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THE BRIDGE BETWEEN NATURE AND TECHNOLOGY: THE IMPACT OF ARTIFICIAL INTELLIGENCE ON FURNITURE DESIGN[1]

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Abstract

The current study investigates the intersection of biomimicry, a design approach inspired by nature, and artificial intelligence, a product of technological innovation. Biomimicry offers solutions by drawing from biological mechanisms to address design challenges, allowing designers to create efficient materials and solutions. Designers using this approach apply insights from studying organisms and natural processes, but conventional computer-aided design software is limited in translating complex biological forms into practical applications. Artificial intelligence (AI)-supported design tools, however, overcome these constraints and provide designers with greater creative freedom. Although studies have brought together the biomimicry approach and furniture design, few studies in English literature systematically analyze the impact of AI-supported software on biomimicry-based furniture design processes. The present research aims to highlight the significance of AI software in facilitating the creation of nature-inspired designs by making the design process more adaptable and innovative. Through a comparative analysis of furniture designs generated with various AI visualization tools, this research examines differences in material use, aesthetic quality, and incorporation of technological advancements. The findings reveal that furniture designs created with AI-supported tools demonstrate notable variations in terms of material efficiency, visual appeal, and representation of contemporary technological trends, emphasizing AI's pivotal role in advancing the field of biomimicry furniture design.

Keywords: Technology, Furniture Structures, Biomimetic Design, Biomimicry, Form-Finding Processes.

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Introduction

Before the term *biomimicry* emerged, the term biomimetics was introduced into the literature by Otto Schmitt to describe the transfer of analogies from biology to technology.[2] Later, the concept was addressed and defined on a broader scale in Janine Benyus's book "Biomimicry: Innovation Inspired by Nature." According to Benyus, biomimicry is a new field of science that studies nature's models and imitates or draws inspiration from these processes to solve human problems. Biomimicry regards nature not only as a source of inspiration but also as a model, mentor, and standard.[3] Overall, biomimicry, as an approach that involves imitating the forms, processes, and functions of nature, has become a source of innovation in various fields such as engineering, architecture, and design.[4] In addition, biomimicry has emerged as a response to the growing calls for alternatives to the ecologically destructive technologies, systems, and approaches of the industrial age, which are characterized by unsustainable human–nature relationships. It models nature to overcome the challenges of sustainable development. In addition, the term has emerged as a response to the growing calls for alternatives to the ecologically destructive technologies, systems, and approaches of the industrial age, which are characterized by unsustainable human–nature relationships. It models nature to overcome the challenges of sustainable development.[5] To ensure sustainability, designers may adopt the level of deep biomimicry, which involves the imitation of forms, processes, and ecosystems, and take this approach as a role model.[6]

Furniture, an important component of the built environment, consists of products that are industrially designed and manufactured. Therefore, this approach is among the methods that should also be utilized in furniture design to make the heavily industrialized furniture sector more sustainable.[7] In furniture design, the use of artificial intelligence tools instead of relatively limited computer-aided software for imitating the forms, functions, and processes of natural organisms enables the creation of freer and more innovative design ideas, surpassing these limitations. The rapid development of artificial intelligence has also led to an increase in the number of advanced tools that enhance this creativity and freedom. Artificial intelligence tools like Midjourney, Gemini, and ChatGPT are among the software that play a role in providing this freedom. Designers can create sustainable furniture design models and ideas that reflect the biomimicry approach by utilizing these software tools that establish a connection between technology and design.

The integration of artificial intelligence technologies into furniture design processes has received increasing attention in recent years. In this context, Zahra has comprehensively examined AI-based techniques used in furniture design, discussing the possibilities that generative design, machine learning, and algorithm-based systems offer to designers.[8] However, although the study reveals the functional capacity of artificial intelligence, it does not include aesthetic and formal analyses of how nature-inspired forms are generated using AI visualization tools. Karič et al. have addressed the application possibilities of artificial intelligence in the furniture and woodworking industries in the context of production, quality control, and generative design, explaining the contributions of

AI-supported systems to the furniture sector during the digital transformation process. Nevertheless, the study does not discuss the aesthetic, functional, and manufacturability dimensions of the design outputs.[9] Li et al. have investigated the innovation potential of AI-generated content in modern furniture design through machine learning tools, revealing the influence of artificial intelligence on design processes around themes such as personalization, sustainability, and production efficiency. However, while the study evaluates the contribution of AI visualization tools to the generation of nature-inspired forms through detailed formal analyses, it does not present aesthetic, structural, and functional comparisons between different tools within the framework of biomimicry-focused furniture design.[10]

It has been observed that the number of studies within the related literature in English on the integration of AI-supported tools into the furniture design process is quite limited. Therefore, the present study is significant for systematically examining the impact of artificial intelligence on the furniture design process and identifying directions on how it can facilitate more accessible and organic design applications.

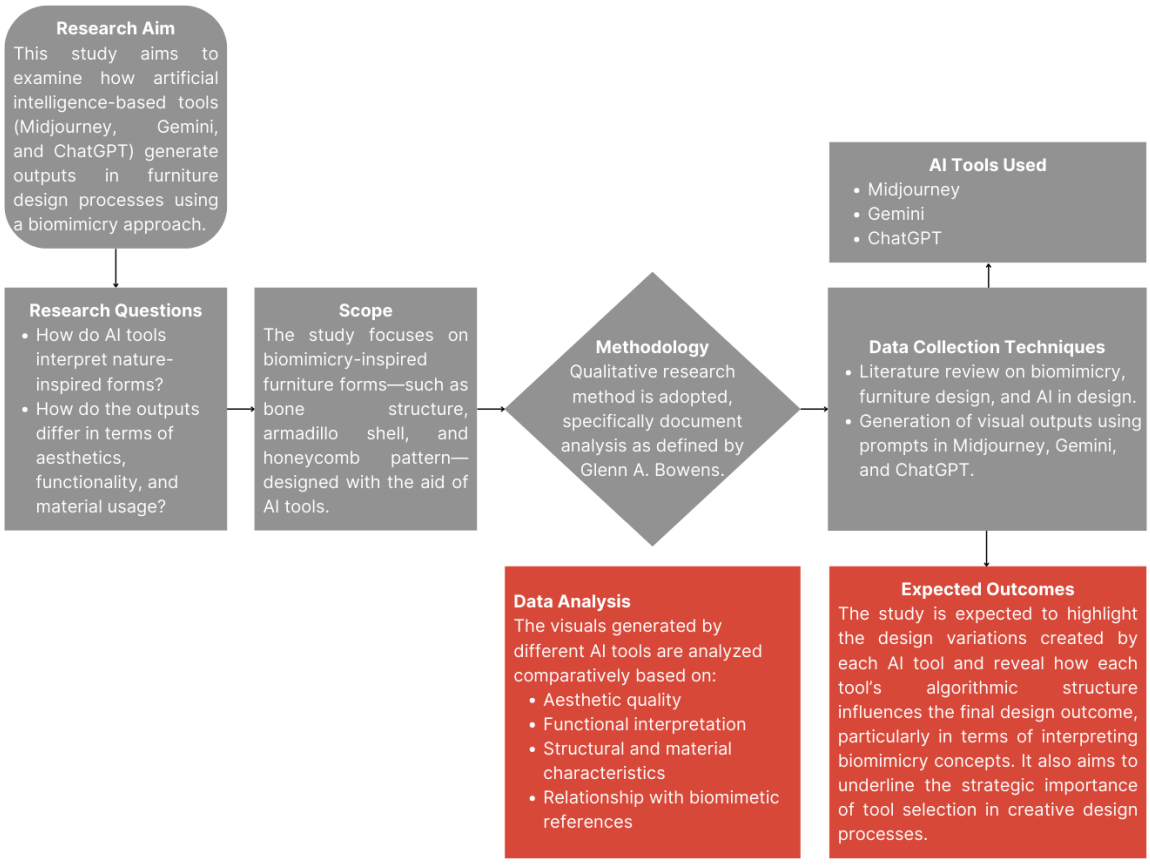


Fig. 1. Research Design. Created by the authors.

In this context, the current study aims to investigate the role of AI-supported tools in the furniture design process based on the biomimicry approach. Another objective of the study is to examine the extent to which these tools perceive

designers' prompts that express their goals of designing innovative and sustainable furniture that imitates natural forms and processes, and the degree to which the outputs generated by these tools align with the prompts.

The scope of this study encompasses furniture designed using the biomimicry method, an approach aimed at achieving more sustainable designs in design fields. The AI-supported tools used in the visual representations of these furniture designs are limited to the Midjourney, Gemini, and ChatGPT software.

In this study, a framework was established based on data obtained from a literature review. In this context, the first section of the study examines the relationship between biomimicry and furniture design; in the second section, the concept of artificial intelligence and AI-supported modeling tools that can be used for visualizing furniture designs are reviewed. In the third section, a comparative analysis of the outputs produced by Midjourney, Gemini, and ChatGPT tools, used to model furniture designs adopting the biomimicry approach, is conducted in terms of aesthetic value, functional potential, manufacturability, and sustainability.

Conceptual Infraestructure. Biomimicry and Furniture Design

The term "biomimicry" is derived from the Greek word bios, meaning life, and mimesis, meaning imitation, and it refers to the imitation of life or nature. Biomimicry is a new scientific discipline that examines natural models and then imitates or draws inspiration from these models and processes to address human problems.[11] The biomimicry approach, viewed as a method of mimicking the forms, processes, and functions in nature within design and engineering, has attracted significant attention in the fields of architecture and interior design.[12] This method is based on the idea that nature serves as a source of inspiration for developing more sustainable, efficient, and resilient structures and products.[13] Therefore, for the biomimicry method to be fully applied, it must not only reflect the aesthetics of natural organisms but also mirror their functions and efficiencies.[14]

Those working in the field of biomimicry generally carry out the imitation of natural functions through two methodologies. One focuses on identifying design challenges and seeking similar solutions in nature to address them, whereas the other aims to discover innovative strategies in nature and adapt them to develop new design methodologies or products.[15] Designers using the biomimicry method often try to overcome technical challenges encountered during the design phase by studying and replicating the strategies observed in the natural world.[16] Thus, this interdisciplinary approach requires examining the problem, identifying relevant natural models, and transforming these biological strategies into innovative design solutions.[17]

Interior designers have various methods for integrating biomimicry into the design process. One of these is the Biomimicry Design Spiral, proposed by industrial designer Carl Hastrich for the Biomimicry Institute, of which Benyus is a founding member (fig. 2).[18] Hastrich's spiral is a systematic approach aimed at transforming design challenges into innovative and sustainable solutions. By incorporating biomimicry principles into the design spiral, this approach facilitates

the creation of products or processes that enhance sustainability, performance efficiency, energy savings, and waste reduction.[19]

Another approach is Kilmer's problem-solving methodology, in which designers begin by clearly defining and understanding the dimensions of the problem. Kilmer initially divides the process into analysis and synthesis stages and later expands these into eight. Unlike Hastrich, Kilmer employs a narrowing approach as the spiral progresses downward, focusing intensively on clarifying the problem.[20]

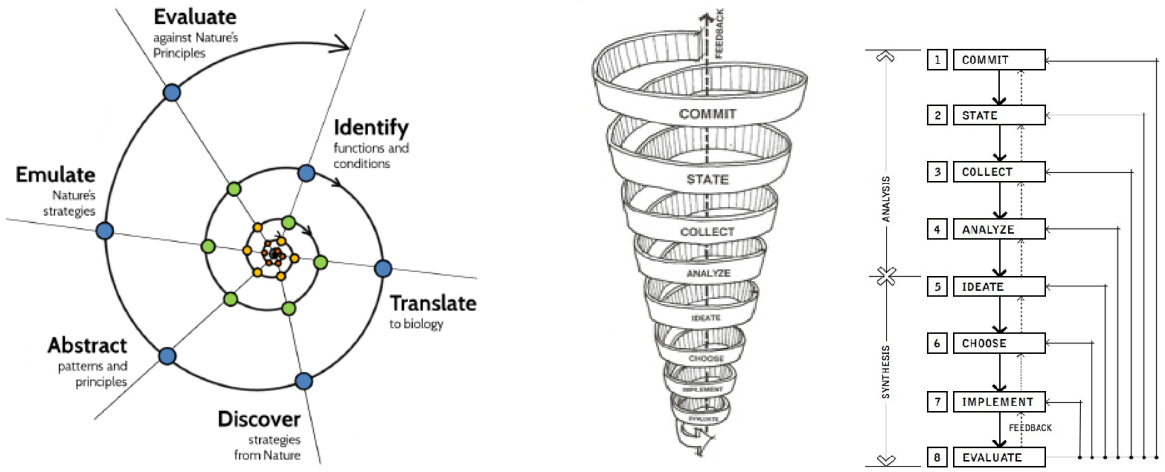


Fig. 2. Carl Hastrich's Biomimicry Design Spiral, 2005 (Left)[21], Kilmer's Biomimicry Design Spiral, 1992 (Right).[22]

The structure of furniture is a crucial element in its design, shape, and functionality. A well-designed structure not only enhances the aesthetic appeal and usability of furniture but also increases its durability. Therefore, understanding and applying furniture structures is essential for creating furniture with both functional and aesthetic value.[23] In furniture design, various factors must be considered to create products with functional, ergonomic, and aesthetic value.[24]

As social and technological advancements occur, the requirements and expectations for furniture design have evolved, introducing important variables that demand attention.[25] These variables include aspects such as aesthetics, ergonomics, comfort, structural integrity, and sustainability.[26] The use of the biomimicry approach in furniture design allows for the creation of organic forms inspired by natural structures while maintaining a focus on efficiency, which not only enables designers to develop furniture with aesthetic value and ergonomic qualities but also enhances sustainability by encouraging the use of materials inspired by ecosystems. Hence, by imitating the complex biological forms and processes found in nature, designers can create aesthetic, functional, and sustainable furniture.

Although computer-aided design (CAD) software goes far beyond mere visualization by offering geometric precision, topological data, and material information, it remains relatively limited and slow in terms of time when it comes to transforming complex biological forms into practical design applications - especially through the integration of biomimicry design methods into furniture design during the earliest stages of idea development. AI-supported software, on the other hand, overcomes these limitations by allowing designers to unleash their creativity without restriction, thereby facilitating the creation of nature-inspired designs. That's why, although the visuals generated by artificial intelligence do not yet constitute designs on their own, they rapidly produce pixel-based representations of design ideas.

Artificial Intelligence

The concept of artificial intelligence (AI) is defined in the Merriam-Webster Dictionary as the ability of computer systems or algorithms to mimic intelligent human behavior; a computer, computer system, or set of algorithms that possesses this ability" .[27] Artificial intelligence facilitates the development of cognitive processes in machines by mimicking the functions of the human brain, including thought patterns, learning, and decision-making abilities.[28]

Types of artificial intelligence include concepts such as natural language processing, expert systems, machine learning, artificial neural networks, and deep learning.[29] Natural Language Processing (NLP) is a significant subtype that enables machines to understand, interpret, and generate human language. This subtype has been a crucial factor in the development of technologies such as chatbots and language translation systems.[30] Another subtype is expert systems, designed to mimic human experts' decision-making abilities in specific fields. These systems are particularly utilized in areas like financial consulting and engineering, where they provide consistent and reliable recommendations.[31]

Machine learning is a subtype of artificial intelligence that allows computers to identify patterns in data and make decisions based on those patterns without requiring explicit programming.[32] Artificial neural networks and deep learning, two subtypes of artificial intelligence, are related to machine learning. These types leverage the power of interconnected networks to enable tasks such as image recognition, speech processing, and natural language understanding, processing large amounts of data in the process.[33]

One of the most influential developments in deep learning–based generative modeling is the Generative Adversarial Network (GAN) architecture. Developed in 2014 by Ian Goodfellow and his colleagues at the University of Montreal, GANs represent a class of unsupervised machine learning models based on deep learning.[34] They function through the simultaneous and competitive interaction of two neural networks: the generator and the discriminator. The generator network aims to produce new images that resemble real data, while the discriminator attempts to distinguish between genuine and synthetic images. This adversarial process continues iteratively, with both networks improving their performance until the generated outputs become indistinguishable from real data. The fundamental goal of GANs is to generate synthetic visuals that closely

approximate the distribution of the original dataset, and this has laid the foundation for a wide range of applications in image generation, design, and visual arts.[35]

As artificial intelligence technology advances, the integration and interaction among its subfields are becoming increasingly critical, fostering new opportunities for innovation and problem-solving across various industries and applications. The development of artificial intelligence has not only facilitated increased interaction among its subtypes but has also promoted practical applications that touch nearly every aspect of human life. Various subtypes of artificial intelligence, such as Natural Language Processing (NLP), expert systems, machine learning, artificial neural networks, and deep learning, serve as fundamental technologies driving this transformation. For instance, NLP has played a significant role in the development of chatbots and language translation systems, making human-computer interactions more intuitive and personalized.[36] As highlighted in recent research, these technologies collectively contribute to improved communication and information flow across different sectors.[37] Businesses have begun to optimize their operations and enhance decision-making processes by leveraging the power of artificial intelligence.[38] Therefore, the integration of artificial intelligence technologies into various fields not only enhances machine capabilities but also reshapes how people interact with technology, leading to more efficient and effective outcomes.

Recent developments in artificial intelligence have significantly improved communication and the flow of information across various domains.[39] AI-supported technologies have transformed communication and information exchange methods by providing more efficient and seamless interactions between humans and machines. Capabilities such as natural language understanding and generation have facilitated more intuitive and personalized communication, enabling individuals to effectively convey their thoughts and ideas.[40] Furthermore, the adoption of artificial intelligence within organizations has the potential to create significant business value. Researchers have identified a wide range of artificial intelligence applications across various business areas, from optimizing operational efficiency to enhancing decision-making processes.[41] Consequently, artificial intelligence technologies are becoming increasingly integrated into various sectors, leading to significant changes in diverse fields of work and different industries.

Artificial Intelligence and Modeling

Within the scope of artificial intelligence, visualization fundamentally encompasses a wide range of digital representations, including graphs, charts, and three-dimensional models that can facilitate problem-solving and exploration.[42] As data complexity increases, traditional visualization methods may prove inadequate for effectively conveying the details of the data. However, AI-driven visualization solutions allow a more intuitive understanding of complex data.[43] The integration of artificial intelligence into visualization has necessitated the development of new technologies that can leverage the power of machine learning.[44]

Artificial intelligence, which shows continuous progress ranging from simple computers to complex machine learning algorithms, has not been limited to traditional fields like computing and information technology; it has also led to innovations in more creative fields, particularly in art. In this context, the concept of AI-Art has emerged at the intersection of technology and creativity, where artificial intelligence is used to produce artistic works in digital format.[45] As generative artificial intelligence models, platforms such as DALL·E and Midjourney have significantly simplified the process of visual creation. These technologies have had a profound impact on image production by enabling visuals to be generated directly from textual inputs through the use of prompts. Unlike traditional methods that often require technical expertise or artistic training, these AI-based systems allow even non-experts to produce complex and visually compelling outputs with minimal effort.[46] This new application of AI has the potential to influence and transform traditional concepts of creativity and aesthetics by offering new tools and methods for artistic production.[47]

One of the tools used for artistic production, Midjourney, has made significant advancements in AI-assisted design. Through this innovation, it has been successfully integrated into the design innovation process, demonstrating the potential of artificial intelligence to enhance and transform traditional design methodologies. The integration of Midjourney exemplifies the evolving role of AI in facilitating creative collaboration and innovation by providing a platform that bridges technology and design thinking.[48]

Another tool for artistic production, Gemini, is an AI network designed to transform written texts into images. In addition to visual production, this network also performs natural language processing tasks such as text summarization, content understanding, and classification.[49] That is to say, this AI tool utilizes advanced algorithms that mimic human-like thinking and creativity to interpret user prompts and generate visual content.

Another artificial intelligence tool developed by OpenAI, ChatGPT, has become one of the most popular tools, demonstrating significant progress in the fields of natural language processing and artificial intelligence. ChatGPT offers remarkable competence in generating human-like text across different contexts and prompts.[50] This AI tool, equipped with six billion parameters, responds to commands by generating text using algorithms programmed to understand natural language inputs.[51] However, ChatGPT has recently begun to be used as a visualization tool as well.

Method

In this study, a literature-based document analysis method has been used. Document analysis is defined as "a systematic process aimed at examining or evaluating both printed and electronic (computer-based and internet-delivered) documents".[52] In the study, a literature review was first conducted to establish the conceptual framework. In this context, the relationship between biomimicry and furniture design was discussed. Subsequently, the concept of Artificial Intelligence and AI-supported visualization software that can be used in the furniture design process was examined. To analyze how AI affects the design process of adopting

the biomimicry approach, AI-supported tools such as Midjourney, Gemini, and ChatGPT were used. The selection of Midjourney, Gemini, and ChatGPT was based on their widespread use, accessibility, and distinct algorithmic approaches to image generation. Midjourney's distinguishing feature lies in its community-based, Discord-integrated interface, which not only enables real-time visual generation through text prompts but also fosters collaborative creativity by allowing users to share, critique, and refine outputs collectively, making it both a generative tool and a participatory design environment.[53] ChatGPT is more than just a tool for responding to simple expressions; it is an advanced language model capable of analyzing complex linguistic structures, mimicking human communication patterns, and generating meaningful content across a wide range of topics. Trained on a comprehensive dataset, it demonstrates high performance in producing and conveying information in diverse fields such as healthcare, technology, finance, and education. Its ability to learn from input data suggests that it can contribute to reducing potential errors in visual production processes by providing accurate and effective guidance.[54] On the other hand, Gemini AI's distinguishing feature lies in its multimodal reasoning capability, enabling seamless integration and interpretation of text, image, audio, video, and code. Developed by Google, Gemini is the first AI model to surpass human-level performance in large-scale multitask language understanding, making it a leading example of advanced problem-solving and cross-modal intelligence.[55] Prompts were entered into the prompts sections of three tools to create visual representations based on biomimicry principles using the AI tools Midjourney, Gemini, and ChatGPT. Each AI tool was tasked with producing designs that materialize imitations of specific natural structures, such as the hollow structure of a bone, the layered architecture of an armadillo shell, and the hexagonal framework of honeycombs.

The prompt used in the study is based on a structural formula consisting of three main components: the object (chair or table), the biological entity and its characteristics to be mimicked (e.g., the hollow structure of bone), and the methodological approach (biomimicry). This structure defines the object to be generated, the natural form it is inspired by, and the method through which this inspiration is applied. It deliberately excludes parameters such as style, material type, production technique, or contextual use. This choice was intentional. The reason for avoiding inputs that directly influence the visual outcome, such as style, material, or technique, is to observe to what extent AI tools can develop their own formal aesthetic interpretations, material selections, and sustainability approaches through their internal algorithms. Material information was not specified in order to assess whether AI tools would choose sustainable materials in terms of manufacturability. Likewise, no particular style or design language was indicated, allowing for an examination of how the tools interpret biomorphic inspiration according to their own aesthetic preferences. Additionally, the concept of sustainability was not included in the prompt, so that the study could test whether AI internalizes sustainable approaches visually through the notion of "biomimicry" alone. In this regard, the simplified structure of the prompt aims to

reveal not only how AI tools respond to explicit directives but also how they formulate a design strategy through their internal decision-making processes.

In recognition of the stochastic nature of generative AI tools, each prompt was executed three separate times per tool to generate a more representative sample of the AI's stylistic tendencies, structural consistencies, and potential errors. Rather than basing evaluations on a single output, this repetition enabled a more reliable comparison across tools. The three visuals produced for each prompt were analyzed collectively, and only after assessing recurring features or significant divergences were conclusions drawn.

Özel and Ürük classified furniture design criteria into three functional categories: practical, aesthetic, and symbolic. The practical function refers to how furniture addresses needs such as sitting, lying down, or working, as well as providing ergonomic solutions based on the user's anthropometric measurements. The aesthetic function describes the appeal of the furniture through elements such as material, color, and form. The symbolic function, which is not required in every piece of furniture, represents aspects such as the user's social status, cultural identity, or personal memories.[56] Öden indirectly evaluated design criteria under four main headings: functionality, aesthetics, user-centeredness, and the relationship between material and form.[57] Özkader and Söğüt classified furniture design criteria into aesthetics and functionality, emphasizing that considering fundamental design principles, such as balance, rhythm, emphasis, harmony, proportion, and ergonomics, enhances both the aesthetic quality and functional performance of furniture design.[58] Therefore in the findings section, the outputs produced by Midjourney, Gemini, and ChatGPT were comparatively analyzed using a standardized evaluation framework consisting of four key criteria: (1) aesthetic value (e.g., visual harmony, compliance with basic design principles, coherence with biomorphic inspiration), (2) functional potential (e.g., ergonomic form, material efficiency), (3) manufacturability (e.g., feasibility for 3D printing or conventional production methods), and (4) sustainability (e.g., ecological compatibility, resource efficiency). In line with prior classifications in the literature, such as Özel and Ürük's distinction between practical, aesthetic, and symbolic functions, as well as Özkader and Söğüt's emphasis on functionality and aesthetic principles, the current study evaluates AI-generated furniture designs using four key criteria. These criteria reflect core concerns in furniture design, including visual harmony, ergonomic appropriateness, production feasibility, and ecological responsibility. Moreover, the inclusion of sustainability as a distinct evaluation criterion is directly aligned with the conceptual framework of biomimicry, which, unlike biomimetics, does not merely focus on the imitation of natural forms or mechanisms but emphasizes the integration of ecological principles such as resource efficiency, circularity, and life-friendly design. Thus, evaluating the AI-generated designs through the lens of sustainability serves not only as a design measure but also as a means to critically assess whether the outputs genuinely reflect the ethos of biomimicry rather than a superficial biomimetic approach. The criterion of manufacturability, defined as the feasibility of realizing the design through 3D printing or conventional production methods, was deliberately included in the evaluation framework as a proxy for assessing

material and resource efficiency. Since the practicality of production inherently reflects the design's alignment with sustainable principles such as minimal material waste, energy-conscious fabrication, and adaptability to existing manufacturing infrastructures, manufacturability serves as an indirect yet critical indicator of the design's ecological viability. Given the AI-generated nature of the visuals, the evaluation of material usage and technique was interpretive, based on visual cues such as texture representation, joinery implications, and form logic. Aesthetic value was assessed using basic design principles, including balance, proportion, and unity. Functional form was evaluated hypothetically, based on assumptions drawn from ergonomic conventions in furniture design.

Findings

The structure of bones in the human body serves as an inspiration for designers. This structure enables the achievement of maximum strength with minimal resources, that is, materials. By mimicking this structure through the biomimicry method, designers can create high-strength products that maintain structural integrity while using less material. Thus, sustainable designs can be achieved by reducing resource usage through the use of materials only where necessary in the furniture structure.

To produce a visual of a chair that imitates the hollow structure of bone, the Midjourney tool was initially utilized. The prompt for creating the design was, "Design a visual of a chair that mimics the hollow structure of bone through biomimicry." The final designs exemplified the application of the biomimicry approach in furniture design by imitating the high strength of bone structure and minimizing material usage. Furthermore, the biomorphic form of these chairs enhances the aesthetic value of the design. The images produced by Midjourney indicate that the design was realized using 3D printing, demonstrating that technology can enable additive manufacturing in biomimetic furniture design instead of traditional subtractive methods. The chairs generated by Midjourney AI demonstrate a high degree of aesthetic coherence, particularly through their organic geometry, balance, and visual rhythm, which align with established design principles. In terms of functional potential, the seamless integration of backrest, seat, and legs suggests strong ergonomic potential and efficient material distribution. Their formal structure and uniform surface texture imply high manufacturability for additive methods like 3D printing, which also supports sustainability by minimizing material waste and allowing the use of recyclable filament materials.

For obtaining secondary examples, the Gemini Advanced tool was utilized. While the same prompt was inserted to obtain visuals, the images generated with this tool feature a simpler design. In the chairs generated by Gemini AI, balance is generally achieved through symmetrical forms. These design outputs are strong in terms of the aesthetic principles of balance, harmony, and proportion. The presence of bone-like perforations in the designs reflects a rhythmic repetition; however, this repetition is more irregular and sparse compared to the examples produced by Midjourney and ChatGPT. Therefore, they exhibit a weakness in terms of rhythm, which indicates that, aesthetically, the Gemini designs fall

behind those of Midjourney. This simple design differentiates the furniture aesthetically from the previous visuals, while it is observed that material usage in these designs has been more optimized. However, the two designs produced with this tool both have a wooden appearance. The preference for wood as a material indicates that traditional subtractive methods were used instead of an additive design method like 3D printing. The excessive use of waste material in structures created by subtractive methods may lead to the biomimicry approach not being fully realized. The logic behind this reproduction may conflict with sustainability, since subtractive techniques often result in greater material loss and reduced resource efficiency, particularly when working with solid wood.

The tertiary examples consist of three different chair designs created using the same prompt entered into the ChatGPT tool, each mimicking the porous structure of bone through the biomimicry approach. In the first design, a holistic fluidity has been achieved between the backrest, seat, and leg parts, resulting in an organic form. The evenly distributed voids reflect the morphological features of biological bone structures. In the second chair, the reduced number of pores indicates a lower use of material, which supports the principle of efficient material usage emphasized in the biomimicry approach. In the third design, both structural balance and aesthetic value are prioritized. The skeletal form with large openings has been arranged similarly to the load-bearing principles found in natural bone systems.

These designs possess a more minimal form compared to the examples generated by Midjourney AI, yet exhibit greater organic and structural integrity than those created using Gemini AI. All three designs prominently feature biomorphic forms and demonstrate how natural structures can be imitated not only aesthetically but also functionally. Moreover, ChatGPT-based designs exhibit moderate-to-high aesthetic value due to their smooth surface transitions and proportional hole distribution inspired by bone morphology. The smoothness of the geometry and closed volume forms suggest feasible manufacturability via additive processes. Hence, the visuals suggest that such biomimicry-based designs are better suited for additive manufacturing technologies like 3D printing rather than traditional subtractive production methods. As these forms are likely to be printed with minimal material use and minimal waste, they also perform well in terms of sustainability, offering a balance between aesthetic expression and ecological responsibility.

Below, we present several tables featuring images of the chairs generated by the authors using artificial intelligence tools (Midjourney, Gemini, and ChatGPT) . These visualizations allow for a comparison of the aesthetic and structural approaches of each system, highlighting differences in morphology, texture, and manufacturability.

Prompt: Design a visual representation of a chair that mimics the hollow structure of bone using the biomimicry method		
Midjourney AI		
		
Gemini AI		
		
ChatGPT		
		

Table. 2. Chair Design Mimicking Bone Structure using AI Tools. Created by the Authors using Midjourney, Gemini, and ChatGPT.

The observed differences in the bone-inspired chair designs can be attributed to the algorithmic approaches and training data underlying each AI tool. Midjourney's diffusion-based model tends to emphasize high-tech, sculptural aesthetics, which are well-suited for additive manufacturing. In contrast, Gemini generates more minimalist and conventional outputs, likely reflecting a database rooted in realistic and manufacturable furniture forms. ChatGPT, although newer

in its visualization capability, produces structurally coherent and organic outputs, but may prioritize formal mimicry over functional realism due to its language-based generative architecture.

Animals from various families possess flexible armored skin composed of hard scales, which can be described as rigid plates embedded in soft tissues. These hard structures of animals that move separately provide protection against predators while allowing the necessary flexibility for efficient movement. Mimicking the layered structure of the armadillo's shell in furniture design will enable the production of impact-resistant and flexible furniture. Consequently, the designed seating element will adapt to the user's body shape and movements, resulting in a more ergonomic, flexible, and comfortable design.

To obtain a visual representation of the seating element that imitates the layered structure of the armadillo's shell, the prompt "Design a visual representation of a chair that mimics the layered structure of the armadillo shell using the biomimicry method" was submitted to two artificial intelligence tools. The seating elements produced by Midjourney not only reflect the kinetic, segmented, and flexible characteristics of the armadillo's shell but also contribute to meeting ergonomic conditions with their flexible structures. Furthermore, the seating elements modeled by Midjourney present a creative design approach that embodies a high level of technological innovation. These designs exhibit strong aesthetic value through the harmonious combination of geometry, color, contrast, and repetition, aligning well with the principles of rhythm, proportion, and emphasis. Moreover, the layered structure enhances material efficiency by allowing flexibility without excessive material mass, supporting the criterion of functional potential. The visually apparent use of modular, potentially 3D-printable components indicates a high level of manufacturability using additive production methods. Since additive manufacturing reduces material waste and enables lightweight construction, the designs also align with sustainability objectives by promoting resource efficiency. Nevertheless, the furniture components can be made using recyclable metal materials, thereby contributing to a sustainable design.

It is observed that only two of the secondary examples created with Gemini AI successfully reflect the form of the armadillo shell. From an aesthetic standpoint, the designs exhibit a soft, biomorphic appeal but offer limited visual rhythm or emphasis. Functionally, the soft structure may support user comfort but lacks visible ergonomic innovation related to movement or support. The use of a traditional and soft material resembling skin in these designs may hinder the complete representation of the armadillo shell's biological characteristics, consisting of rigid plates embedded in flexible tissues. Additionally, these designs tend to adhere more closely to traditional forms in both material and structure compared to the more innovative and high-tech approaches seen in the outputs from Midjourney. The use of traditional materials such as synthetic leather may raise sustainability concerns, whereas incorporating innovative materials like mycelium can lead to a more sustainable design that aligns with the principles of deep biomimicry.

Compared to other examples, the tertiary examples created with ChatGPT more successfully and realistically reflect the segmented outer surface of the armadillo shell. In the generated designs, the form composed of overlapping hard plates - characteristic of the armadillo shell - is clearly visible. The designs excel in visual rhythm and form repetition, enhancing their aesthetic value and offering a biomorphic coherence aligned with natural shell geometry. However, while other artificial intelligence tools abstract the creature's shell to produce more flexible designs, the ChatGPT tool directly imitates the form, resulting in chairs with rigid surfaces. Functionally, the segmented surface may enhance back support and comfort through adaptive structuring, despite the overall rigid appearance. In all examples, the material selection appears to be wood. The use of wood enables the reproduction of a segmented natural structure with a material that is both traditional and organic. In this context, the chairs generated by ChatGPT exhibit a preference for a natural material while also selecting one that allows the layered form to be realized. These AI-generated chairs are simpler compared to the high-tech aesthetic of those created by Midjourney, yet they are among the most precise representations of the concept of layering in design. Unlike the softer and more amorphous forms observed in the outputs of Gemini AI, these designs offer structural continuity through the sequential arrangement of segments. Manufacturability appears feasible through CNC machining or layered woodcrafting techniques. The use of natural wood contributes to ecological compatibility, but unless recycled or sustainably sourced, the design's sustainability potential remains limited.

The variation in how each tool represented the armadillo shell can be linked to their algorithmic priorities. Midjourney demonstrates a higher capacity for kinetic abstraction, generating flexible and visually rich structures that reflect movement and layering. Gemini, however, produces softer and more traditional forms, which may be due to its grounding in more literal and less abstract data sets. ChatGPT closely replicates the segmented surface structure but often sacrifices ergonomic adaptability in favor of visual accuracy, highlighting a trade-off influenced by its prompt interpretation logic and current visualization constraints.

The hexagonal structure of honeycombs enables the construction of large volumes with minimal energy and resource expenditure. Mimicking this structure in furniture design facilitates the seamless interlocking of hexagonal cells, allowing for the creation of large structures with minimal material usage. This approach reflects the biomimicry principle, which transfers nature's efficiency and functionality into design. Furthermore, utilizing 3D printing technology in the production of honeycomb-based furniture will enable the incorporation of biodegradable materials, such as bioplastics, into the design. Thus, this not only enhances material efficiency but also allows for the creation of more environmentally friendly and sustainable designs.

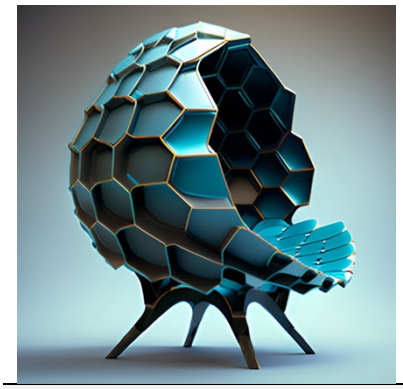
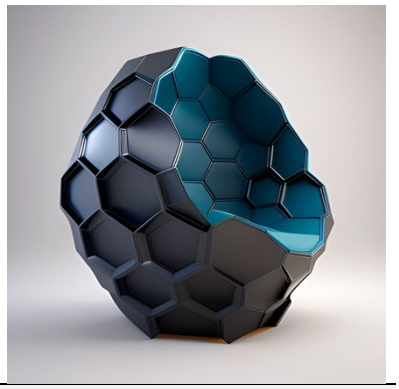
Prompt: Design a visual representation of a chair that mimics the layered structure of an armadillo shell using the biomimicry method		
Midjourney AI		
		
Gemini AI		
		
ChatGPT		
		

Table. 2. Chair Design Mimicking the Kinetic Structure of an Armadillo Shell using AI Tools. Created by the Authors using Midjourney, Gemini, and ChatGPT.

To obtain visual representations of furniture designs that imitate the efficient material usage of honeycombs, the prompt "Design a visual representation of a table that mimics the hollow structure of a honeycomb using the biomimicry method" was submitted to three artificial intelligence tools. The images produced by Midjourney successfully reflect the principles of biomimicry by mimicking the hexagonal structure of the honeycomb, which allows for the creation of a strong and lightweight structure using minimal material. The resulting table designs

exhibit a dynamic, futuristic, and modern appearance, enhancing their aesthetic value. The Midjourney examples display strong visual emphasis and rhythm, adhering to the principles of repetition and contrast. These features contribute to their high aesthetic value, positioning them closer to experimental or concept furniture. Among the furniture representations produced by the AI-supported software, two are made of plastic, whereas one uses metal, which allows for the use of bioplastic and recycled metal materials in the furniture depicted in the images, contributing to sustainable production. Functionally, these tables appear structurally sound due to their centralized and evenly distributed load-bearing legs; however, certain tabletop geometries may compromise usability in practical contexts. Manufacturability is notably high in the Midjourney outputs due to the modularity and geometric clarity, making them suitable for additive manufacturing methods such as 3D printing. Nevertheless, intricate geometries may require energy-intensive processes, posing a potential trade-off in sustainability unless biodegradable or recycled materials are explicitly prioritized.

Wood was the preferred material for the furniture images generated by Gemini AI. The hollow structure that imitates the honeycomb allows for high strength to be achieved with minimal material, thereby increasing material efficiency, while the use of wood makes the design sustainable. The Gemini designs follow basic principles of symmetry and proportion, offering a familiar and modest aesthetic that aligns. This organic structure, which can also be produced using materials like bioplastics through 3D printing, reflects a more traditional aesthetic compared to the designs produced by Midjourney, thus making these designs more suitable for industrial production. However, the visual integration of the honeycomb pattern is mostly limited to the table base, reducing the potential aesthetic conformity between the tabletop and base. Moreover, their subtractive production approach using wood may limit sustainability if resource consumption and waste output are not optimized through CNC or modular cutting strategies.

In the furniture visuals generated by the ChatGPT software, the honeycomb form is utilized not only as an aesthetic motif but also as a structural element. ChatGPT outputs from an aesthetic standpoint, the hexagonal grid system is applied consistently, adhering to the principle of unity. Notably, the repeated placement of hexagonal perforated structures in the legs and surfaces of the tables demonstrates the applicability of natural systems to furniture design. Thus, through a biomimicry approach, tables designed in this manner achieve a durable load-bearing system with minimal material use, similar to what is observed in nature. However, in two of the examples, it is noted that the tabletop has been designed using the honeycomb pattern in a non-functional way. The surface, featuring a perforated form, prioritizes visual expression over usability, indicating that the ChatGPT AI tool may overlook functionality while generating furniture design visuals. All three tables are modeled using natural wood, which contributes to a design emphasizing user-friendliness, lightness, ergonomics, and sustainable use. However, as with the furniture designed by Gemini AI, the use of wood points to subtractive rather than additive manufacturing techniques, hindering material efficiency optimization. These examples generated by ChatGPT offer a simpler, manufacturable, and user-oriented aesthetic compared to the futuristic and high-

tech approach of Midjourney designs. Although they present a more holistic design composition than those of Gemini AI, this holistic approach tends to come at the expense of functionality. Sustainability potential increases when these designs are produced using certified wood or wood waste; however, unlike Midjourney designs, the lack of material innovation (e.g., bioplastics) slightly reduces their positive future-oriented environmental value.

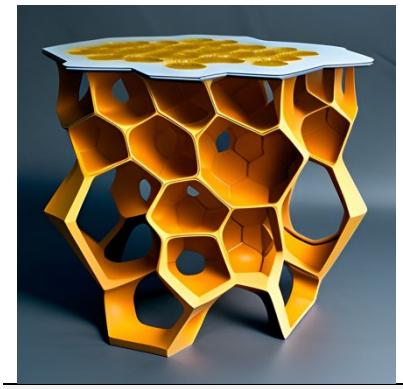
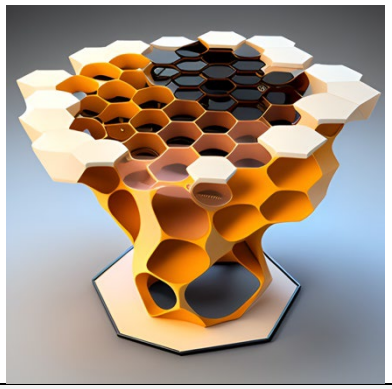
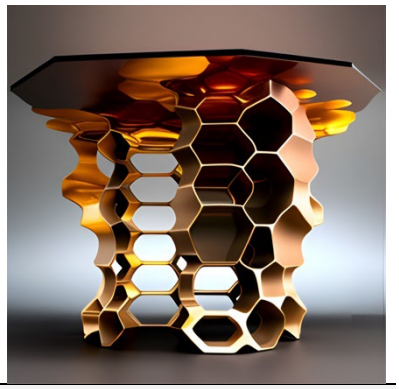
Prompt: Design a visual representation of a table that mimics the hollow structure of a honeycomb using the biomimicry method		
Midjourney AI		
		
Gemini AI		
		
ChatGPT		
		

Table 3. Table Design Mimicking the Structure of a Honeycomb using AI Tools. Created by the Authors using Midjourney, Gemini, and ChatGPT.

The differences among the honeycomb-inspired tables reveal how each AI tool interprets structural efficiency and form. Midjourney's outputs reflect a futuristic, high-performance aesthetic that aligns with additive techniques and sustainable materials, likely informed by data emphasizing innovation. Gemini, grounded in conventional design databases, opts for wooden textures and balanced proportions, favoring practicality over visual experimentation. ChatGPT's designs successfully embed the hexagonal form as a structural motif, but occasionally disregard functional usability, such as in perforated tabletops, indicating the tool's current limitations in balancing visual coherence with practical constraints.

These comparative findings reveal how different AI tools interpret the same biomimicry-based prompt through distinct algorithmic structures and material aesthetics. Building upon these observations, the conclusion reflects on the broader implications of these tools for the future of sustainable design.

Conclusion

The present comparative analysis of furniture visualizations created using artificial intelligence-supported tools reflects the innovative potential and various outcomes that can be achieved through the application of artificial intelligence support and biomimicry in design. The study reveals that the outputs produced by the Midjourney, Gemini AI, and ChatGPT tools exhibit significant differences in terms of material usage, aesthetic value, and technological innovations while mimicking biological structures and transforming them into furniture designs.

The visual representations provided by Midjourney illustrate designs that imitate biological structures such as the hollow structure of bone, the armadillo shell, and the honeycomb, integrating 3D printing methods into the design, which expresses a high level of technological advancement. These designs optimize material usage through an additive design approach rather than a subtractive one, offering futuristic and dynamic furniture concepts that embody the principles of biomimicry while pushing the boundaries of creativity. The designs, which allow for the use of innovative materials such as bioplastics and recycled metals suitable for 3D printing, align with the sustainability goals of the biomimicry approach and enhance the potential of layered manufacturing to transform furniture design.

On the other hand, the Gemini AI tool has produced more traditional and simplified designs by using materials suited to conventional subtractive manufacturing methods, typically wood. While these designs continue to connect with nature through the use of organic materials and the biomimicry approach, they tend to reflect a more traditional approach in terms of aesthetics and production techniques. This attachment to conventional materials and methods may hinder the full expression of biomimicry's potential, particularly in the context of achieving high-tech, flexible, and innovative designs.

The third tool, ChatGPT, has produced simpler yet structurally coherent designs. The organic fluidity in the bone-inspired chairs, the forms directly reflecting the overlapping segments of the armadillo shell, and the integration of the honeycomb's structural system into table surfaces all demonstrate that ChatGPT effectively conveys nature-referencing details. However, certain design weaknesses have also been identified, particularly where functionality is

compromised, such as the impractical use of perforated forms on tabletops. Additionally, while the use of wooden materials makes the ChatGPT designs more manufacturable and user-friendly, it also points to a subtractive manufacturing approach rather than additive methods, which may limit material efficiency. In addition to material and production considerations, the study also evaluated aesthetic value through basic design principles such as balance, proportion, harmony, rhythm, and emphasis. It was observed that Midjourney outputs displayed stronger visual rhythm, contrast, and emphasis, whereas Gemini AI designs tended to rely on proportional simplicity and visual harmony derived from traditional forms. ChatGPT-generated designs exhibited a more neutral aesthetic, with holistic integrity but less visual emphasis. Furthermore, the inclusion of functionality-based criteria revealed that certain outputs (particularly from ChatGPT) visually expressed biomimicry but occasionally neglected ergonomic usability, especially where design features, such as perforated tabletops, challenged practical use, which underscores the necessity of integrating both form and function when applying biomimicry in design.

In this context, the outputs reveal that beyond the use of organic materials, how the material is used and which technique is employed to generate the form are also critical factors influencing the proper application of the biomimicry approach. By incorporating manufacturability as a key evaluation criterion, the study identified how tools like Midjourney, aligned with 3D printing aesthetics and logic, are more suited to additive manufacturing processes. These approaches support material optimization and align more closely with sustainability goals than subtractive methods implied by Gemini and ChatGPT outputs. Additionally, sustainability was not only assessed in terms of material selection but also through the degree to which the biomimicry approach was abstracted and functionally reinterpreted, which highlights how biomimicry, when applied beyond mere aesthetic imitation, serves as a powerful framework for sustainable and efficient design solutions. These findings confirm that the selected evaluation framework, based on aesthetic value, functional potential, manufacturability, and sustainability, effectively captured the nuanced strengths and weaknesses of each AI tool within the context of biomimicry-based design.

In conclusion, this study demonstrates that the choice of an AI-based design tool significantly affects the final design outputs. Even when using the same prompts, each tool's algorithmic structure, material approach, and interpretation of form yield different results, turning the selection of design software into a strategic decision for the designer. In light of the findings, designers are encouraged to select AI tools based on their project needs, whether to prioritize manufacturability, visual innovation, or sustainability carefully. Designs generated through tools that incorporate advanced manufacturing techniques (e.g., 3D printing) are more likely to holistically reflect the sustainable, aesthetic, and functional potential of the biomimicry approach. Manufacturers should explore the integration of additive manufacturing techniques that align with AI-generated organic forms. The investigation of furniture design reflecting the biomimicry approach using AI-supported tools opens new pathways for designers to develop designs that mimic organic forms and processes in nature, ultimately

contributing to the development of more sustainable and innovative design practices. Furthermore, this study is expected to shed light on future studies with respect to its reliance on visual analysis with/without quantitative validation, such as user testing or manufacturability assessments. Future research may incorporate user-centered evaluations, explore the integration of AI tools with CAD/CAM systems, and examine how different AI algorithms interpret the same prompt across varying cultural and functional design contexts.

NOTES

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