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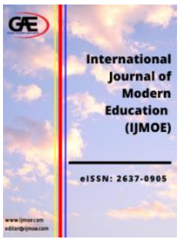

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FROM AI-GENERATED DESIGNS TO PHYSICAL PROTOTYPES: CASE STUDY ON THE FINAL STAGES OF LIGHTING PRODUCT DEVELOPMENT IN INDUSTRIAL DESIGN EDUCATION

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Abstract:

This paper investigates how AI-generated designs are transformed into physical prototypes in industrial design education, with a focus on lighting product development. The use of text-to-image generation tools has enhanced the ideation phase by allowing students to explore a wide range of design possibilities efficiently. However, challenges occur when converting these digital concepts into functional physical prototypes, as maintaining design integrity and navigating material and production limitations prove difficult. Through a qualitative case study, involving 20 industrial design students, this research examines a structured four-phase process: (1) ideation through AI tools, (2) transitioning AI-generated images to sketches, (3) refining sketches into 3D models, and (4) developing physical prototypes. A comparative analysis was conducted to assess how closely the final prototypes aligned with the original AI-generated designs in terms of form, function, and material choice. Findings showed that while some prototypes preserved crucial design elements, others required significant adjustments due to material constraints and manufacturing challenges, impacting the final output on prototypes stage. This research highlights the critical role of prototyping in connecting digital concepts with physical products. It emphasizes the need for teaching material selection, production methods, and adaptive design strategies to support students in overcoming real-world challenges.

Keywords:

AI-Generated Design, Concept Development, Digital-to-Physical Prototyping, Industrial Design Education

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Introduction

Generative artificial intelligence (AI) tools incorporated into industrial design education present transforming possibilities for creativity and innovation. Particularly in text-to-image generators have changed the ideation process by allowing students to quickly picture design ideas depending on textual prompts (Cotroneo & Hutson, 2023). These tools allow for the exploration of varied aesthetics and forms, breaking conventional barriers in ideation such as time constraints and design fixation (Fathoni, 2023). Although these advantages, there are still difficulties regarding AI-generated designs, especially in turning these creative outputs into functioning, manufacturable products (Faruqi et al., 2024). Bridging this gap is mostly dependent on prototyping, which helps designers to test and refine their ideas for functionality, usability, and manufacturability. In industrial design education, prototyping provides students with hands-on experience, developing a deeper understanding of material constraints and practical applications (Martins, 2014). However, existing research primarily focuses on the benefits of AI tools in ideation and 3D modeling stages, leaving the prototyping phase largely underexplored. Lighting product design, which demands precision in aesthetics and functionality, offers an ideal context to examine the challenges and educational value of prototyping.

Problem Statement

Generative AI tools, such as text-to-image generators, have significantly enhanced creativity and efficiency in the ideation phase of industrial design by enabling students to generate diverse visual concepts rapidly (Stigsen et al., 2023). However, while these tools serve as effective facilitators for idea generation, the outputs often lack technical and functional considerations required for real-world applications (Faruqi et al., 2024). This limitation presents a major challenge in translating imaginative AI-generated designs into practical, user-centered products. The standard design process consists of several stages, including ideation, sketching, 3D modeling, and prototyping, each of which plays a role in refining and validating a design (Elsen et al., 2012; Bao et al., 2016). While existing research has emphasized the role of 3D modeling in improving the functionality and manufacturability of AI-generated designs (Faruqi et al., 2024), the transition from 3D models to physical prototypes remains largely unexplored. Without physical prototyping, designs cannot be fully tested for structural integrity, material suitability, and user interaction (Håkansson & Nergård, 2012).

This gap is particularly evident in AI-driven workflows, where students often struggle with:

1. Maintaining design consistency across different phases.
2. Selecting suitable materials that align with both aesthetic and functional requirements.
3. Addressing manufacturing constraints, including fabrication limitations and assembly issues.

In lighting product design, where both aesthetic and functional considerations are critical, these challenges can be more demanding. Students may struggle to ensure that the final physical prototype accurately reflects both the original AI-generated concepts and the refined 3D models, leading to compromises in design quality.

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Aim and Objectives of the Study

Aim of this research is to examine how AI-generated designs are transformed into functional physical prototypes by focusing on lighting product development in industrial design education. The study specifically seeks to:

1. To compare the initial AI-generated designs with the final physical prototypes, focusing on how closely the prototypes reflect the original AI-generated concepts in terms of form, function, and material selection.
2. To identify the common challenges students face when transitioning from AI-generated designs to physical prototypes.

Literature Review

Role of Prototyping in Design Education

Prototyping is a crucial element of the design process, serving as the bridge between conceptual ideation and practical implementation. In design education, prototyping enables students to transform abstract concepts into physical models, facilitating the evaluation of design feasibility and usability. It facilitates practical exploration of material properties, structural integrity, and user interaction, which are critical for refining design outcomes (Schaeffer & Palmgren, 2017; Sciannamé, et al. 2019). Through the prototyping process, students develop problem-solving skills, gaining insight into material constraints, structural integrity, and user interaction (Bohmer et al., 2017).

Moreover, prototyping promotes an iterative design approach, where students can test, identify flaws, and refine designs based on practical feedback (Viswanathan & Linsey, 2020). This process not only enhances the quality of the final product but also expands students' understanding of design principles. For lighting product design, prototyping is particularly significant as it enables students to evaluate critical aspects such as light dispersion, structural balance, and aesthetic appeal. Studies have shown that incorporating prototyping into design education improves students' ability to balance creative idea with technical feasibility (Sciannamé, et al. 2019). This can be seen, that prototyping exercises to facilitate the development of many abilities ranging from fundamental form training to context-rich training (Schaeffer & Palmgren, 2017).

AI in Prototyping

Generative AI tools, particularly text-to-image generation have transformed the design-to-prototype process. By allowing designers to quickly visualise and build design ideas, AI shortens the early ideation phase, enabling students to explore new aesthetic and functional possibilities (Brisco et al., 2023). Although generative AI has mostly been explored as a tool for ideation and aesthetic exploration, new studies show how well it could enhance prototype processes (Edwards et al., 2024). Apart from that, AI-generated designs provide a creative starting point, inspiring students to explore unusual forms and capabilities not possible via conventional sketching method (Cotroneo & Hutson, 2023). In the prototyping phase, AI can assist in identifying material properties, suggesting manufacturing techniques, and simulating the performance of design elements under various conditions. For example, AI-driven platforms that integrate Computer-Aided Design (CAD) tools can rationalize the process of converting conceptual models into detailed blueprints for fabrication (Regassa Hunde, & Debebe Woldeyohannes, 2022).

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Despite these advantages, AI-generated designs often lack manufacturability considerations, making human intervention essential in refining them into practical prototypes (Faruqi et al., 2024). AI can generate complex geometries, but fabricating these forms with real-world materials remains a challenge. Therefore, human involvement remains essential to refine and adapt AI-generated outputs into manufacturable prototypes.

Challenges of Transitioning from Digital to Physical in Product Design
The transition from digital design to physical prototypes presents several challenges, particularly in the context of design education. One of the most significant challenges is material selection, as students must consider the compatibility of chosen materials with their finalize design and functional requirements (Sörensen, Jagtap & Warell, 2016; McComb et al, 2018). For example, lightweight materials may lack the required structural stability for specific designs, but aesthetically pleasing materials may be impractical because of to cost or manufacturability constraints. Another major challenge is ensuring consistency between digital models and tangible prototypes. Complex geometries or intricate details developed in 3D models may not transition smoothly into physical form due to restrictions in fabrication methods, such as 3D printing resolution or manual assembly procedures (Arisoy & Kara, 2014). Furthermore, manufacturability issues can develop when students overlook practical aspects like as joint strength, tolerances, and assembly methods.

User feedback is another important component of the prototype process. While digital models can provide an accurate visual depiction of a design, physical prototypes are required for evaluating user interaction and ergonomics. Studies have shown that incorporating user feedback during the prototyping process considerably improves design outcomes by addressing usability and functionality issues that may not be visible in digital models (Nissinen, 2015).

To highlight the research gap, Table 1 presents a comparison of past studies focusing on AI in design education and prototyping.

Table 1: Summary of Past Studies on AI in Design and Prototyping

Study	**Focus**	**Prototyping Considered?**	**Main Finding**
Cotroneo & Hutson (2023)	AI in design ideation	No	Explored prompt engineering for creative AI applications
Stigsen et al. (2023)	AI-generated forms in product design	No	Investigated how AI diffusion expands design possibilities
Faruqi et al. (2024)	AI and 3D modeling for manufacturing	No	Studied the impact of fabrication constraints on AI-generated 3D models
Edwards et al. (2024)	AI-driven prototyping	Partially	Introduced AI-assisted rapid prototyping in design education
Present Study	**AI-generated designs transitioning to physical prototypes**	**Yes**	**Analyzes how AI-generated forms are transformed into physical prototypes**

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Methodology

This study adopts a qualitative case study approach to examine how industrial design students translate AI-generated images into functional physical prototypes. The methodology is designed to align with the research objectives of evaluating the comparison AI-generated image with final prototypes output and identifying challenges in the prototyping phase.

Research Process

The study was structured into a four-phase process to analyze the design transition from AI-generated concepts to final prototypes:

1. Phase 1: Ideation through AI Tools – Students used text-to-image generators to create initial lighting design concepts based on structured text prompts.

2. Phase 2: AI-Generated Designs to Sketches – Students translated their selected AI-generated images into refined hand sketches, improving form, function, and structural feasibility.

3. Phase 3: Sketches Refinement to 3D Modeling – Using Rhinoceros 3D software, students developed detailed CAD models, considering material constraints and manufacturability based on refine final sketch.

4. Phase 4: Physical Prototype Development – Students fabricated 1:1 scale prototype using suitable material.

Figure 1 presents a flowchart of the research methodology.

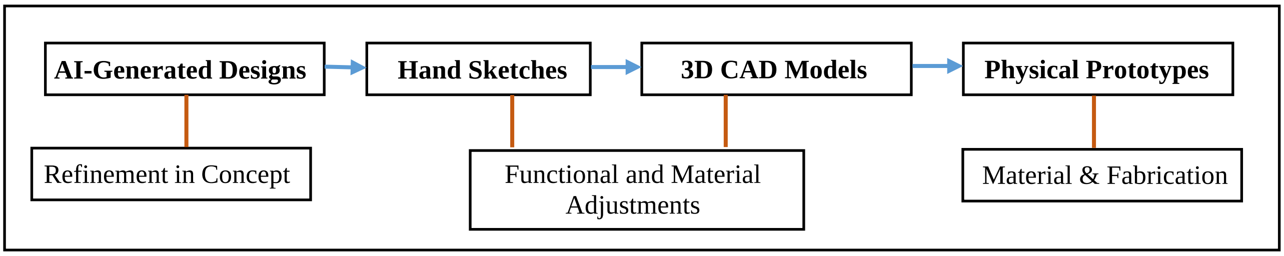

Figure 1: Research Methodology Flowchart

Respondent Selection

A total of 20 Bachelor of Industrial Design students at College of Creative Arts, UiTM Kedah Branch participated in the study. These students were selected based on their subject requirement in *Advanced Industrial Design for Manufacturing* (IDE510) and prior experience with design software and willingness to engage with AI-based ideation tools. The study was conducted as part of a lighting product design project in their coursework.

While the study involved 20 respondents, only 5 were chosen for a more detailed analysis to show a variety of design outcomes. These 5 were selected based on differences in their design styles, how functional their designs were, and the level of innovation in their final work. This selection helped ensure that the examples showed a wide range of design complexity, from simple functional changes to very creative solutions. This approach was intended to align the

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presented examples with the study's objective of examining how AI-generated concepts are transformed into functional prototype designs.

Phase 1: Ideation through AI-Generated Designs

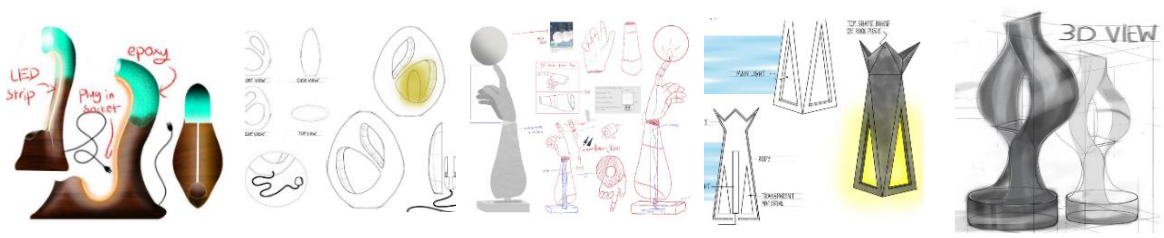
In Phase 1, students utilized text-to-image website tools such as *Stablecog*, *Ideogram*, and *Recraft* to generate initial lighting design concepts. The process involved creating structured text prompts that guided the AI in producing varied visual outputs. These prompts included specific elements such as form inspiration, material selection, and lighting aesthetics, allowing students to explore a wide range of creative possibilities. The AI-generated images were then evaluated for both their creative potential and functional feasibility. After reviewing the outputs, students selected one design concept to refine and develop further, focusing on enhancing the chosen concept's practical application and aesthetic appeal for the next phase of the design process. (*Refer Figure 2*)

Participant A **Participant B** **Participant C** **Participant D** **Participant E**

Figure 2: Example of AI-Generated Design Images from Selected Participant in Phase 1

Phase 2: AI-Generated Design to Sketches

In this phase 2, students take their selected AI-generated design and convert them into initial design sketches. The focus here is on refining the concepts, enhancing their functionality, and considering practical aspects such as ergonomics and user interaction on their lighting product. Students translate digital, abstract forms into detailed, practical representations, ensuring maintaining of essential design features from AI-generated images while considering technical details such as light source positioning, material selections, and structural components. These sketches demonstrated the progression from concept to a more feasible product. Sketching helps students better understand the functional aspects of the design before moving to the 3D modeling phase. (*Figure 3*)



Participant A **Participant B** **Participant C** **Participant D** **Participant E**

Figure 3: Example of Final Design Sketches from Selected Participant in Phase 2

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Phase 3: Sketches Refinement into 3D Models

In this phase 3, the refined design sketches were translated into 3D models using CAD software (Rhinoceros 3D modeling software). Students enhance the designs by considering technical details such as structural stability, proportions, and manufacturability. During this phase, students also focus on ensuring that the 3D model can be practically realized in the prototyping phase. This includes considerations for material properties and ease of assembly. The final 3D models are evaluated for practicality, ensuring they are ready for physical production. (*Figure 4*)

Participant A **Participant B** **Participant C** **Participant D** **Participant E**

Figure 4: Example of Final 3D Model Renderings from Selected Participant in Phase 3

Phase 4: Physical Prototype Development

In Phase 4, students developed physical prototypes using a combination of 3D printing and manual fabrication techniques. Based on the specific requirements of their designs, students selected materials such as PLA filament for 3D printing, wood, or acrylic considering factors like durability, aesthetics, and ease of fabrication. Throughout this phase, students faced various challenges, including issues related to material strength, dimensional accuracy, and the complexity of the assembly process. They overcame these challenges through modifying their designs and refining fabrication techniques, assuring that the final prototypes were functional, stable, and aligned with the desired design purpose. (*Refer Figure 5*)

Participant A	Participant B	Participant C	Participant D	Participant E
Material : Finish Plywood and Acrylic with Led Lighting	Material : 3D Printed PLA filament with plastic finish and solid pine wood	Material : Plastic Globe and 3D Printed PLA filament	Material : 3D Printed PLA filament , Finish Plywood and Acrylic	Material : Finish Plywood, Pine wood and Acrylic

Figure 5: Example of Final Prototyping with Its Material from Selected Participant in Phase 4

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Analysis: Comparing AI-Generated Designs to Final Prototypes

The study employs comparative analysis, which focuses on evaluating how closely the final physical prototypes reflect the initial AI-generated designs in phase 1. The researcher, with significant expertise in industrial design, conducted the comparative analysis to ensure a thorough and reliable evaluation. This analysis was guided by a structured rubric that focused on main aspects such as functionality, aesthetic appeal, and usability. The rubric was grounded in the principles of functional design and assessed factors like ergonomics, material feasibility, and alignment with aesthetic objectives. The researcher's academic background and professional experience in industrial design provided a strong basis for effectively evaluating the transformation process.

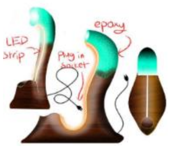
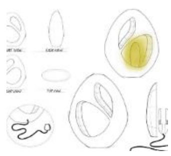
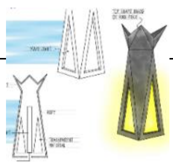
The evaluation criteria for this analysis can be seen in Table 2.

Table 2: Evaluation Criteria and It's Description

Evaluation Criteria	Description
Form Similarity [1]	Assessed how closely the prototype's shape and visual characteristics resembled the AI-generated design.
Functional Features [2]	Evaluating how well the prototype retained or improved essential functional elements, such as light source placement, structural integrity, and usability.
Material Choices [3]	Compared the materials implied in AI-generated images with those used in the final prototype, analyzing deviations and constraints.

The findings are summarized in Table 3, which presents the comparative analysis for selected participants. Observations on adjustments are also noted. (*Refer Table 3*)

Table 3: Example of Comparative Analysis of AI-Generated Designs, Refined Sketches, 3D Models and Final Prototyping in Lighting Product Development

Participant	AI-Generated Design	Refined Sketch	3D Model	Final Prototype	Main Observations	Overall Similarity
A					Simplified form for stability; wood used instead of sleek material; lighting moderately preserved.	[1] Low: Significant form changes. [2] Moderate: Retained lighting placement. [3] Low: Material shift.
B					Organic form evolved but lost material and texture detail; moderate lighting adjustments.	[1] Low: Form changes evident. [2] Moderate: Lighting and usability adapted. [3] Low: Texture changed.
C					Prioritized stability; simplified hand details; functionality improved despite material constraints.	[1] High: Form preserved. [2] High: Functional features enhanced. [3] Low: Material fidelity reduced.
D					Geometric form retained; lighting	[1] Low: Significant form simplification.

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					function improved; material application simplified.	[2] Moderate: Lighting improved. [3] Moderate: Material adapted.
E					Organic form maintained but reduced detail and material complexity in the prototype.	[1] Moderate: Captured flow. [2] Moderate: Lighting retained. [3] Low: Material complexity reduced.

Discussion on Identifying Challenges in Transitioning from Ai-Generated design to Physical Prototypes

The transition from Ai-generated design to physical prototypes presented several main challenges for the students in this study. These challenges, primarily related to material selection, design adjustments and manufacturing constraints significantly influenced the final prototypes and varied from the students' original AI-generated concepts. By analyzing the comparative data, several patterns emerged regarding these obstacles.

Material Selection Challenges

One of the most significant challenges encountered was the difficulty in selecting materials that could accurately recreate the concept of the AI-generated designs. Students found that the materials they initially planned were either unavailable, too expensive, or impractical for the prototyping phase. For instance, materials like composite plastics or metals that would have matched the aesthetic and functional needs of their designs were often inaccessible due to cost or fabrication limitations. As a result, many students resorted to using more readily available materials, such as PLA, acrylic, or wood. This is because these materials were easier to work with and less expensive, and it occasionally resulted in a visible deviation from the desired look and feel of the finished product.

For example, Participant A initially planned to adopt a smooth, sleek surface but had to choose for wood material due to the constraints of available materials. This material change impacted the visual quality and surface texture, which significantly changed the final prototype compared to the AI-generated design. (*see Figure 6*)

AI-Generated Design	**Final Prototype**
	
AI-generated design featuring sleek surface.	Final prototype using wood, showing material shift after refinement in sketch and 3D model

Figure 6: Side-by-side visual comparison of AI-Generated Design and Final Prototype for Participant A

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Design Adjustments

During prototyping, students had to make multiple revisions to their designs because of to both material and manufacturing challenges. One of the main areas of adjustment was structural integrity, as many designs needed additional support to withstand the physical constraints of the prototyping process. For example, Participant E had to strengthen certain part of the design to ensure the prototype could withstand its own weight without collapsing, because the Ai-generated image did not account for material strength constraints. (*see Figure 7*)

AI-Generated Design | **Final Prototype**

AI-generated design showing the organic form. | Final prototype with structural adjustments for durability and usability.

Figure 7: Visual comparison showing AI-Generated Design and Final Prototype for Participant E.

Manufacturing Constraints

The transition from AI-generated designs to physical prototypes reveals significant manufacturing constraints, particularly material selection and assembly limitations. For Participant B, the original AI-generated design featured complex curves and a delicate handle, which posed challenges in the prototyping phase. The material chosen for 3D printing (PLA) couldn’t replicate the fine finish intended in the digital design, may resulting in a rougher texture and visible imperfections. Furthermore, the 3D printer's resolution was inadequate for capturing the handle's intricate details, while the size and finish requirements significantly increased production costs. Therefore, Participant B simplified the geometry for manufacturability, opting for a combination of 3D-printed PLA and wood materials. Structural modifications were implemented to enhance stability, and the design's proportions were adjusted to align with the constraints of the available fabrication tools. These modifications, while deviating from the original design, preserved the product's functionality and met ergonomic requirements. (*see Figure 8*)

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AI-Generated Design	**Final Prototype**
	
AI-generated design showing the complexity of form.	Final prototype with form adjustment with more suitable assembly.

Figure 8: Visual Comparison Showing AI-Generated Design And Final Prototype For Participant B.

In summary, transition from AI-generated designs to physical prototypes brought many challenges, leading students to adjust their designs and choose different materials Some parts of the designs were adjusted, while others stayed mostly the same. However, students had to make changes to the design, materials, and structure to create prototypes that were practical and easy to produce. These changes were mainly due to limits in the materials and tools available, as well as the need to make the prototypes strong and functional.

Conclusion

This study explored how AI-generated designs are transformed into physical prototypes in industrial design education, focusing on lighting product development. Through a qualitative case study, findings revealed that while AI enhances ideation efficiency, challenges occur during the transition to physical prototyping. These challenges primarily include material selection constraints, manufacturability limitations, and maintaining design similarity across development stages. The research successfully addressed its objectives by comparing AI-generated designs with final prototypes, demonstrating that while some prototypes retained their original AI-generated form, others underwent significant modifications due to structural and material constraints. Additionally, the study identified main challenges in transitioning from AI to prototyping, particularly the difficulty in replicating AI-suggested materials and the technical refinements needed for manufacturability. These results emphasize the importance of teaching adaptive design strategies that balance AI-generated creativity with real-world production feasibility.

This research contributes to industrial design education by demonstrating the practical limitations of AI-generated ideation and the critical role of prototyping in design validation. The findings reinforce the need to integrate material selection knowledge and manufacturing techniques into AI-driven workflows. Additionally, the study extends the discussion on AI's role in the design process, moving beyond ideation to focus on its impact on physical realization. While the study provided valuable insights, several limitations were observed. AI-generated designs often suggested materials that impractical for prototyping, requiring students to adapt their choices. Some prototypes needed modifications to structure and assembly, impacting their fidelity to the original AI design. Additionally, complex AI-generated forms were difficult to fabricate due to 3D printing limitations and manual assembly challenges. To address these issues, future studies should explore AI-assisted material selection tools and better integration of AI into CAD modeling and fabrication processes.

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For further exploration, researchers could investigate AI-generated design refinement frameworks to improve manufacturability and develop hybrid AI-human workflows that balance AI-driven ideation with expert adjustments for production feasibility. Expanding the study to different product categories, such as furniture, automotive design, and consumer electronics, could also provide deeper insights into AI's role across diverse design applications. By addressing these gaps, future research can enhance AI's usability in industrial design education, ensuring that students not only generate creative concepts but also develop practical, manufacturable solutions.

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