research is motivated by the need to merge AI-driven design tools with ecological principles to create responsive, regenerative, and living urban systems. The Sunflower Parasol project exemplifies this synthesis, demonstrating how AI can act as a collaborative design partner in developing nature-inspired, climate-adaptive shading structures.

Problem statement

Despite growing awareness of climate adaptation strategies, contemporary urban shading systems remain largely static, material-intensive, and environmentally unsustainable [11, 12]. These systems typically rely on synthetic materials that contribute to waste accumulation and fail to engage with ecological processes such as evapotranspiration or solar tracking. While advancements in artificial intelligence (AI) have transformed design visualization and performance simulation, their application in developing biomimetic and living shading systems remains underexplored [7, 8].

In landscape architecture, the integration of AI and biomimicry presents an opportunity to move beyond conventional static structures toward adaptive, data-informed, and ecologically responsive design solutions. However, there is a research gap in understanding how AI can be systematically employed to simulate, test, and generate biodesign concepts that replicate natural behaviors – such as heliotropism or humidity regulation – within urban microclimates [6, 12]. Moreover, the

lack of accessible, high-fidelity AI visualization tools limits experimentation in early design stages, constraining innovation in climate-adaptive architectural design [14, 15].

This study addresses these challenges by exploring how AI-assisted design tools, particularly the Nano Banana platform, can augment biodesign thinking in developing responsive, ecologically integrated shading systems. Through the Sunflower Parasol concept, the research aims to demonstrate the potential of AI as a collaborative design partner that bridges the gap between digital modeling and living ecological performance, contributing to the discourse on regenerative and climate-resilient urban design.

Research objectives

The primary objective of this research is to explore how artificial intelligence (AI) can enhance biodesign thinking to create responsive and ecologically integrated shading systems within urban environments. Building on the conceptual foundation of the Sunflower Parasol, the study aims to demonstrate the potential of AI as a design collaborator that bridges digital modeling and living systems for climate adaptation.

The specific objectives are to:

1. Investigate how AI-driven generative modeling and visualization tools can simulate biomimetic forms and environmental behaviors inspired by *Helianthus annuus* L. (sunflower morphology and heliotropism).
2. Examine the role of AI tools such as Nano Banana in facilitating rapid prototyping, environmental simulation, and high-fidelity visualization for climate-adaptive urban design.
3. Develop a speculative design framework that integrates principles of landscape architecture, biomimicry, and computational intelligence to guide the creation of living, regenerative shading systems.
4. Evaluate the implications of AI-assisted biodesign for promoting sustainable, adaptive, and symbiotic urban environments in the context of accelerating climate change.

Through these objectives, the study contributes to the growing discourse on AI-assisted ecological design, highlighting pathways toward regenerative and climate-resilient urban futures.

Research Methodology

This study adopts a qualitative and design-based research methodology, combining theoretical exploration, digital experimentation, and visual analysis to investigate the integration of artificial intelligence (AI) in biodesign-oriented landscape architecture. The approach is structured into three interrelated phases: conceptual development, computational simulation, and visual synthesis.

In the conceptual development phase, relevant literature on biomimicry, AI-assisted design, and climate-responsive architecture was reviewed to establish the theoretical foundation of the Sunflower Parasol concept [6, 7, 8]. Key ecological strategies from *Helianthus annuus* L. — including heliotropism, evapotranspiration, and surface morphology — were analyzed to identify potential analogues for design translation.

The computational simulation phase involved the use of AI-driven generative modeling and parametric visualization tools. ArchiCAD served as the primary modeling platform for structural development, while the Nano Banana AI tool [9] was employed for generating photorealistic renderings, simulating environmental performance, and visualizing vegetated canopies under varying climatic conditions. Iterative digital experiments enabled the refinement of form, materiality, and environmental response.

Finally, in the visual synthesis phase, the outputs were evaluated qualitatively to assess their capacity for climate responsiveness, ecological integration, and aesthetic coherence. The process highlights AI not merely as a visualization aid but as a collaborative design partner capable of simulating natural processes and enhancing ecological innovation. Findings from these phases collectively inform a speculative framework for integrating AI-assisted biodesign into climate-adaptive urban infrastructure.

Expected results and contribution

The research is expected to demonstrate that integrating artificial intelligence (AI) into biodesign processes can significantly enhance the capacity of landscape architecture to address climate adaptation challenges. Through the Sunflower Parasol project, the study anticipates producing a speculative prototype that illustrates how AI-assisted generative modeling and visualization can replicate natural logics — such as heliotropism, evapotranspiration, and solar regulation

— to create responsive and ecologically active shading systems.

The expected outcomes include:

1. A conceptual and visual model of a living, AI-assisted shading structure that dynamically interacts with its environment.
2. A methodological framework for integrating AI-driven biomimetic design into climate-adaptive landscape architecture.
3. Insights into the role of AI as a co-creative design partner, capable of mediating between synthetic materials and living systems.
4. New perspectives on how computational design tools, such as Nano Banana, can support regenerative and sustainable urban design practices.

The broader contribution of this research lies in advancing discourse on AI-assisted ecological design by bridging the gap between digital intelligence and environmental responsiveness. It proposes a shift from static, material-based solutions to adaptive, symbiotic infrastructures that promote resilience and regeneration in the urban fabric. Ultimately, the study positions AI not as a replacement for human creativity, but as a catalyst for co-evolutionary design thinking that aligns with natural systems.

Overview of previous research

Urban heat and the limits of conventional shading

The urban heat island (UHI) phenomenon is well documented as a critical urban-climate challenge: cities routinely record higher temperatures than surrounding rural areas, with impacts on health, energy use, and air quality [1]. Evidence and reviews highlight that rising urban temperatures increase cooling demand and exacerbate heat-related morbidity, emphasizing the need for multi-scalar mitigation strategies. Conventional shading — awnings, fixed canopies, and polyester parasols — provides immediate local comfort but is often made from non-biodegradable, resource-intensive materials and lacks dynamic responses to changing microclimatic conditions [1, 2].

Green infrastructure, evapotranspiration, and adaptive microclimates

Green infrastructure (vegetation, green roofs, and living facades) reduces ambient temperatures through shading and evapotranspiration;

reviews note significant cooling potentials but also stress the importance of species selection, irrigation needs, and maintenance regimes for sustained performance [2]. Studies show that integrating vegetation into built elements can moderate surface temperatures and improve human thermal comfort, but uptake is limited by maintenance costs, structural constraints, and insufficient integration with responsive control systems. These limitations suggest the value of hybrid approaches that combine living systems with intelligent control and adaptive form.

Biomimicry and natural logics for responsive design

Biomimicry has been influential in framing design strategies that emulate functional principles found in nature — using nature as model, measure, and mentor [16]. Architectural and landscape research has translated biological phenomena (e.g., light-responsive movement, structural efficiency, moisture capture) into kinetic facades, shading devices, and material innovations [6, 4]. Work on plant heliotropism (sun-tracking) and growth-mediated responses, notably in *Helianthus annuus* L., provides an empirical basis for designing structures that track solar position or modulate orientation to optimize shading and daylighting [17, 18]. Biomimetic strategies thus offer conceptually appropriate templates for shading systems that actively manage incident radiation and microclimate.

Engineered living materials and living architecture

The field of Engineered Living Materials (ELMs) and research into living architecture explore how biological cells and organisms can be integrated into materials and building systems to provide self-repair, responsiveness, and environmental services [19, 20]. Reviews document promising advances — microbial-based concretes, photosynthetic biocomposites, and plant-

-integrated systems — but also identify hurdles in durability, safety, regulatory frameworks, and integration with digital design workflows. ELMs point toward a future where shading devices are not merely vegetated add-ons but hybrid systems with emergent, regulated behaviors.

Computational design, AI, and generative visualization

Computational design methods (parametric and generative design) have enabled architects and landscape designers to explore vast design spaces, optimize for performance metrics, and prototype complex biomimetic geometries [8, 7]. More recently, AI-driven tools — ranging from physics-informed simulation to generative image models — have accelerated visual iteration and enabled new forms of designer-machine collaboration. Contemporary image and model-generation systems (e.g., Google’s Nano Banana as integrated within the Gemini ecosystem) demonstrate rapid, high-fidelity visualization workflows that support concept development and stakeholder communication [10]. While promising for visualization and early-stage ideation, many AI tools remain underleveraged for integrative performance simulation and for translating visuals into constructible, living prototypes.

Gaps and syntheses relevant to the Sunflower Parasol

Cross-disciplinary reviews indicate several converging gaps: (1) a scarcity of research that operationalizes biological behaviors (e.g., heliotropism, evapotranspiration) into digitally simulated, constructible shading systems; (2) limited integration between AI visualization tools and engineering/biological performance models; and (3) sparse empirical studies on hybrid living/synthetic canopies that are both ecologically functional and digitally designed. Collectively, these gaps motivate exploratory, design-led research that

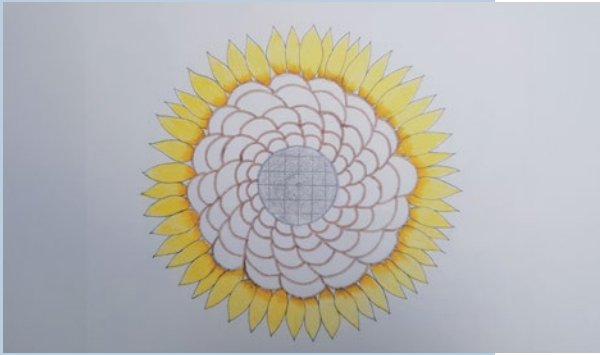


Fig. 1 Hand sketch of Sunflower parasol design.
Source: Own study.

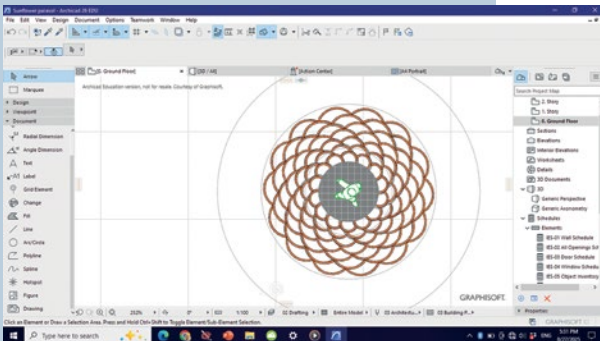


Fig. 2 Development of the parasol design in ArchiCAD.
Source: Own study.

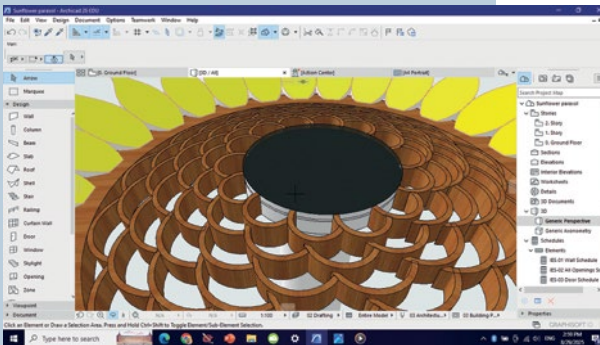


Fig. 3 3D view of the parasol design in ArchiCAD.
Source: Own study.

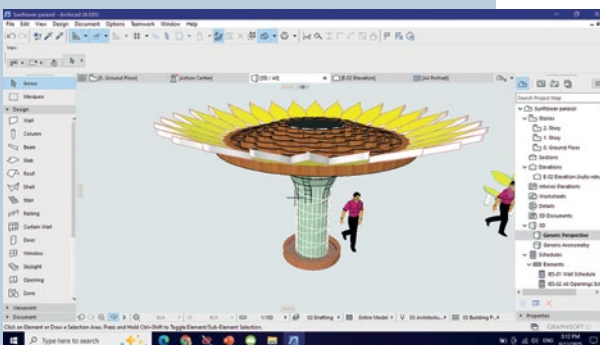


Fig. 4 3D view of the parasol design in ArchiCAD.
Source: Own study.

couples biomimetic theory, ELM concepts, and AI-assisted generative workflows — precisely the niche the Sunflower Parasol aims to occupy by using AI as a co-creative tool to prototype living, climate-responsive shading.

Methodology

The initial phase of the design process involved a detailed study of the geometric and morphological patterns of *Helianthus annuus* L. (the common sunflower). Hand sketches were produced to explore the flower's radial symmetry, petal arrangement, and central disc geometry — features that informed the conceptual framework of the Sunflower Parasol's canopy design. In the subsequent phase, the design was digitally developed and refined using Building Information Modeling (BIM) software, ArchiCAD. This platform facilitated accurate 3D modeling, structural visualization, and iterative adjustments to optimize both aesthetic composition and functional performance.

Figure 1 illustrates a hand sketch of *Helianthus annuus* L., highlighting the Fibonacci spiral pattern evident in the central seed head. This natural geometric arrangement served as the primary inspiration for the design of the Sunflower Parasol's porous wooden canopy, envisioned as a structural framework that supports the growth of climbing plants. The initial hand sketch was subsequently refined and digitally modeled in ArchiCAD. The software's 3D visualization capabilities facilitated a more detailed exploration of form, proportion, and material expression. Dimensional calculations were performed to ensure that the canopy achieved an appropriate scale, balancing aesthetic considerations with structural and functional requirements. The design also incorporated practical factors, such as estimating the number of users who could be shaded simultaneously, to enhance usability and comfort.

Next, the design was adjusted further to mimic the geometric structure

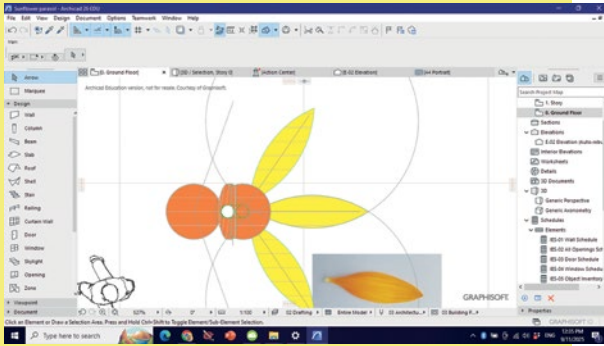


Fig. 5 Bench design based on the geometry of *Helianthus annuus* L. ray floret. Source: Own study.

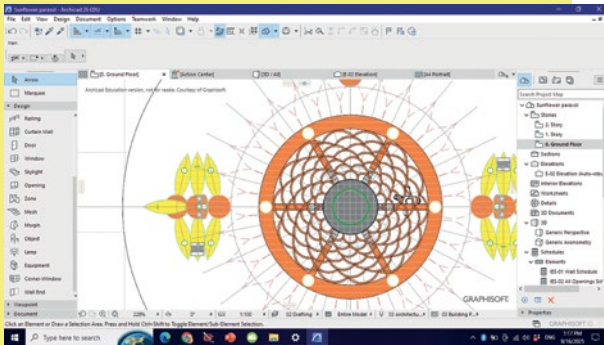


Fig. 6 Arrangement of the benches around the Sunflower parasol. Source: Own study.

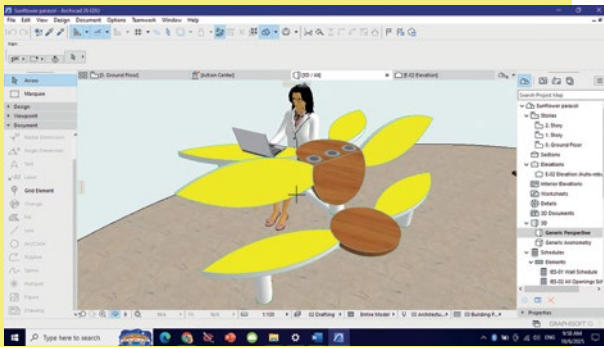


Fig. 7 Bench design with three seats, two backrests, and two work surfaces. Source: Own study.

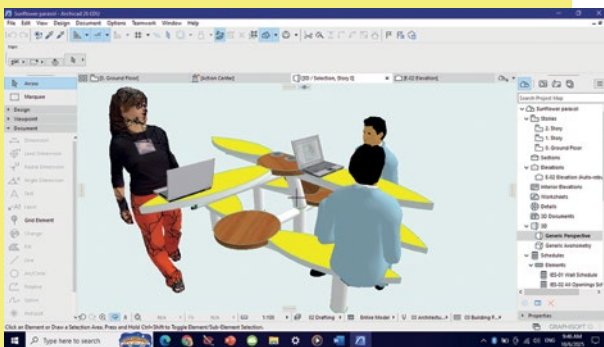


Fig. 8 Bench design with four seats and three work surfaces. Source: Own study.

of the flower of *Helianthus annuus* L. The height of the structure was calculated to be in harmony with established rules for safety and comfort of users of the public space. Figures 3 and 4 show case the 3D views of the parasol in ArchiCAD'S 3D view window. The design integrates a centrally positioned solar panel that powers the parasol's lighting system, enhancing the structure's energy efficiency and overall sustainability. Inspired by the elegant curvature of the *Helianthus annuus* L. flower, the canopy's support beams translate botanical geometry into architectural form.

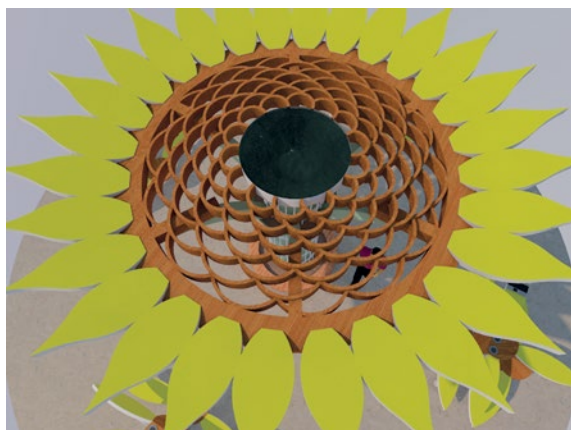


Fig. 9 Render of the parasol's canopy using CineRender.
Source: Own study.



Fig. 10 Render of the parasol's side-view using CineRender.
Source: Own study.

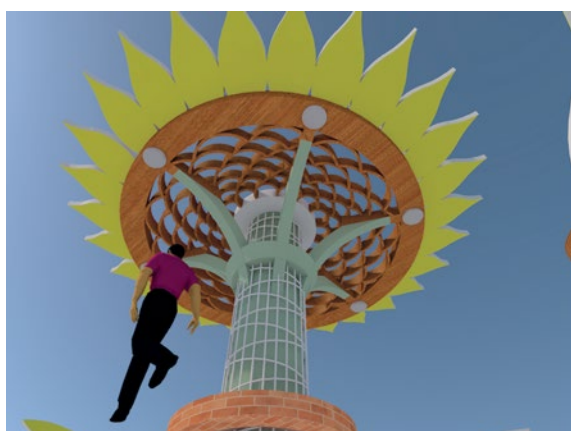


Fig. 11 Render of the parasol's view from the bottom using CineRender. Source: Own study.

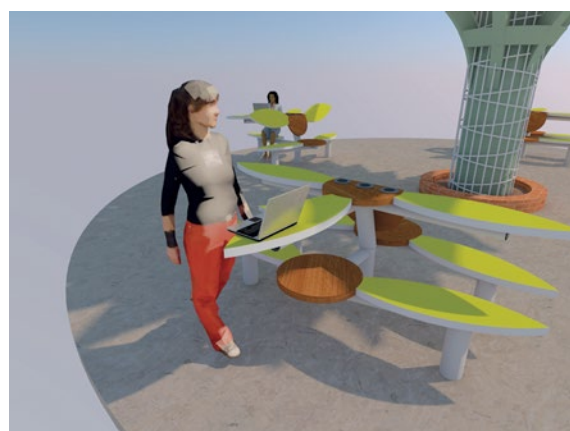


Fig. 12 Render of view of the parasol bench using CineRender.
Source: Own study.

Subsequently, benches inspired by the spear-like geometric shape of the ray floret of *Helianthus annuus* L. were designed to be positioned beneath the parasol as shown in figures 5 to 8. Some of the benches were designed in response to contemporary health science trends, which discourage prolonged sitting. Each of these benches incorporates an attached platform that allows users to place a laptop or book, enabling them to work comfortably outdoors while standing.

The penultimate step in the design process involved generating several 3D views of the parasol using ArchiCAD's built-in rendering engine, CineRender. While the resulting renders were visually appealing, they did not fully convey the

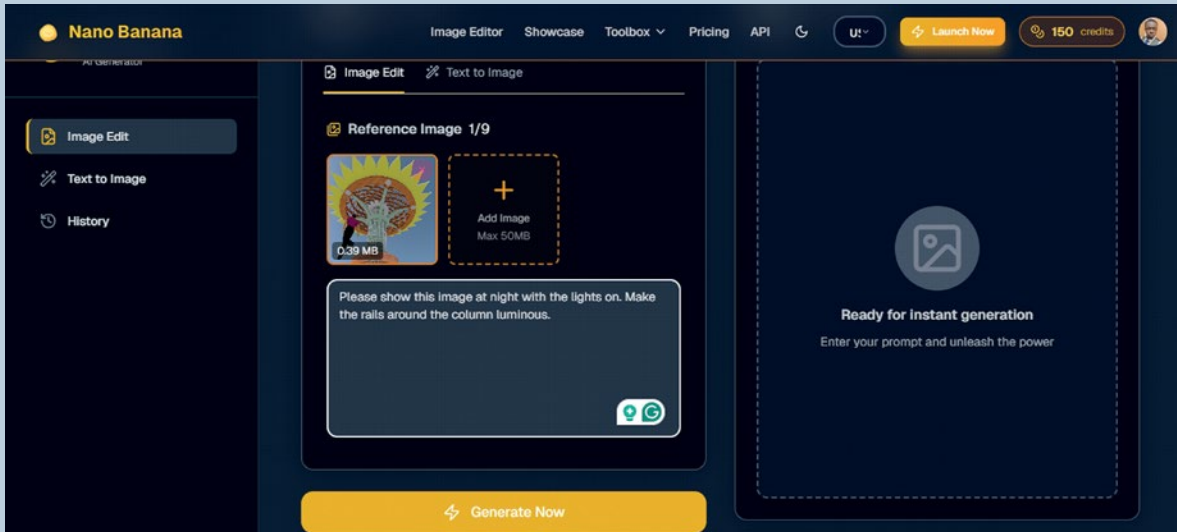


Fig. 13 Render of view of the parasol bench using CineRender.

Source: Own study.

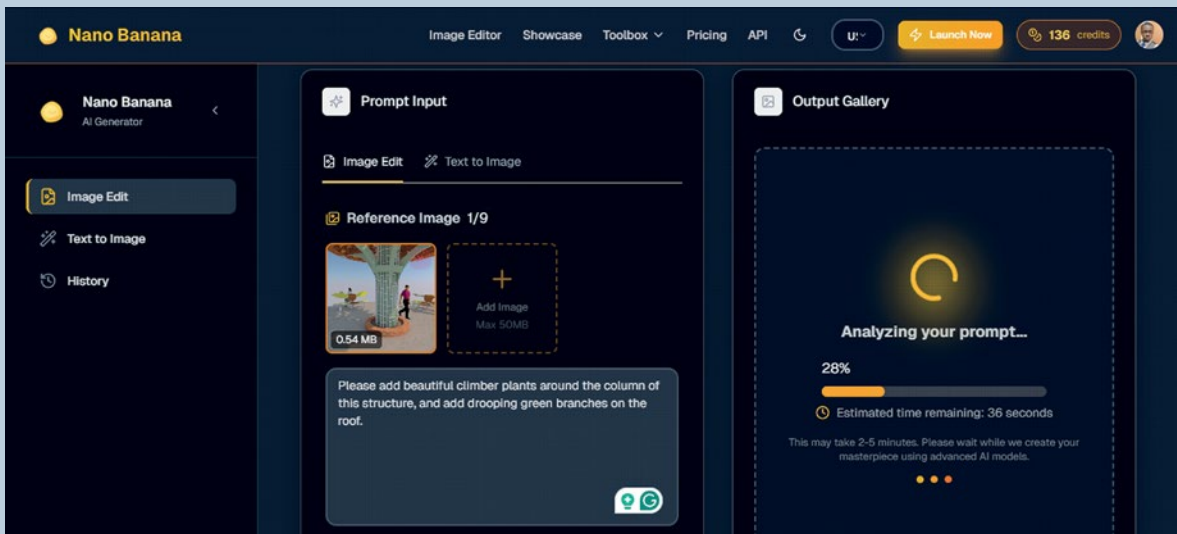


Fig. 14 Screenshot showing the Nano Banana AI tool processing the rendering instructions.

Source: Own study.

intended experience. The author sought to illustrate the parasol's lighting system at night and depict lush climbers growing around the central pillar and cascading from the canopy. Due to ArchiCAD's limited selection of plant materials, Artificial Intelligence was employed to enhance these visualizations. Below are the basic perspective views of the design derived from CineRender.

The final step involved uploading the CineRender images to the Nano Banana online AI platform. Specific prompts were provided for

each image to guide the AI in applying desired effects, such as night-time lighting and the addition of plant materials. Screenshots of the prompts are presented below (Fig. 13 and 14), followed by the resulting images (Fig. 15-18).

Results and Discussion

The design experiment produced detailed renderings of the Sunflower Parasol, illustrating both its aesthetic and functional potential. Figure 15 presents a Nano Banana AI rendering of the

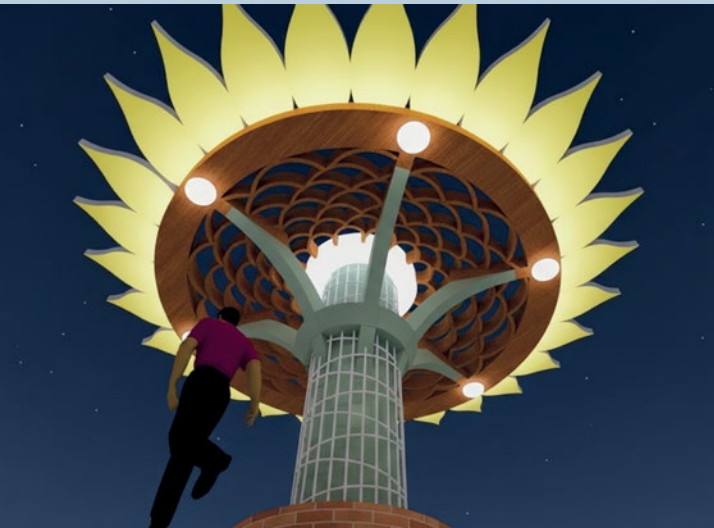


Fig. 15 Nano Banana AI render of the parasol lighting system.
Source: Own study.



Fig. 16 Nano Banana AI render of the parasol's greenery.
Source: Own study.



Fig. 17 Nano Banana AI render of the parasol's sunset mood.
Source: Own study.



Fig. 18 Nano Banana AI render of the benches' lighting.
Source: Own study.

parasol's lighting system, which highlights the yellow hues of the sunflower's ray florets. The lighting is powered by a solar panel positioned atop the canopy. Its placement and orientation were optimized using ArchiCAD and Nano Banana simulations, allowing the canopy to emulate the natural heliotropic behavior of *Helianthus annuus* L., maximizing illumination and solar energy capture. The solar system is estimated to provide up to 6 hours of nighttime lighting under full sun conditions.

Figure 16 depicts the parasol integrated with climbing plants, suggesting a living structure capable of supporting urban biodiversity. The design encourages interactions with pollinators such as bees and small birds. Figures 17 and 18 illustrate the canopy's suitability for nighttime activities, providing seating for up to 10-12 users simultaneously, accommodating study, work, or social interactions comfortably.

Functionally, the porous wooden canopy allows partial light penetration while supporting vegeta-

tion growth, facilitating microclimate regulation through shading, evapotranspiration, and thermal buffering. Preliminary estimates indicate the canopy could reduce local ground temperature by 2-4°C during peak sun hours, enhancing user comfort in dense urban settings.

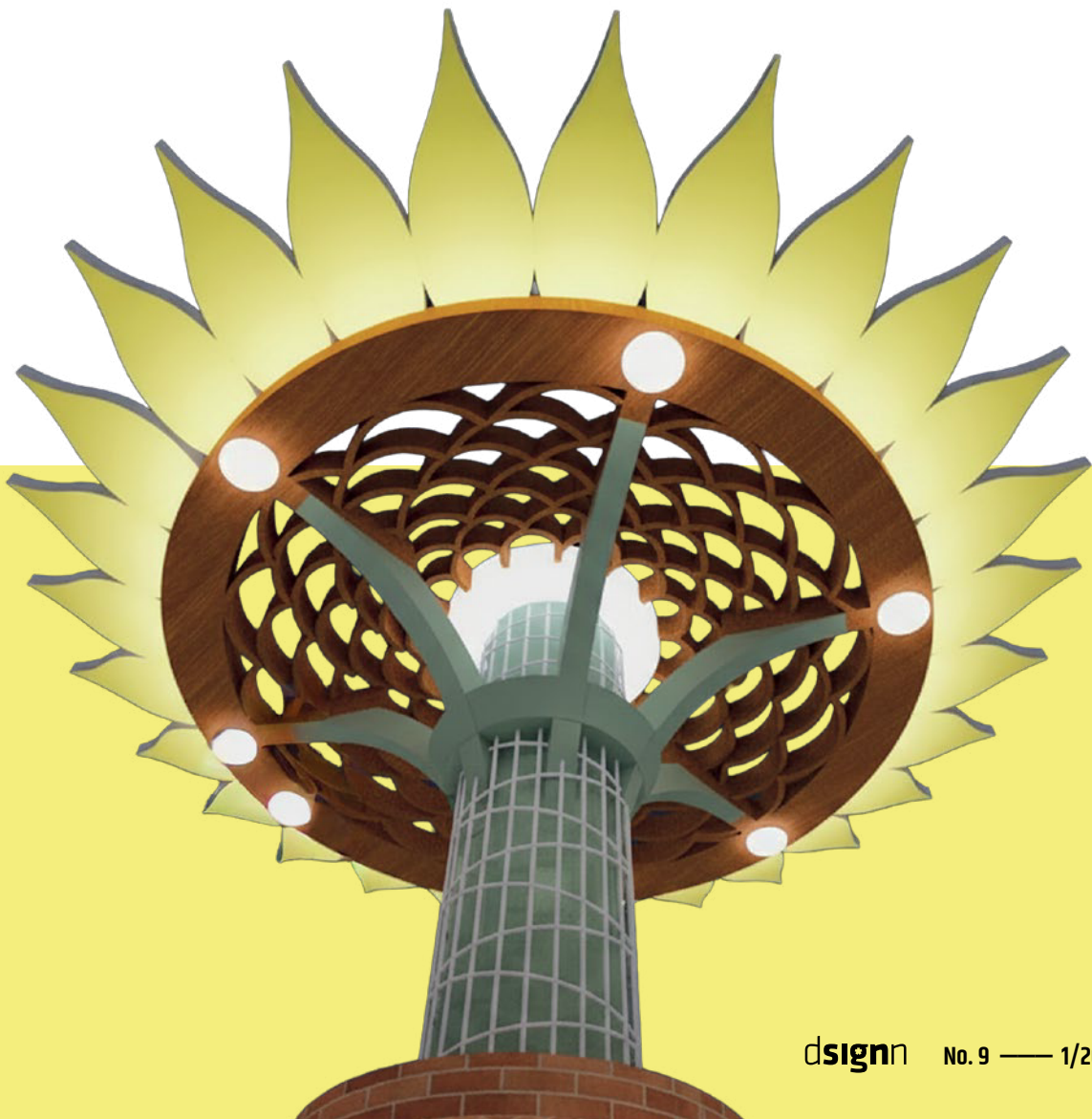
From a computational perspective, the integration of AI-assisted visualization with ArchiCAD enabled rapid iterative design, testing multiple configurations in a short period. This allowed optimized placement of structural elements, vegetation supports, and lighting fixtures. The results suggest that AI can act as a collaborative design partner, bridging natural inspiration, functional requirements, and environmental performance within a single workflow.

Overall, the Sunflower Parasol demonstrates how AI-assisted biodesign can produce visually compelling, ecologically responsive, and user-

-centered shading systems, providing a model for climate-adaptive urban infrastructure. These findings underscore the potential of computational intelligence not merely as a visualization tool, but as a strategic partner in designing regenerative and symbiotic urban environments.

Conclusion

This study demonstrates the potential of integrating artificial intelligence (AI) with biomimetic principles to develop climate-responsive urban shading systems. The Sunflower Parasol project exemplifies how computational tools can act as collaborative design partners, translating the natural logics of *Helianthus annuus* L. — such as heliotropism, structural geometry, and evapotranspiration — into functional, ecologically integrated infrastructure.



The combination of ArchiCAD and AI-assisted visualization via Nano Banana enabled rapid iterative design, precise structural scaling, and simulation of environmental performance, resulting in a living canopy capable of supporting vegetation, regulating microclimates, and accommodating users comfortably. Moreover, the incorporation of solar-powered lighting demonstrates the feasibility of self-sustaining, multifunctional urban structures that merge aesthetics, utility, and ecological responsiveness.

Overall, the findings suggest that AI-assisted biodesign can move beyond traditional visualization, serving as a tool for regenerative, adaptive, and symbiotic urban design. By bridging natural inspiration, functional requirements, and computational intelligence, this approach offers a scalable framework for creating shading infrastructure that responds dynamically to climate challenges

while enhancing biodiversity, user comfort, and urban resilience. Future research could further quantify performance metrics and explore material innovations to advance AI-assisted living architecture in diverse urban contexts. ■

Benjamin Chemarum

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