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Enhancing Industrial Product Aesthetics, Ergonomics, and Usability With Artificial Intelligence-Driven Generative Design

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Abstract

Generative design is an AI-driven process that utilizes algorithms to generate, evaluate, and optimize multiple design solutions based on predefined constraints. This study explores the impact of AI-driven generative design on home appliances' aesthetics, ergonomics, and usability. To achieve this, a mixed-methods approach was adopted, incorporating a literature review, workshop study, and an investigation of user feedback gathered from 30 participants, including industrial design students, engineering students, and users. These participants evaluated AI-generated designs from their perspectives, focusing on visual appeal, comfort, and ease of use. Generative design software was used to investigate alternative design solutions, such as product forms and control placement positions. The findings indicate that AI-generated designs improve visual appeal and contribute to a more intuitive user experience. However, it was observed that AI-generated designs occasionally prioritized aesthetics over practicality, leading to usability concerns and requiring further refinement to align with real-world manufacturing constraints. The study concludes that while generative design is a valuable tool for enhancing home appliance design, its effectiveness depends on balancing AI-driven optimization with practical considerations.

Keywords: Artificial Intelligence, Creativity and Efficiency, Design Optimization, Generative Design, Industrial Product Design.

Yapay Zekâ Destekli Üretken Tasarımla Endüstriyel Ürün Estetiği, Ergonomisi ve Kullanılabilirliğinin Geliştirilmesi

Öz

Üretken tasarım, önceden tanımlanmış kısıtlamalara dayanarak çoklu tasarım çözümleri üreten, değerlendiren ve optimize eden algoritmalar kullanan yapay zekâ destekli bir süreçtir. Bu çalışma, yapay zekâ destekli üretken tasarımın ev aletlerinin estetiği, ergonomisi ve kullanılabilirliği üzerindeki etkisini araştırmaktadır. Bu amacı gerçekleştirmek için, literatür taraması, atölye çalışması ve 30 katılımcıdan (endüstriyel tasarım öğrencileri, mühendislik öğrencileri ve son kullanıcılar) elde edilen kullanıcı geri bildirimlerinin incelendiği karma yöntemli bir yaklaşım benimsenmiştir. Katılımcılar, görsel çekicilik, konfor ve kullanım kolaylığına odaklanarak YZ tarafından üretilen tasarımları kendi bakış açılarıyla değerlendirmiştir. Ürün formları ve kontrol yerleşimleri gibi alternatif tasarım çözümlerini incelemek amacıyla üretken tasarım yazılımı kullanılmıştır. Bulgular, yapay zekâ ile üretilen tasarımların görsel çekiciliği artırdığını ve daha sezgisel bir kullanıcı deneyimine katkıda bulunduğunu göstermektedir. Ancak, YZ tarafından üretilen tasarımların zaman zaman estetiği işlevselliğin önüne koyduğu, bu nedenle kullanılabilirlik sorunlarına yol açtığı ve gerçek dünya üretim kısıtlarıyla uyum sağlamak için ek düzenlemeler gerektirdiği gözlemlenmiştir. Çalışma, üretken tasarımın ev aletleri tasarımını geliştirmek için değerli bir araç olduğunu; ancak etkinliğinin, YZ destekli optimizasyon ile pratik gereksinimler arasında kurulacak dengeye bağlı olduğunu ortaya koymaktadır.

Anahtar kelimeler: Endüstriyel Ürün Tasarımı, Tasarım Optimizasyonu, Üretken Tasarım, Yapay Zekâ, Yaratıcılık ve Verimlilik.

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1. Introduction

This study investigates artificial intelligence-driven generative design and explores its use in industrial design. Generative design is an advanced iterative design process that leverages computational algorithms, often powered by artificial intelligence (AI), used by engineers and designers to produce alternative solutions based on predefined parameters and constraints (Hughes et al., 2021). It enables the designers to rapidly generate multiple design alternatives, evaluate them against specific criteria, and refine the options to meet evolving requirements (Lutkevich, 2024). Unlike traditional design methods, which rely on manual input and human creativity, generative design begins with defining objectives, such as decreasing material usage, optimizing structural integrity, and improving aesthetics or cost efficiency (Saadi, 2024). The software autonomously creates multiple design iterations by modifying the input data and the parameters of defined constraints (Tsang and Lee, 2022). By simulating real-world conditions and analyzing performance metrics, generative design aims to identify solutions that are not only innovative but also highly efficient (Regenwetter et al., 2022). Generative design mimics nature's evolutionary processes, using variation, selection, and optimization to arrive at designs that are often lighter, stronger, and more sustainable (Luu et al., 2024).

During the study, two AI-based design tools, Vizcom and MidJourney, were employed to support the generative design process. Vizcom enabled the rapid transformation of conceptual sketches into high-quality visual renderings, facilitating the exploration of form and detail at early design stages ("Vizcom AI," 2025). MidJourney, a text-to-image generation platform, was used to create a wide range of design variations based on descriptive prompts, allowing for the assessment of alternative aesthetic and structural configurations ("Midjourney," 2025). These tools played a central role in generating the visual content presented to participants for evaluation in terms of aesthetics, ergonomics, and usability.

As part of the study, a structured workshop was conducted to evaluate AI-generated design outputs in a controlled setting. The workshop included 30 participants, consisting of industrial design students, engineering students, and end-users, who were selected to represent diverse perspectives on product evaluation. During the session, participants were introduced to the concept of AI-powered generative design and were presented with visual outputs created using Vizcom and MidJourney. They were then asked to assess the designs based on aesthetics, ergonomics, usability, and manufacturability through a combination of surveys, informal interviews, and group discussions. The workshop setting allowed for direct observation of participant reactions and provided valuable qualitative insights that complemented the survey data.

1.1. Background, Motivation, and Objectives

Generative design's ability to automate complex problem-solving makes it a transformative tool for modern engineering and product development (Balamurugan and Ramamoorthy, 2025). It accelerates innovation cycles, reduces production costs, scales customization, and promotes sustainable practices (Ghorbani, 2024). Applications of generative design span diverse industries, including architecture (e.g., space optimization and energy-efficient structures), aerospace (e.g., lightweight components like Airbus's "bionic partition"), automotive (e.g., aerodynamic parts), and manufacturing (e.g., resource-efficient designs)(Channi et al., 2025).

Nowadays, the field of consumer product design is experiencing a significant paradigm shift, precipitated by technological advancements and evolving consumer expectations (Lei, 2000). The integration of generative AI emerges as a crucial factor in this transformation, offering novel opportunities for enhancing creativity and efficiency in the product development process (Keskar, 2024). Generative AI, characterized by its capacity to create diverse and innovative design concepts, presents a promising solution to the challenges inherent in traditional design methodologies (Ghorbani, 2024).

Our study aims to explore how AI-powered generative design can transform industrial design by expanding creative possibilities and streamlining workflows while tackling practical issues such as usability, ergonomics, and manufacturability of consumer products. Therefore, the research question is "What is the role of AI-powered generative design in improving aesthetic innovation, ergonomics, and overall user experience of consumer products?" It focuses on comparing the design outcomes from AI-driven tools with those from traditional methods, assessing aspects like product form, usability, and manufacturability. The study also aims to understand how generative design can simplify industrial design processes and address design biases, while highlighting potential challenges in real-world applications. Ultimately, our goal is to provide comprehensive insights into the advantages and limitations of AI-driven design, guiding industry practitioners and researchers in leveraging these technologies to create products that are not only visually appealing but also functionally superior and user-friendly.

1.2. Scope of the Study

Our study proposes an AI-powered design process that can be used to design consumer appliances for domestic use, and takes automated coffee makers as the sample product to work on during our field experiments. The study encompasses the generation of design alternatives using AI tools and the subsequent evaluation of these alternatives through expert reviews and user testing. By using a specific product type and research method, we aim to identify the practical challenges associated with implementing AI-driven design processes and provide actionable insights for industrial designers and manufacturers to be used in real-world production.

2. Generative AI in Consumer Product Design, Literature Review

This section examines current academic and industry perspectives on AI-powered generative design.

Figure 1. Facial feature and mood recognition by Vizcom AI (Verbal description is generated by the Author in Vizcom AI, and the faces are from (Chukwunweike et al., 2024))

AI software initially appeared as simple feature recognition algorithms, such as basic geometric shape or written letter recognition (Dutta Majumder, 1988), and later shifted to more complex subjects like face recognition and even face mood determination (Figure 1) (Gowda et al., 2019). In time, AI developed into a fully-fledged tool that can analyze product features, as seen in Figure 2, having the potential to take part in various phases of the design process (Quan et al., 2023).

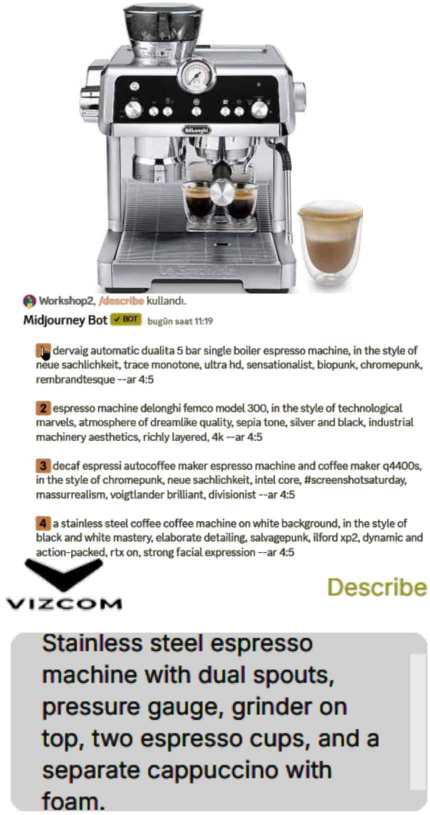

Figure 2. Image of a coffee maker and its descriptions made by MidJourney and Vizcom AI tools

Historically, product design has been a time-consuming and labor-intensive endeavor, reliant on human creativity and iterative refinement of the designs by using manual methods such as sketching, painting, technical drawing, modeling, etc. (Karlsson and Alfgården, 2024). However, the increasing demand for personalized and innovative products, coupled with the imperative for rapid time-to-market requirements, has put considerable pressure on designers to innovate more expeditiously and effectively (Κυρτσίδου, 2024). The competitiveness of industrial products is a critical focus, requiring continuous evaluation and improvement to ensure market relevance, cost-efficiency, and adaptability to evolving global trade and technological dynamics (Özsoy, 2020). AI alleviates this pressure through its distinct capabilities outlined below.

2.1. The Role of AI in Industrial Design

AI generally plays a multifaceted role in current industrial design by streamlining the entire design process from ideation to production (Agboola, 2024). AI supports the design process by analyzing market trends and consumer data, offering valuable insights that help tailor products to shifting user needs and preferences (Madanchian, 2024). AI aids in rapid concept generation, allowing designers to explore a wide array of innovative ideas quickly (Ghorbani, 2024). AI's ability to use metaphors (Özsoy, 2009) can be helpful in quickly developing product concepts. AI-driven tools can simulate these design ideas, optimizing parameters such as material usage, performance, and cost efficiency (Özsoy, 2025). AI also supports prototyping and testing using virtual simulations, reducing the need for time-consuming and costly physical models (Zimmerling et al., 2019). Overall, AI bridges the gap between creative exploration and practical manufacturing, enhancing both the aesthetic appeal and functionality of industrial products (Özsoy, 2025).

2.2. Generative Design: Definition and Key Principles

Generative design is a computational process that leverages AI and advanced algorithms to iteratively generate and evaluate a wide array of design alternatives based on predefined constraints and performance criteria (Regenwetter et al., 2022). Its key principles include:

Constraint-Based Exploration: Designers input parameters such as material properties, dimensions, and cost limits, which the system uses to define the design space.

Optimization and Iteration: The process iteratively refines design options, as shown in Figure 3, seeking optimal solutions that balance factors like strength, weight, and aesthetic appeal.

Figure 3. Design is developed through iterations (author's work in Vizcom AI)

Performance-Driven Simulation: AI algorithms simulate how each design performs under real-world conditions, enabling data-driven decision-making.

Automation and Innovation: By rapidly producing multiple design variants, as shown in Figure 4, generative design encourages creativity and helps overcome traditional design limitations.

Figure 4. Rapidly produced 4 groups of design variants (from the workshop study)

2.3. AI's Impact on Product Aesthetics, Ergonomics, and User Experience

In terms of aesthetics, AI algorithms can analyze vast datasets of consumer trends and design elements to create visually appealing forms that resonate with contemporary tastes (Monser and Fadel, 2023). AI has a potential impact on product aesthetics, ergonomics, and user experience by enabling designers to generate innovative, data-driven solutions that were previously unimaginable (Balakrishnan and Najana, 2024). With the use of different query words, AI can come up with very unexpected design results (Villalba and Palomar, 2024). When it comes to ergonomics, AI-powered tools simulate human interaction and optimize design parameters, such as grip, balance, and button placement, to enhance comfort and usability, as seen in Figure 5 (Balakrishnan and Najana, 2024). Furthermore, by integrating user feedback and performance simulations, AI ensures that the final product offers an intuitive and satisfying user experience (Dasaka, 2024). Therefore, the AI-based approach not only accelerates the design process but also leads to novel products that effectively balance form, function, and user engagement (Ghorbani, 2024).

Figure 5. Left: AI-generated coffee maker designs based on a text prompt including the keyword “coffee machine.”. Right: Designs generated by modifying the prompt—replacing “coffee machine” with “user ergonomics.” While the resulting forms are no longer identifiable as coffee makers, they retain visual similarities to the original outputs. This illustrates how altering prompt keywords can guide the AI toward ergonomically focused, yet stylistically consistent, design variations (from the workshop).

2.4. Comparison of Traditional and AI-Driven Design Approaches

Traditional design approaches rely heavily on the designer's intuition, experience, and iterative manual processes (Badke-Schaub and Eris, 2014). Designers often begin with sketches with increasing detail levels, then they build mock-ups, gradually refining their concepts through repeated revisions based on subjective feedback and practical tests (Boggs, 2010). This process, while creative, can be time-consuming and may inadvertently limit the exploration of unconventional design possibilities due to inherent biases and habitual thinking (Peavey et al., 2012).

In contrast, AI-driven design approaches harness the power of algorithms running on fast processors to analyze large datasets to rapidly generate a multitude of design alternatives based on predefined parameters (Balakrishnan and Najana, 2024). By using this automated-fast iterative process, generative design enables a broader exploration of the design space, often uncovering innovative solutions that may not be immediately apparent through traditional methods (Khan and Awan, 2018), as seen in Figure 5. Additionally, AI-powered tools incorporate simulation and optimization techniques that quantitatively assess each design’s performance under real-world conditions, thereby enhancing both usability and manufacturability (Özsoy, 2025).

Due to the positive improvements it generated, the integration of AI in industrial design has significantly increased in recent years, with generative design emerging as one of the most transformative AI tools, especially in consumer product development (De Onate, 2024). While traditional methods excel in integrating human creativity and nuanced understanding of user needs, AI-driven approaches offer enhanced efficiency and objectivity, complementing the human designer’s vision (Agboola, 2024). The convergence of these methodologies promises a more holistic design process, where the strengths of both human intuition and computational power lead to products that are not only visually striking but also functionally superior and highly user-centric (Lopez and Bhutto, 2023).

3. Methodology

This section outlines the study's planning, provides an overview of the MidJourney system used, describes the participants, explains the product selection process, and details the data collection and analysis methods.

3.1. Study Planning and Approach

We adopted a mixed-methods approach that integrates both qualitative and quantitative methodologies to evaluate the impact of AI-powered generative design on consumer product development. Our case study compares design alternatives generated by AI-driven tools with those produced using traditional methods. After the sessions, structured surveys, in-depth interviews, and observational usability tests were conducted to gather feedback on the aesthetics, ergonomics, and overall user experience of the products. The collected data was analyzed using the Analysis of Variance (ANOVA) technique to quantify performance differences alongside qualitative content analysis to capture nuanced insights (Stahle and Wold, 1989). The IBM SPSS Statistics 30 software package is used for performing the analysis (“SPSS 30,” 2024). This comprehensive approach enabled us to assess not only the technical merits of AI-generated designs but also their practical implications in real-world applications, providing a robust foundation for comparing AI-driven and traditional design methodologies.

3.2. MidJourney AI System

MidJourney is an AI-powered online software tool that generates images from textual descriptions and creates variations of selected images based on text prompts (Lehtimäki, 2024). In the context of AI-powered generative design, a prompt refers to a structured textual input or command that guides the behavior of an artificial intelligence model, particularly those based on natural language processing or multimodal generation (Subramonyam et al., 2025). Prompts are used to communicate design intentions, stylistic preferences, functional requirements, or thematic constraints to the AI system (Patel et al., 2024). The quality and specificity of a prompt directly influence the nature of the generated outputs, making prompt formulation a critical aspect of controlling and refining the design process (Kulkarni and Tupsakhare, 2024). In design applications, prompt engineering serves as an interface between human creativity and algorithmic generation, enabling designers to explore a wide range of alternatives by iteratively modifying textual instructions (Burlin, 2023). With a range of features, it can transform user sketches into rendered visuals or 3D representations.

Compared to similar tools like DALL·E 2 and Stable Diffusion, MidJourney produces more realistic and meaningful results (Zhang and Yin, 2024). For this reason, it was chosen for use in our study. The software is accessible via discord.com, a messaging and digital distribution platform, where users can subscribe and create designs.

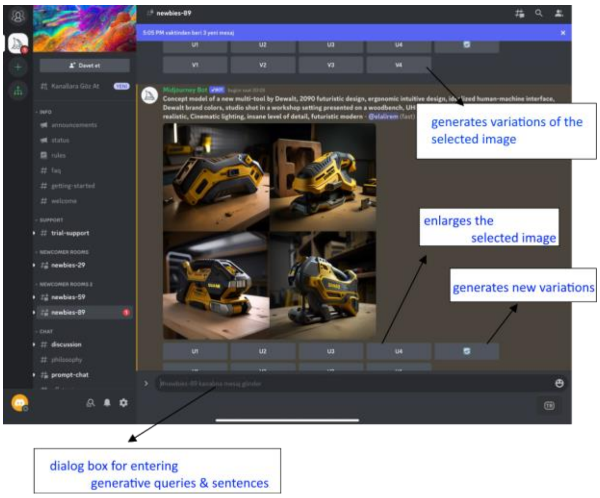

Figure 6. MidJourney user interface - MidJourney Bot

After subscribing, users can access their workspace through the MidJourney Bot section shown in Figure 6 to view their creations, or they can explore public channels to find inspiration and receive support from other community members. Each time the software is run, it generates four different variations based on the query text provided. Users can choose to regenerate four more images with the same query or modify the query, blend previously generated images, change their scale as many times as they need, or download the results for later use.

3.3. Participant Selection and Demographics

To ensure a balanced perspective on AI-powered generative design in consumer product development, the study included 30 participants from three distinct groups: industrial design students (10), engineering students (10), and general consumers (10). Participants represented an age range as follows: 18 individuals (60%) aged 18-25, 5 individuals (17%) aged 26-35, and 7 individuals (23%) aged 36-45.

In terms of gender distribution, 17 participants (57%) were female, 12 participants (40%) were male, and 1 participant (3%) identified as non-binary or preferred not to disclose their gender. Among the industrial design students, grade levels varied, with 30% being from 2nd year, 40% from 3rd year, and 30% from 4th year in their education, while engineering students are selected from the last year of their education close to graduation. When evaluating participants' familiarity with AI tools in design, 9 participants (30%) reported that they regularly use AI in their design work, 12 participants (40%) had some exposure to AI tools, and 9 participants (30%) had no prior experience with AI in design. This distribution ensured that feedback came from both casual and everyday users, providing a more comprehensive assessment of AI-generated designs. All the participants are volunteers, and they all gave their consent for the data obtained during this study to be used for academic research purposes.

3.4. Product Selection Criteria

Our product selection focused on widely used consumer items that present distinct challenges in aesthetics, ergonomics, and usability. We wanted to investigate a product for everyday use to ensure practical relevance for a broad audience. We also wanted the product to be sophisticated enough to allow meaningful comparisons between traditional and AI-driven approaches, considering factors like control placement, material choice, and overall form. Therefore, automatic coffee makers were chosen as they incorporate diverse design elements -from interactive digital interfaces to exterior details requiring ergonomic and practical considerations- making them ideal for evaluating AI's impact on industrial product design.

3.5. The Case Study – Workshop Sessions

The case study began with a briefing in which the process and the MidJourney environment were explained to the participants (Figure 7). Then, the next session was participated in only by the industrial design students investigating various market products belonging to firms such as IKEA, De Longhi, etc. While examining the available commercial designs, they also did hand sketches for their product designs.

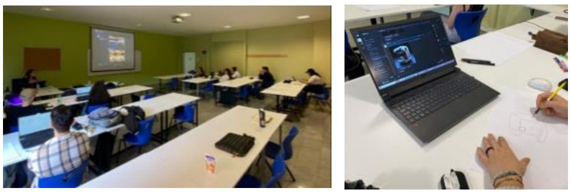

Figure 7. Photos from the industrial design workshop day,
Left: During the briefing about the MidJourney environment.
Right: The product research and initial sketches are being done

After initial sketches were produced, half of the industrial design students continued developing their designs with traditional methods, while the other half used AI, allowing them to generate a diverse set of design solutions for each product. In the third session, the two industrial design student groups cooperated with engineering students to convert their product sketches into physical or digital prototypes (Figure 8). In the third session, they were introduced to a group of end-users to engage in simulated interactions and hands-on evaluations using prototypes in terms of predefined constraints. The evaluation criteria varied by participant group: industrial design students focused on the product's usage scenario, overall feasibility, novelty, and its impact on the design workflow; engineering students assessed material efficiency, manufacturability, size constraints, structural integrity, and functional requirements; while end-users provided feedback on usability, comfort, visual appeal and perceived aesthetics.

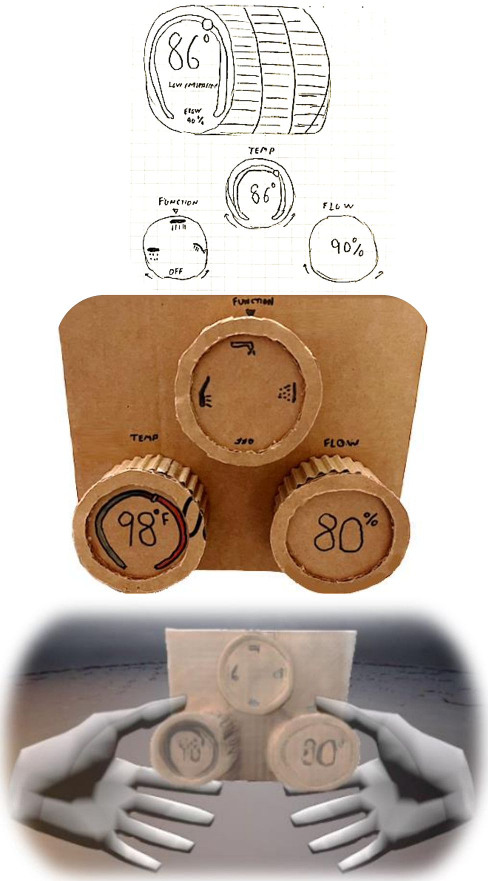

Figure 8. A sketch and cardboard mock-up of a product user interface (Khor, 2023) and a digital prototype (from the workshop)

3.6. *Data Collection and Analysis*

Data was collected through structured surveys and interviews done face to face, where participants rated the products based on usability, aesthetics, and comfort on a Likert scale (1-5) as shown in Appendix 1 (Batterton and Hale, 2017). Open-ended feedback was gathered to capture qualitative insights about both the products and the design process. The collected data, shown in Appendix 2, were analyzed using both quantitative and qualitative methods (Garbarino and Holland, 2009). Quantitatively, survey results were processed using descriptive statistics, including means, standard deviations, and frequency distributions, to assess general trends in participant preferences. Qualitatively, interview transcripts and observational notes were coded using thematic analysis (Fabia, 2018), which revealed recurring themes such as visual innovation, ergonomic challenges, and usability improvements.

Correlation analysis was applied to see the relationships between participants' familiarity with AI and their satisfaction levels (Franzese & Iuliano, 2018). An ANOVA test was conducted to evaluate the statistical significance of differences between responses to AI-generated and traditionally designed products. The test resulted in an F-value of 25.10 with a p-value < 0.0001, indicating a statistically significant difference between the perceived qualities of AI-generated designs across aesthetics, usability, manufacturability, and overall satisfaction. In other words, participants rated these aspects differently, suggesting that AI-generated designs excel in some areas, such as aesthetics, while facing challenges in others, such as manufacturability. Finally, a comparative verbal assessment of AI-generated and traditionally designed products was performed as group work, during which ideas and final thoughts were exchanged in a brainstorming approach, highlighting differences in creativity, efficiency, and user satisfaction. By combining multiple data collection and analysis methods -including informal interviews guided by a structured survey- the study offered a comprehensive evaluation of AI-driven generative design in consumer product development, highlighting how these designs were perceived by different user groups. The findings obtained in this evaluation can be found in the following sections.

4. Findings and Discussion

This section presents a comparative analysis of AI-driven generative design versus traditional design approaches, focusing on their impact on product aesthetics, ergonomics, user experience, and manufacturability. It is informed by the survey data (Listed in Appendix 2 and summarized in Figure 9), observational notes, and final group discussions, and it reflects the perspectives of all participant groups: Industrial design students, engineering students, and end-users.

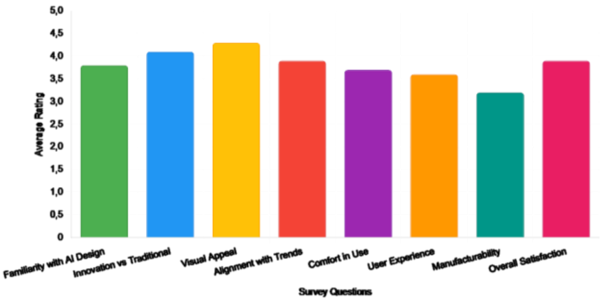

Figure 9. Graphical summary of ratings gathered from participants (Produced by using data in Appendix 2).

4.1. Aesthetic Innovation and Visual Appeal

Participants generally agreed that AI-powered generative design expands the range of aesthetic possibilities beyond what is typical in traditional design workflows. Survey responses reflected this sentiment, with 83% of participants stating that AI-generated designs appeared more modern and innovative, and a high average visual appeal rating of 4.3/5. Participants highlighted the use of organic shapes, minimalist features, and futuristic styling in the coffee maker prototypes.

However, some participants found the designs overly complex or abstract, raising concerns about practicality. Industrial design students noted that while visually compelling, the AI-generated forms often lacked balanced proportions and the refined subtleties seen in human-designed products. They emphasized the importance of human oversight to refine AI-generated aesthetics and adapt them to commercial viability and user familiarity.

4.2. Ergonomic Considerations and User Interface Enhancements

The survey revealed mixed but generally positive opinions on the ergonomics of AI-generated designs. The comfort of interaction received a moderate rating of 3.7/5, and 65% of participants felt that the handle and button placements were more intuitive than their traditional counterparts. Despite these advantages, several participants reported usability issues, such as awkward button placements and unintuitive form features. End-users noted that while the products looked sleek, some controls were hard to locate or operate, aligning with open-ended survey responses citing unintuitive lids and complex forms. Engineering students stressed that AI's structural efficiency sometimes overlooks human interaction patterns, which can compromise usability.

Additionally, 72% of the participants agreed that testing ergonomics through virtual prototypes alone was insufficient. They advocated for integrating AI tools with virtual or augmented reality (VR/AR) environments to enhance evaluation. This integration would allow designers to explore AI-generated models more effectively before physical prototyping, enabling faster and more accurate adjustments (Tammisto, 2025).

4.3. Manufacturability and Production Feasibility

Manufacturability emerged as one of the most critical challenges in the study. AI-generated designs received the lowest average rating of 3.2/5 in terms of ease of production, with 70% of participants -mostly designers and engineers- agreeing that additional modifications were needed before manufacturing could begin. The intricate curves and complex geometries of some AI outputs were noted as difficult to replicate using standard processes like injection molding.

Engineering students observed that many AI-optimized structures, while material-efficient, often required non-standard fastening methods or advanced techniques such as 3D printing or multi-axis CNC machining, increasing cost and production time. However, they acknowledged that AI's ability to reduce material use while maintaining structural strength could lead to better resource efficiency in custom or low-volume production scenarios. They recommended that future AI tools include manufacturability-aware constraints to produce outputs that align better with common production capabilities.

4.4. *Ethical and Intellectual Property Considerations*

As generative AI becomes more integrated into industrial design, it raises important ethical and intellectual property (IP) concerns that must be addressed (Mbah, 2024). One of the primary ethical challenges is the potential for AI-generated designs to unintentionally replicate or infringe upon existing products (Ok and Emmanuel, 2025). Since AI models are trained on vast datasets that include past designs, there is a risk that new outputs may resemble patented or copyrighted designs, leading to legal disputes over ownership and originality (Thongmeensuk, 2024). Defining the boundary between inspiration and infringement remains a key challenge in the industry. During the final brainstorming session, these ethical issues are observed firsthand by the participants.

They also determined another problem, like the one arising from using big data, which is transparency in the design process. They stated that many AI-generated designs are created using complex algorithms that may lack explainability, making it difficult for designers and companies to fully understand how a particular output was generated. This opacity raises concerns about accountability, especially in industries where safety and regulatory compliance are critical. If an AI-generated design leads to a product failure, determining liability - whether it falls on the AI developer, the designer, or the company - becomes a complex legal and ethical question.

Furthermore, approximately 63% of the engineering student participants pointed out the potential job displacement problem that might arise due to the rise of AI use in design. While AI is intended to assist rather than replace human designers, increased automation in the design process could reduce the demand for some design roles. Therefore, educational establishments and companies must carefully coordinate and balance AI adoption with workforce development, ensuring that human creativity remains central to the design process.

To address these challenges, future regulations may need to establish clearer guidelines for AI-generated intellectual property, ensuring that designers and companies have legal protection for their innovations. Additionally, increased transparency in AI algorithms, along with ethical AI training practices, will be essential to foster trust and responsible implementation in industrial design.

4.5. *Statistical Summary of User Perceptions*

To complement the qualitative findings and thematic analyses discussed above, Table 1 presents the descriptive statistics derived from participant responses across eight key evaluation criteria. These criteria were measured using 5-point Likert-scale survey items, and the table includes the mean ratings, standard deviations, and frequency distributions for each item.

Table 1. Descriptive statistics

Description	Mean (Average Rating)	Standard Deviation	Frequency Distribution (in %)
Familiarity with AI-powered generative design	3.8	0.6	1: 5%, 2: 10%, 3: 20%, 4: 40%, 5: 25%
Innovativeness of AI-generated designs	4.1	0.5	1: 2%, 2: 5%, 3: 18%, 4: 45%, 5: 30%
Visual appeal of AI-generated design	4.3	0.4	1: 1%, 2: 4%, 3: 15%, 4: 50%, 5: 30%
Alignment with consumer trends	3.9	0.5	1: 3%, 2: 7%, 3: 20%, 4: 45%, 5: 25%
Comfort in interacting with AI-generated product	3.7	0.7	1: 4%, 2: 10%, 3: 25%, 4: 40%, 5: 21%
Enhancement of user experience	3.6	0.6	1: 5%, 2: 8%, 3: 30%, 4: 37%, 5: 20%
Ease of manufacturability	3.2	0.8	1: 10%, 2: 20%, 3: 35%, 4: 25%, 5: 10%
Overall satisfaction with AI-generated design	3.9	0.6	1: 3%, 2: 7%, 3: 25%, 4: 40%, 5: 25%

The highest-rated aspect was the visual appeal of AI-generated designs, with a mean score of 4.3 and low variability (SD = 0.4), suggesting strong consensus among participants that the designs were aesthetically engaging. Similarly, perceived innovativeness scored 4.1, indicating that most users found AI-generated outputs to be original and forward-looking. This aligns with earlier qualitative feedback praising the designs' modern and futuristic characteristics.

Familiarity with AI-powered generative design averaged 3.8, with a moderate standard deviation of

0.6, reflecting varied experience levels, consistent with the earlier finding that designers and engineers were more familiar than end-users. Ratings for alignment with consumer trends (3.9) and overall satisfaction (3.9) also demonstrate a generally positive reception.

In contrast, aspects related to practical implementation, such as comfort during interaction (3.7), enhancement of user experience (3.6), and particularly ease of manufacturability (3.2), received lower mean scores and greater variability. The low score and high standard deviation (0.8) in manufacturability indicate diverse views and underlying concerns regarding the feasibility of translating AI-generated forms into real-world products, an issue also emphasized in the qualitative findings.

The frequency distributions further illustrate the spread of responses, with more polarized opinions in areas like usability and manufacturability, while aesthetic-related items tended to show stronger clustering toward higher scores (4 and 5). Overall, these quantitative results provide empirical support for the discussion themes and reinforce the conclusion that while AI-generated design offers clear aesthetic and conceptual advantages, challenges persist in usability and production feasibility.

The ANOVA results, while significant, are limited in generalizability due to the small sample size (n=30), which may reduce statistical power, compromise representativeness, and hinder verification of assumptions like normality and homogeneity of variances. This can lead to less precise estimates and restricted applicability to broader populations. Future studies should employ larger, more diverse samples through random or stratified sampling and conduct replication studies to enhance the robustness and generalizability of findings.

5. Conclusion

This study investigated the role of AI-powered generative design in shaping product aesthetics, ergonomics, user experience, and production feasibility. The findings, supported by survey data and qualitative feedback, indicate that AI-driven tools significantly enhance aesthetic innovation by generating unconventional and visually compelling forms. This was reinforced by a high average visual appeal rating of 4.3/5 and strong agreement (83%) among participants that AI-generated designs appear more modern and innovative than their traditionally designed counterparts.

In terms of ergonomics and usability, AI-assisted design offered several advantages, such as improved weight distribution and seamless integration of controls. However, the average usability rating of 3.6/5 and multiple participant comments highlighted recurring issues with button placement and interaction logic. These limitations underscore the importance of human-centered design principles and real-world testing, especially when transitioning from digital models to physical products.

From a user experience perspective, participants found AI-generated products visually intriguing and saw them as premium, futuristic designs. Yet this positive perception did not always translate to intuitive interaction, with 35% of participants reporting unintuitive controls or difficult-to-use features. These findings suggest that while AI can enhance user engagement through form, human oversight is still necessary to ensure functionality and clarity.

On the manufacturing side, AI-generated designs posed practical challenges due to their complex geometries and structural optimizations. The lowest rated aspect of the study was manufacturability, with an average score of 3.2/5, and 70% of participants agreed that additional modifications were required before production. While AI's ability to reduce material waste and suggest efficient structures is valuable, adapting these forms to standard production methods remains a key barrier to implementation at scale.

The study also brought attention to ethical and legal concerns, including a lack of transparency in how AI-generated outputs are formed, potential copyright infringements, and concerns about job displacement, particularly among engineering student participants. These considerations highlight the growing need for regulatory frameworks and clear guidelines around intellectual property and accountability in AI-assisted design.

Importantly, the study emphasizes that AI is not a replacement for human creativity but a powerful tool that enhances it. AI can rapidly explore a large number of design options, reducing time spent on early ideation and enabling designers to focus on refinement and user-centered improvements. However, successful integration into industrial workflows will require designers and manufacturers to adapt their roles, workflows, and skillsets to accommodate this new design paradigm.

In short, AI-powered generative design represents a transformative shift in industrial design practice. When combined with human intuition, ethical oversight, and practical design experience, it has the potential to significantly advance product aesthetics, ergonomics, and innovation while reminding us that the best outcomes arise from thoughtful collaboration between humans and machines.

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Appendix 1 . Survey Questions

	General Questions (For All Participants)	
1	How familiar are you with AI-powered generative design?	Likert Scale: 1 - Not familiar, 5 - Very familiar
2	Have you seen AI-generated products before?	(Yes/No)
3	In your opinion, how innovative do you think AI-generated designs are, compared to traditional designs?	Likert Scale: 1 - Not innovative, 5 - Very innovative
	Aesthetics & Visual Appeal	
4	How visually appealing do you find the AI-generated design of the product?	Likert Scale: 1 - Not appealing, 5 - Very appealing
5	Does the AI-generated design look more modern and innovative compared to traditional design?	Yes/No
6	In your opinion, does the AI-generated design align with current consumer trends?	Likert Scale: 1 - Not at all, 5 – Completely
7	What aspects of the AI-generated design make it visually appealing or unappealing?	Open-ended
	Ergonomics & Usability	
8	How comfortable is the AI-generated design when interacting with the product?	Likert Scale: 1 - Very uncomfortable, 5 - Very comfortable
9	Is the handle/button placement of the AI-generated product more intuitive compared to the traditional design?	Yes/No
10	Did you experience any difficulties in using the AI-generated product? If yes, please explain.	Open-ended
11	Do you think the AI-generated design enhances user experience compared to the traditional design?	Likert Scale: 1 - Worse than traditional, 5 - Much better than traditional
12	If you could improve one aspect of the AI-generated design for better usability, what would it be?	Open-ended
	Manufacturability & Practicality (For Designers & Engineers)	
13	How easy would it be to manufacture the AI-generated design using standard production techniques?	Likert Scale: 1 - Very difficult, 5 - Very easy
14	Did the AI-generated design require additional modifications to be manufacturable?	Yes/No
15	What were the biggest challenges in adapting the AI-generated design for production?	Open-ended
	Overall Satisfaction & Final Thoughts	
16	How satisfied are you with the AI-generated design?	Likert Scale: 1 - Not satisfied, 5 - Very satisfied
17	Would you prefer AI-generated designs over traditionally designed products in the future?	Yes/No
18	Do you think AI-powered generative design should be more widely integrated into industrial design workflows? Why or why not?	Open-ended
19	What is your main takeaway from this study regarding AI in generative design?	Open-ended

Appendix 2. Survey Results

	General Questions (For All Participants)	
1	How familiar are you with AI-powered generative design?	Average Rating: 3.8/5 Summary: Designers and engineers were more familiar (avg. 4.2), while end-users had lower familiarity (avg. 3.2).
2	Have you seen AI-generated products before?	Yes: 60% (Mostly designers and engineers) No: 40% (Mostly end-users)
3	How innovative do you think AI-generated designs are, compared to traditional designs?	Average Rating: 4.1/5 Summary: Participants appreciated the uniqueness but noted some impracticalities in usability.
	Aesthetics & Visual Appeal	
4	How visually appealing do you find the AI-generated design of the product?	Average Rating: 4.3/5 Summary: Most agreed that the designs were aesthetically pleasing.
5	Does the AI-generated design look more modern and innovative compared to the traditional design?	Yes: 83% No: 17% Summary: Participants found the designs sleek and futuristic but sometimes unnecessarily complex.
6	Does the AI-generated design align with current consumer trends?	Average Rating: 3.9/5 Summary: While visually appealing, some features were impractical for mass production.
7	What aspects of the AI-generated design make it visually appealing or unappealing?	Common Positive Feedback: Unique, organic shapes Minimalist and futuristic aesthetic Common Negative Feedback: Some designs felt over-engineered Lack of traditional design cues made them feel less familiar
	Ergonomics & Usability	
8	How comfortable is the AI-generated design when interacting with the product?	Average Rating: 3.7/5 Summary: The hand mixer's handle was praised, but the toaster's button placement felt unnatural to some users.
9	Is the handle/button placement of the AI-generated product more intuitive compared to the traditional design?	Yes: 65% No: 35% Summary: Improvements were noted, but some placements felt random due to the AI's optimization choices.
10	Did you experience any difficulties in using the AI-generated product? If yes, please explain.	Common Issues Reported: Some buttons were harder to reach The coffee maker's lid design was unintuitive Overly complex forms in some products reduced usability
11	Do you think the AI-generated design enhances user experience compared to the traditional design?	Average Rating: 3.6/5 Summary: Mixed responses—some praised ergonomic improvements, while others found AI-generated forms less intuitive.
12	If you could improve one aspect of the AI-generated design for better usability, what would it be?	Top Suggestions: Refine button and handle placement based on real-world usage Simplify some overly complex forms Ensure better weight distribution in handheld products
	Manufacturability & Practicality (For Designers & Engineers)	
13	How easy would it be to manufacture the AI-generated design using standard production techniques?	Average Rating: 3.2/5 Summary: Many AI-generated designs would be difficult to produce.

14	Did the AI-generated design require additional modifications to be manufacturable?	Yes: 70% No: 30% Summary: Most designs require simplification before prototyping.
15	What were the biggest challenges in adapting the AI-generated design for production?	Common Issues: Complex geometries that were difficult to mold or assemble Material inefficiencies due to AI's unconventional structures High production costs for intricate designs
	Overall Satisfaction & Final Thoughts	
16	How satisfied are you with the AI-generated design?	Average Rating: 3.9/5 Summary: Designers and engineers found it exciting but required improvement, while users preferred simpler, familiar designs.
17	Would you prefer AI-generated designs over traditionally designed products in the future?	Yes: 55% No: 45% Summary: Most participants liked AI's potential but emphasized the need for human oversight.
18	Do you think AI-powered generative design should be more widely integrated into industrial design workflows? Why or why not?	Common Responses: Yes, but as a tool, not a replacement for human designers Great for concept generation, but requires refinement for usability Could improve efficiency, but should not override human creativity
19	What is your main takeaway from this study regarding AI in generative design?	Common Themes: AI enhances creativity, but is not yet perfect for usability Requires modifications for practicality Best used as a collaborative tool rather than a standalone solution