Component-Wise Sketching and Generation for Car Interior Design

Jeongche Yoon
Department of Industrial Design
KAIST
Daejeon, Republic of Korea
jeongche.yoon@kaist.ac.kr

Seung-Jun Lee
Department of Industrial Design
KAIST
Daejeon, Republic of Korea
seung-jun.lee@kaist.ac.kr

Donghyeok Ma
Department of Industrial Design
KAIST
Daejeon, Republic of Korea
donghyeok.ma@kaist.ac.kr

Seok-Hyung Bae
Department of Industrial Design
KAIST
Daejeon, Republic of Korea
seokhyung.bae@kaist.ac.kr

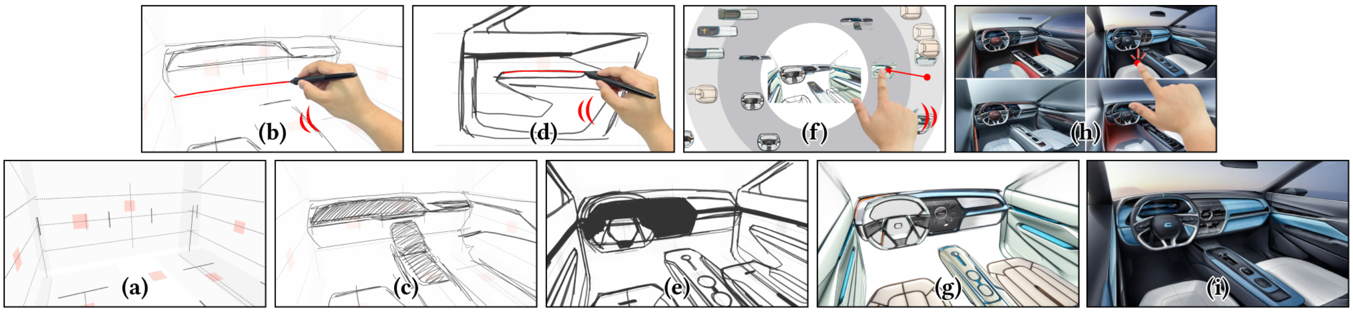

Figure 1: When using 2D generative AI, car interior designers often face challenges in generating realistic renderings from sketches of entire cabins and in exploring numerous combinations of various interior components. To address these challenges, we propose a simple yet effective component-wise design workflow consisting of four stages: *sketching components*, where designers (a) choose a *3D cabin template* of a car body type among many, consisting of cards that represent key components, (b) sketch a cabin roughly on top of the chosen template to (c) establish an initial concept, and (d) sketch each component in detail (e) to elaborate the concept; *generating components* and *composing cabin*, where designers (f) generate 2D renderings for multiple variations of each component and compose them in perspective views using the *mixing palette* to (g) pre-visualize the cabin; and *generating cabin*, where designers (h) generate high-quality cabin renderings using the preferred pre-visualization as input and (i) select a desired output.

Abstract

While car exterior designers are adopting 2D generative AI in their workflows, interior designers still face significant challenges. AI often fails to capture intended forms and layouts from interior sketches typically drawn in extreme perspectives and containing multiple components. Moreover, designers must rely on extensive manual work to explore numerous combinations of various components across different views. Thus, we propose a novel workflow in which designers sketch components individually, generate refined renderings for each component, and compose them to pre-visualize concepts. This pre-visualization then serves as input for generating high-quality renderings. We first interviewed interior designers to identify key challenges. We next developed a proof-of-concept system and conducted a pilot study to test its usefulness. We finally improved the system based on additional requirements and conducted a formal user study, demonstrating that our simple yet effective workflow supports designers in exploring, composing, and refining cabin designs into high-quality results.

CHI '26, Barcelona, Spain

ACM ISBN 979-8-4007-2278-3/26/04
https://doi.org/10.1145/3772318.3790912

CCS Concepts

• **Human-centered computing → Interaction techniques**.

Keywords

Car interior design; 3D sketching; 2D generative AI

ACM Reference Format:
Jeongche Yoon, Seung-Jun Lee, Donghyeok Ma, and Seok-Hyung Bae. 2026. Component-Wise Sketching and Generation for Car Interior Design. In *Proceedings of the 2026 CHI Conference on Human Factors in Computing Systems (CHI '26), April 13–17, 2026, Barcelona, Spain.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3772318.3790912

1 INTRODUCTION

With recent advances in 2D generative AI, its application to car exterior design has been actively studied. As a result, car exterior designers are now increasingly using 2D generative AI to obtain realistic renderings from their rough sketches, helping them quickly explore a wide range of possibilities and refine them into concrete concepts [33]. In contrast, car interior design has received comparatively little attention, and interior designers still face significant challenges in applying 2D generative AI to their workflows.

Whereas car exteriors are approximately single, unified forms [21, 41], car interiors consist of multiple components layered over one another [13, 16, 30], making them much more complex. This complexity makes it difficult for 2D generative AI to faithfully capture the intended forms, sizes, and positions of individual components from designers' sketches, resulting in unrecognizable renderings unsuitable for actual design processes (Figure 2). Furthermore, designers must explore and compare numerous combinations of various components across different views, requiring extensive manual work in current workflows.

To address these challenges, we propose a simple yet effective workflow for car interior design using 2D generative AI (Figure 1). In our workflow, rather than using a complete sketch directly as input, designers sketch each component individually, generate refined renderings from these sketches, and compose them in perspective views to pre-visualize an entire cabin. This pre-visualization serves as input for generating high-quality cabin renderings from any desired viewpoint, at a level of quality suitable for professional use.

This paper makes the following contributions:

- We interview car interior designers and identify the key challenges they face when applying 2D generative AI in practice (Section 3).
- We propose a novel workflow tailored to address these challenges and validate its feasibility through a pilot study with car interior designers (Section 4).
- We introduce novel user interfaces, including the *3D cabin template* and the *mixing palette*, that enhance the proposed workflow (Sections 5 and 6).
- We conduct a formal user study with car interior designers, showing that our system enables fluent expression of complex car interiors, efficient exploration of design alternatives, and rapid production of high-quality design outputs (Sections 7 and 8).

2 RELATED WORK

In this section, we first describe the unique complexity of car interior design and the challenges designers face when producing concept renderings in the early stages. We then review prior attempts to apply 2D generative AI to car design and discuss why they are limited in interior contexts. Finally, we introduce 3D card-based sketching as a method to guide 2D generative AI and explain how our work extends previous approaches in this area.

2.1 Car Interior Design

In the early stages of the car interior design process, designers collaborate with engineers to establish engineering packages that define the dimensions and spatial arrangements of interior components, accounting for car segment, ergonomics, and safety regulations [3, 30]. Based on these packages, designers develop each component's specific form, color, material, as well as its usability and manufacturing strategy. From concept ideation through mass production, designers communicate their ideas primarily through cabin renderings across design and engineering teams. Consequently, designers invest substantial time and effort in creating cabin renderings that adhere to engineering packages and achieve a high level of visual realism.

At the same time, the inherent structural complexity of car interiors further complicates this process. Car interiors comprise multiple components, such as dashboards, door trims, consoles, steering wheels, and seats [13, 16, 30]. These elements are typically designed with the manufacturability, assemblability, and cabin spaciousness in mind, often resulting in box-like forms with low profiles [37, 43]. Each component is positioned relative to reference planes that enclose the cabin space [19]. The size and placement of components vary depending on the vehicle's type and intended use [4, 19, 30, 37]. For instance, a pickup truck may feature a large steering wheel and a high seating position, while a roadster tends to have a smaller steering wheel and a lower seating position. Each component must meet a high standard of design quality, while contributing to a cohesive and harmonious cabin interior as a whole [13].

Due to this complexity, designers face several challenges when producing concept renderings. They must accurately depict all components at appropriate sizes and positions in accordance with the specifications of the target vehicle. In addition, they must adopt wide fields of view and extreme perspectives to convey interior views as experienced by occupants [12, 16, 41]. At the same time, they must sketch multiple ideas for each component and compose them within perspective views of the cabin to explore alternative combinations and identify the most suitable one. Moreover, they must redraw the entire scene from scratch when visualizing the design from a new viewpoint.

This study aims to support the early stages of car interior design, where designers must rapidly explore a wide range of possibilities and visualize their ideas as high-quality renderings.

2.2 2D Generative AI-Based Car Design

In car exterior design, many approaches have been proposed to help designers generate realistic renderings that faithfully capture their creative intent using 2D generative AI. Various studies and commercial tools let designers produce outputs that closely align with their text prompts and sketches [1, 2, 5, 26, 32, 42, 44]. Some studies let designers generate renderings from multiple viewpoints using 3D references such as 3D CAD models [29], physical prototypes [47, 48], and 3D sketches [27]. Other methods further incorporate engineering constraints, such as aerodynamic performance [18, 38].

However, 2D generative AI often struggles to produce high-quality renderings when input sketches contain many overlapping elements or are drawn in extreme perspectives [7, 24]. This poses a significant challenge for car interior design, where every component must appear at the appropriate scale in the correct position according to car body types.

Previous studies have attempted to overcome such limitations by introducing constraints such as color cues [39], bounding boxes [28], or segmentation masks [35]. However, these methods are typically based on simplified line sketches of single objects and struggle to generate coherent scenes composed of multiple components. Other approaches attempt to separate stylistic elements (e.g., color and material) from functional elements (e.g., size and structure), generating them independently and recombining them [11, 15]. Yet, they still face difficulties producing consistent renderings from complex line drawings, such as those found in car interior sketches. To address these unique challenges in using 2D generative AI to produce realistic cabin renderings from complex line sketches, this study proposes a simple yet effective approach that generates component renderings separately, composes them into a pre-visualization, and then generates a full cabin rendering.

2.3 3D Card-Based Sketching

3D sketching is an interaction technique that allows designers to express form ideas as 3D curves using pen input, much like drawing on a digital tablet. The most commonly used 3D sketching method involves projecting 2D curves onto predefined 3D planes, resulting in 3D planar curves [10, 17, 20, 22, 23, 25, 36, 45]. While simple, arranging 3D cards in space and sketching directly on them allows designers to effectively represent complex shapes [22, 23, 25] and spatial layouts [10, 36], and works well for car interior components characterized by box-like forms with low profiles.

Prior work [40] has demonstrated the potential synergy between 3D card-based sketching and 2D generative AI for scene design. Similar to our approach, this work lets users sketch and project generated results onto 3D cards to create realistic scenes. However, it targets general 3D scenes with buildings and items. In contrast, our work targets car interiors and specifically aims to enable designers to generate multiple renderings per component, compare them at a glance, and experiment with numerous combinations to achieve a desired cabin design.

3 EXPERT INTERVIEW

We interviewed professional car interior designers to investigate how 2D generative AI tools are incorporated into existing design workflows and to uncover the challenges and unmet needs designers face when applying these tools in car interior design practice.

3.1 Participant

We recruited 10 professional car interior designers (8 males, 2 females, ages: 25-43), each with work experience averaging 9.2 years (min: 3 years, max: 19 years). At the time of the interviews, 6 designers were employed at 3 international car manufacturers, and 4 designers were working at 2 international car design studios. All the designers were using 2D generative AI tools in their work.

3.2 Procedure

The interviews began with a short survey in which the designers rated and commented on the usefulness and limitations of applying 2D generative AI in car interior design practice. Building on their responses, we then conducted semi-structured interviews that encouraged the designers to elaborate on their survey answers and share additional reflections. In relevant cases, the designers also presented examples from their professional work to illustrate specific points. Each session lasted approximately 40 minutes. The survey questions were as follows:

- Which 2D generative AI tools do you use, at which stages, for what purposes, and how often?
- What do you consider to be the strengths and limitations of these tools in the car interior design process?
- How do you typically deal with or work around these limitations?

3.3 Finding

From the interviews, we identified 3 main findings on how car interior designers use 2D generative AI, along with the key challenge they face and a potential direction for addressing it.

• **Designers use 2D generative AI to explore, develop, and simulate.** First, in the early concept exploration stage, they use general AI tools such as Midjourney [32] and Dall-E [34] to collect inspiring reference images. Second, in the sketching stage, they use AI tools specialized in car design such as Vizcom [44] or Optic [42] to obtain realistic renderings and to preview how their sketches could evolve in different directions. Third, in the early 3D CAD modeling stage, they capture texture-less 3D models from multiple viewpoints and provide the images as input to Vizcom [44] or Optic [42] in order to explore color, material, and finish (CMF).

• **Designers could not generate entire cabins from sketches.** The designers reported difficulties in obtaining usable results when directly inputting sketches of entire cabins into 2D generative AI. In contrast to rendered 3D model views, hand-drawn sketches often led the AI to misinterpret component shapes, sizes, and positions, producing results that the designers characterized as *"almost useless"* (Figure 2). Consequently, many described having to iteratively generate images until achieving something *"usable,"* followed by extensive refinement with 2D editing tools such as Photoshop. A few further explained that they produced *"perfect sketches"* over several hours to obtain higher-quality results, and they emphasized that this contradicted the *"fast and efficient workflow"* they had originally expected from 2D generative AI.

• **Designers could generate individual components from sketches.** Interestingly, several designers reported that 2D generative AI was effective for producing renderings of individual components. The designers explained that components are often sketched in orthographic views, which they considered faster and easier for ideation than perspective drawing, and that providing these orthographic sketches as input produced *"refined"* renderings. The designers further noted that they typically created component sketches, input them into 2D generative AI to obtain alternative renderings, and then used resulting inspiration to inform subsequent sketches of the overall cabin.

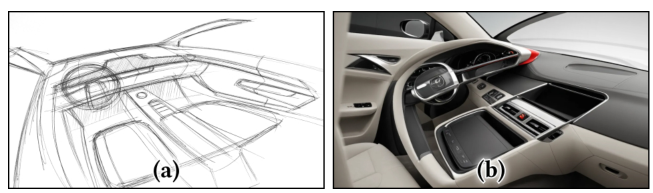

Figure 2: During the expert interviews, one designer (male, age: 32, work experience: 3 years) presented examples from his own work to illustrate that using freehand cabin sketches as input to 2D generative AI often produces unrecognizable, mangled results in which components' shapes and layouts were ignored, making them unsuitable for design practice. (a) A cabin sketch drawn by the designer. (b) A cabin rendering generated by 2D generative AI.

4 PROOF OF CONCEPT

Building on insights from the expert interviews, which highlighted the usefulness of 2D generative AI for rendering individual components, we designed a novel workflow that enables designers to develop component-wise sketches into high-quality cabin renderings. We implemented a proof-of-concept system and conducted a pilot study to test its feasibility, from which we derived design requirements to support professional car design practice.

4.1 Workflow

Our novel workflow adopts a strategy of sketching and generating each component individually then composing the results in perspective views later, rather than directly inputting an entire cabin sketch into 2D generative AI. The workflow consists of four sequential stages (Figure 3).

• **Sketching components.** Designers begin by sketching the key components of car interiors, such as dashboards, door trims, consoles, steering wheels, and seats (Figure 3a). Instead of having to depict an entire cabin in a single drawing, they can work on each component individually, which reduces the challenge of complex perspective drawing and enables clearer and more precise representation.

• **Generating components.** Designers then use these sketches as input to produce refined renderings (Figure 3b). As highlighted in the expert interviews, 2D generative AI is particularly effective in producing polished images from orthographic sketches. This step also enables designers to explore diverse design alternatives by generating multiple renderings from the same sketch.

• **Composing cabin.** Once a full set of renderings has been generated for all components, designers compose them into a pre-visualization of the cabin (Figure 3c). The renderings are automatically placed in perspective views at the correct scale and position, and designers can experiment by swapping renderings in and out, which supports exploration of multiple combinations before committing to a final design.

• **Generating cabin.** In the final stage, designers use the completed pre-visualization as input to produce renderings of the entire cabin (Figure 3d). Because the quality of 2D generative AI outputs depends heavily on the quality of input images [31], providing compositions of refined renderings rather than raw sketches makes it possible to produce high-quality cabin images that are faithful to the original design intent and suitable for professional workflows.

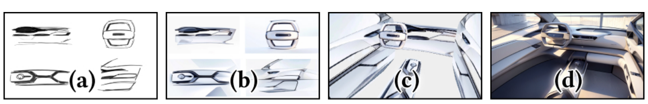

Figure 3: Workflow overview. The designer progresses through four sequential stages of (a) sketching components, (b) generating components, (c) composing cabin, and (d) generating cabin to develop component-wise sketches into a high-quality cabin rendering.

4.2 Pilot Study

We designed and implemented a minimal proof-of-concept system (Figure 4) and conducted a pilot study to examine the feasibility of the proposed workflow, from which we derived further requirements for making it applicable in car interior design practice.

• **Participant.** We invited 4 designers (3 males, 1 female, ages: 31-36) who had previously participated in the expert interviews, each with work experience averaging 9.5 years (min: 3 years, max: 19 years).

• **Procedure.** First, in a 15-minute tutorial session, we followed a script to guide the designers through all system features step-by-step. Second, in a 60-minute task session, the designers freely used our proof-of-concept system to create a cabin rendering following our workflow. Third, in a 30-minute debriefing session, we collected feedback on their experiences and suggestions for improvement.

• **Result.** The 4 designers used our proof-of-concept system for 4 hours and successfully created high-quality cabin renderings (Figure 5). The designers created 15.8 component sketches and 8.8 component renderings on average to produce a final cabin rendering. The final renderings accurately reflected the shapes, sizes, and positions that the designers had intended in their sketches. All the designers agreed that the results were satisfactory and of a suitable quality for practical use.

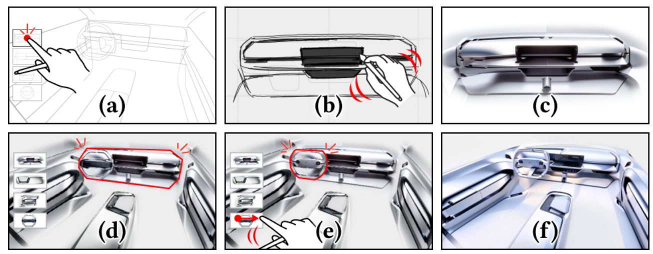

Figure 4: The designer can (a) select a component (in this case, the dashboard), (b) sketch it in the corresponding orthographic view, and (c) generate renderings from the sketch. (d) The system applies a 2D projective transformation to display the renderings in a predefined perspective view, where (e) the designer can explore different combinations by swiping thumbnails to replace components (in this case, the steering wheel), and use the resulting pre-visualization as input to (f) generate a rendering of the entire cabin.

4.3 Design Requirement

Based on the insights obtained from the debriefing interviews with the designers, we defined the design requirements (DR) of our system as follows:

• **DR1: support for diverse car body types.** The designers found pre-defined positions and orientations of individual components useful for maintaining spatial constraints but noted the lack of configuration variety. Therefore, the system should provide component templates that cover a wide range of car body types.

• **DR2: seamless transition between perspective and orthographic views.** The designers preferred sketching an entire cabin in perspective views while refining individual components in orthographic views. Therefore, the system should enable smooth transitions between these two views for fluid sketching workflows.

• **DR3: generation of multiple alternatives from a single sketch.** The designers appreciated receiving diverse renderings from a single sketch, as it enabled them to effortlessly expand design space. Therefore, the system should continue to generate multiple alternatives for each sketch.

• **DR4: efficient exploration of component combinations.** The designers found it inefficient to manually replace components one by one when testing different combinations. Therefore, the system should streamline this process by presenting multiple combinations at a glance and allowing quick selections and comparisons.

• **DR5: free navigation of viewpoints.** The designers wanted to view their designs from different perspectives such as the driver's seat or the passenger seat. Therefore, the system should support viewpoint navigation during both sketching and composing.

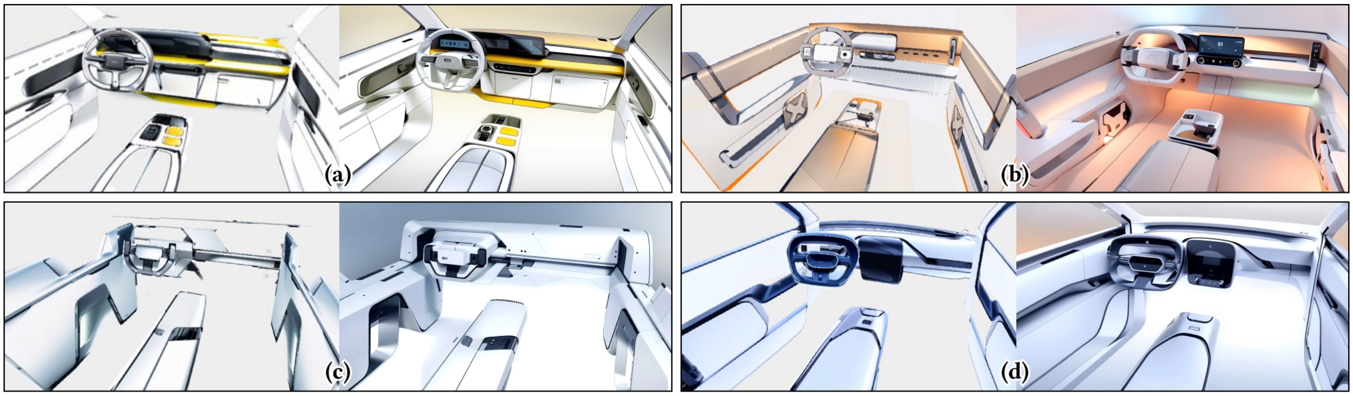

Figure 5: The final pre-visualizations (left) and renderings (right) produced by the designers in the pilot study. (a) An "*urban crossover SUV*" by P1, (b) a "*youthful off-road*" by P2, (c) a "*futuristic electric vehicle*" by P3, and (d) a "*minimal smart car*" by P4.

• **DR6: tightly integrated workflow.** The designers valued the integration of sketching, generating, and composing within a single cohesive process. Therefore, the system should maintain this integration to help designers stay focused and work efficiently.

5 SYSTEM

Based on the above design requirements, we developed a novel interactive system that enables car designers to produce high-quality cabin renderings through sketching, generating, and composing key components of car interiors (Figure 1).

5.1 User Interface

To support the proposed workflow, we introduced two key user interfaces: the *3D cabin template* and the *mixing palette* (Figure 6).

• **3D cabin template.** The 3D cabin template captures the spatial dimensions and ergonomic placement of key components for each car body type, and it can be adjusted to reflect the specific characteristics of the target car model (Figure 6a) (DR1). Designers can view all cards in perspective views or individual cards in the corresponding orthographic views, enabling them to sketch in either mode according to their needs (DR2). Sketches and renderings are automatically projected onto the corresponding cards (DR6), and designers can switch viewpoints at any time, allowing them to view and work with their designs from different angles (DR5).

• **Mixing palette.** The mixing palette serves as a central hub where designers can explore a wide range of component combinations (Figure 6b). Multiple renderings generated from each component sketch are displayed together (DR3, DR6), and designers can freely arrange them on the palette. The system automatically assembles the components closest to the center to pre-visualize cabin configurations (DR4). Designers can switch viewpoints at any time to review and evaluate designs from different angles (DR5).

5.2 Sketching Components

Designers can use the 3D cabin template as a guide to rapidly sketch new interior concepts (Figure 7). They can explore overall layouts and key curves in perspective views while refining individual components in orthographic views. They can create multiple variations of sketches and iteratively develop their ideas.

5.3 Generating Components

Designers can generate multiple renderings from their component sketches. The system uses the orthographic sketch of each component as input and produces outputs with a minimal rendering style that emphasizes outlines and volumes (Figure 8). Because 2D generative AI often introduces unwanted backgrounds, the system automatically applies background removal to generated results.

5.4 Composing Cabin

Designers can use the mixing palette to compose rendered components in perspective views and identify desirable cabin configurations (Figure 9). They can organize components into different zones according to their preferences, and the system pre-visualizes cabins in real time based on the most preferred components.

5.5 Generating Cabin

Designers can generate multiple high-quality renderings from cabin pre-visualizations (Figure 10). The system produces photorealistic outputs that preserve the visual continuity of interior components, such as the smooth transition from the dashboard to the door trims, meeting the quality standards required for professional use. These generated results can be readily utilized for presentation, design review, and further development.

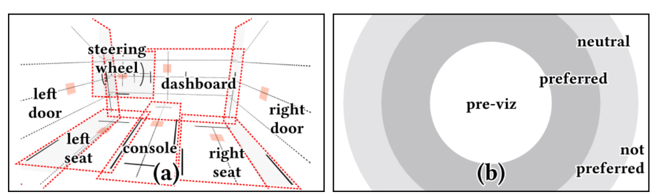

Figure 6: Two key user interfaces. (a) The *3D cabin template* visualizes the positions and dimensions of key components based on car body types. (b) The *mixing palette* displays renderings of components, which the designer can organize into zones: preferred (dark gray), neutral (light gray), and not preferred (outer white). A cabin pre-visualization that consists of the components nearest the center is shown at the center.

6 IMPLEMENTATION

We implemented our system using the Unity 3D game engine. Our system is conceptually compatible with any 2D-to-2D model, but in this study we used Vizcom [44] and Optic [42], which are widely used by professional car designers, to generate component and cabin renderings, respectively. The system was executed on a Lenovo Legion 5i gaming laptop with Windows 11 OS, Intel Core i9-14900HX CPU, 32 GB of RAM, and Nvidia GeForce RTX 4070 GPU, paired with a Wacom Cintiq Pro 24 Touch digital tablet supporting both multi-touch and pen inputs.

7 USER STUDY

We conducted a formal user study to evaluate the benefits of our proposed system for car interior design practice. Because creative design tasks are difficult to replicate, we adopted a workshop-style study in which designers freely used our system, rather than a controlled experimental setup in which designers would repeatedly perform the same tasks using both our method and a baseline. This allowed us to closely observe designers engaging in creative work in conditions similar to real-world practice.

We invited 6 professional designers with extensive experience in car design to participate in a workshop, where they were tasked with creating new design concepts covering all 12 standard car body types [9], ranging from superminis to pick-ups. The designers produced high-quality results using our system, while we gathered detailed data on their workflows and experiences.

7.1 Participant

Since our aim was to investigate whether our system could provide practical benefits to professional car designers, we recruited designers who were working in the car industry to participate in our in-depth, hands-on workshops. The participants were 6 car interior designers with work experience averaging 9.2 years (Table 1). At the time of our study, they were working as senior (P1, P3, P4, P6) or junior (P2, P5) designers at international car manufacturers (P1, P3) or design studios (P2, P4, P5, P6). They had led or participated in an average of 8.6 concept and production projects. All the designers were using 2D generative AI in their work.

P	G	A	Y	Affiliation	Job title	Expertise
P1	M	40	15	Global OEM	Senior designer	Production design
P2	M	23	1	Design studio	Designer	Concept design
P3	M	41	10	Global OEM	Senior designer	Production design
P4	M	36	11	Design studio	Design team manager	Production & concept design
P5	M	32	4	Design studio	Designer	Production & concept design
P6	M	37	14	Design studio	Senior design manager	Production design

Table 1: Participant demographics for the user study (P: participant, G: gender, A: age, Y: years of work experience).

7.2 Task

Each designer was asked to use our system to create new interior design concepts for 2 car body types randomly assigned from the 12 types defined by the European New Car Assessment Programme (Euro NCAP) [9] and to produce a cabin rendering from a desired viewpoint for each type. Each designer was given up to 75 minutes per car, which a pilot test indicated was sufficient. For each task, the 3D cabin template corresponding to the assigned car body type was provided (Table 3).

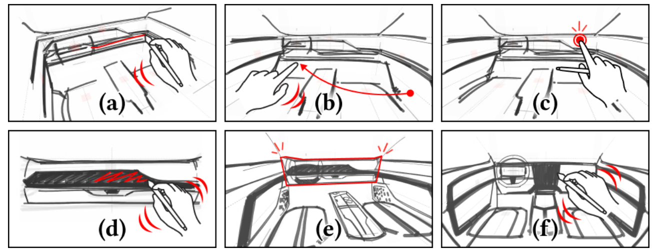

Figure 7: Sketching components. (a) The designer can first roughly sketch on 3D cards while (b) freely rotating the view. The designer can then (c) double-tap a 3D card to (d) enter the corresponding orthographic view, where he can perform detailed sketching on top of the current sketch. (e) Upon returning to the perspective view, the sketch is automatically updated. The designer can press a keyboard shortcut to create empty templates as needed (f) to sketch different interior concepts.

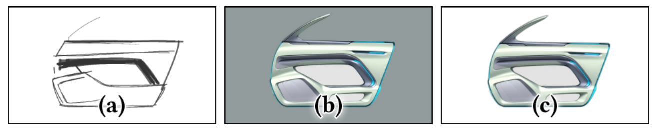

Figure 8: Generating components. When the designer presses a keyboard shortcut, the system (a) captures each component sketch in the orthographic view, (b) generates renderings from the sketch, and (c) applies background removal [14].

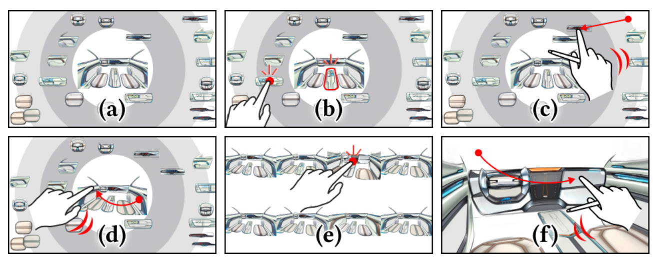

Figure 9: Composing cabin. The designer can (a) load component renderings generated from single or multiple sketches onto the mixing palette, then (b) preview components in perspective by holding them and (c) drag and drop components into different zones according to preferences, while (d) freely rotating the view. The designer can (e) open the review board to view all possible combinations of components placed in the preferred zone and tap one of them to (f) examine it from different views.

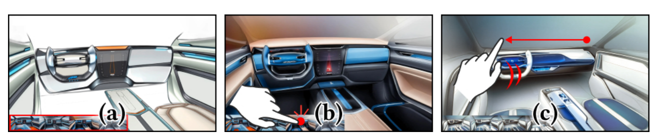

Figure 10: Generating cabin. When the designer presses a keyboard shortcut, (a) the system generates cabin renderings (outlined in red) from the current cabin pre-visualization and the designer can (b) tap a thumbnail to view it in full-screen. The designer can (c) swipe the screen to switch between renderings generated from different cabin pre-visualizations.

To let the designers fully focus on sketching and composition rather than time-consuming parameter tuning, we preset default parameters based on preliminary testing (Table 2). Specifically, for component generation, we used Vizcom Design Sketch v1 model that can rapidly produce multiple renderings in marker and colored pencil style, and for cabin generation, we used Optic v0.6.0 that can produce high-quality results with detailed materials and lighting.

Stage	Model	Text prompt	Influence	
			Model	Drawing
Generating components	Vizcom design sketch v1	"*clean, solid shape featuring subtle futuristic details*"	50%	70%
Generating cabin	Optic v0.6.0	"*photorealistic car interior*"	90%	85%

Table 2: Models and preset parameters used for the two generating stages in the user study.

7.3 Procedure

The workshop comprised three sequential sessions. First, in a 60-minute tutorial session, we followed a script to guide the designers through all system features step-by-step. Second, in a 150-minute task session, the designers completed their design tasks, and were provided with a single-page cheat sheet covering all system features. Third, in an individual 60-minute debriefing session, each designer filled out surveys and participated in an interview about their experiences using the system.

7.4 Measurement

We measured the frequency, duration, and order of each activity pertaining to the stages of sketching components, generating components, composing cabin, and generating cabin. Specifically, the sketching components stage comprised navigating, sketching in perspective views, and sketching in orthographic views; the generating components stage comprised waiting for generation to complete; the composing cabin stage comprised arranging component renderings on the mixing palette and reviewing pre-visualizations; and the generating cabin stage comprised waiting for generation to complete and reviewing the results (Figure 12).

We also collected counts of sketches, pre-visualizations, and final renderings, as well as the number of curves drawn, the view used to draw each curve (perspective or orthographic), and the components each curve represented. Throughout the task session, we positioned a camera behind each designer's shoulder and recorded the screen and hand interactions. Satisfaction with the system's key features and overall user experience were assessed through a 5-point Likert scale survey and the Creativity Support Index (CSI) [8].

7.5 Result

The 6 designers used our system for 13 hours in total and successfully created new interior design concepts for all 12 car body types, resulting in 12 final pre-visualizations and 12 corresponding final renderings (Figure 11), spending 1 hour and 5 minutes per car on average. They spent 53.5% of time on sketching, producing 3.3 sketches per car. They spent 41.5% of time on composing, producing 6.4 pre-visualizations per car. Finally, they spent 5.0% of time on generation, producing 66 component renderings and 14.7 cabin renderings per car (Table 3).

The 5-point Likert scale scores indicated high satisfaction across usability with an average score of 4.4 (±2 SE: 0.2) on Q1-12, and across usefulness with an average score of 4.6 (±0.2) on Q13-18 (Figure 13). The CSI scores indicated strong creativity support, with average scores of 9.0 (±0.7) for exploration, 8.2 (±0.9) for expressiveness, 8.8 (±1.0) for enjoyment, 8.8 (±0.8) for immersion, 9.4 (±0.6) for result worth effort, and 8.5 (±0.8) for collaboration (Figure 14).

8 DISCUSSION

In this section, we discuss how our system helped the designers explore and refine cabin designs in their work processes. First, we examine how the 3D cabin template supported the designers visualize and review designs throughout the tasks. Then, we explain how the designers achieved satisfactory design outputs by sketching and composing in different strategies. Finally, we reflect on the benefits of our integrated workflow and consider its applicability to professional car interior design practice.

Participant	Body type	Output (#)			Time spent (h:mm (%))					3D curves per sketch (# (persp/ortho))					
		Sketch	Pre-viz	Rendering	Sketch (P)	Sketch (O)	Compose	Generate	Total	Dashboard	Door trim	Console	Steering wheel	Seat	Total
P1	Large family car	4	7	12	00:10 (16.5)	00:17 (27.1)	00:34 (52.4)	00:02 (4.0)	01:05 (100.0)	30.3 (16.3/14.0)	18.0 (5.3/12.7)	23.5 (17.0/6.5)	13.5 (0.0/13.5)	10.3 (1.8/8.5)	95.6 (40.4/55.2)
	Pick-up	3	6	12	00:12 (16.2)	00:21 (29.1)	00:37 (51.0)	00:02 (3.7)	01:14 (100.0)	52.0 (10.3/41.7)	16.7 (2.4/14.3)	19.7 (10.3/9.4)	16.7 (0.4/16.3)	4.3 (0.6/3.7)	109.4 (24.0/85.4)
P2	Large MPV	4	6	8	00:14 (25.2)	00:19 (33.4)	00:22 (37.7)	00:02 (3.7)	00:58 (100.0)	48.0 (3.3/44.7)	31.5 (0.0/31.5)	27.3 (1.3/26.0)	22.8 (0.8/22.0)	10.0 (3.0/7.0)	139.6 (8.4/131.2)
	Roadster	3	6	20	00:16 (22.0)	00:17 (24.0)	00:39 (52.3)	00:01 (1.7)	01:14 (100.0)	58.7 (7.4/51.3)	32.3 (11.3/21.0)	30.3 (4.0/26.3)	26.7 (8.4/18.3)	7.7 (0.0/7.7)	155.7 (31.1/124.6)
P3	Small off-road	3	8	12	00:12 (22.3)	00:13 (24.7)	00:23 (42.2)	00:06 (10.8)	00:55 (100.0)	93.7 (78.0/15.7)	28.7 (28.7/0.0)	25.7 (0.0/25.7)	30.0 (1.0/29.0)	17.3 (0.0/17.3)	195.4 (107.7/87.7)
	Large off-road	3	8	20	00:15 (22.2)	00:11 (17.3)	00:35 (52.1)	00:05 (8.4)	01:08 (100.0)	80.0 (77.3/2.7)	49.0 (32.7/16.3)	38.0 (0.0/38.0)	24.3 (0.0/24.3)	21.3 (5.0/16.3)	212.6 (115.0/97.6)
P4	Business/van	4	7	16	00:10 (17.5)	00:15 (25.4)	00:31 (52.5)	00:02 (4.6)	00:59 (100.0)	108.0 (51.0/57.0)	63.0 (9.8/53.2)	19.3 (1.4/17.9)	19.0 (0.0/19.0)	17.3 (0.0/17.3)	226.6 (62.2/164.4)
	Small MPV	4	8	36	00:11 (20.5)	00:09 (18.3)	00:30 (55.2)	00:03 (6.0)	00:54 (100.0)	94.8 (74.0/20.8)	61.5 (28.8/32.7)	20.8 (7.3/13.5)	21.0 (0.0/21.0)	27.8 (0.0/27.8)	225.9 (110.1/115.8)
P5	Small family car	3	6	12	00:15 (23.6)	00:34 (51.6)	00:15 (23.5)	00:01 (1.3)	01:07 (100.0)	253.3 (77.6/175.7)	41.7 (10.4/31.3)	72.3 (14.0/58.3)	106.0 (4.3/101.7)	17.0 (1.0/16.0)	490.3 (107.3/383.0)
	Executive	3	5	16	00:15 (24.0)	00:35 (54.4)	00:12 (18.4)	00:02 (3.2)	01:05 (100.0)	136.7 (54.7/82.0)	59.7 (0.0/59.7)	38.3 (0.0/38.3)	136.0 (0.3/135.7)	4.7 (0.0/4.7)	375.4 (55.0/320.4)
P6	Supermini	3	5	4	00:17 (23.8)	00:28 (39.5)	00:25 (34.2)	00:01 (2.5)	01:13 (100.0)	93.3 (20.0/73.3)	100.0 (35.3/64.7)	47.3 (3.0/44.3)	82.3 (0.6/81.7)	31.7 (1.7/30.0)	360.6 (60.6/300.0)
	Sport	3	5	8	00:22 (33.8)	00:17 (26.4)	00:18 (28.5)	00:07 (11.3)	01:06 (100.0)	81.0 (46.3/34.7)	54.3 (14.7/39.6)	53.3 (4.1/49.2)	35.7 (0.0/35.7)	44.0 (43.0/1.0)	268.3 (145.0/123.3)
Average	–	**3.3**	**6.4**	**14.7**	**00:14 (22.3)**	**00:20 (31.2)**	**00:27 (41.5)**	**00:03 (5.0)**	**01:05 (100.0)**	**94.7 (43.0/51.6)**	**46.4 (15.0/31.4)**	**34.7 (8.3/26.4)**	**44.5 (1.3/43.2)**	**17.8 (4.7/13.1)**	**238.0 (72.2/165.7)**

Table 3: Body type, number of outputs (sketch, cabin pre-visualization, and cabin rendering), time spent (sketching in perspective views, sketching in orthographic views, composing cabin, and generating components and cabin) and number of 3D curves per sketch by component (dashboard, door trim, console, steering wheel, and seat) for each task, ordered by participant.

Figure 11: The final pre-visualizations (left) and renderings (right) produced by the designers in the user study. (a) A large family car by P1. (b) A pick-up by P1. (c) A large MPV by P2. (d) A roadster by P2. (e) A small off-road by P3. (f) A large off-road by P3. (g) A business and family van by P4. (h) A small MPV by P4. (i) A small family car by P5. (j) An executive by P5. (k) A supermini by P6. (l) A sport by P6.

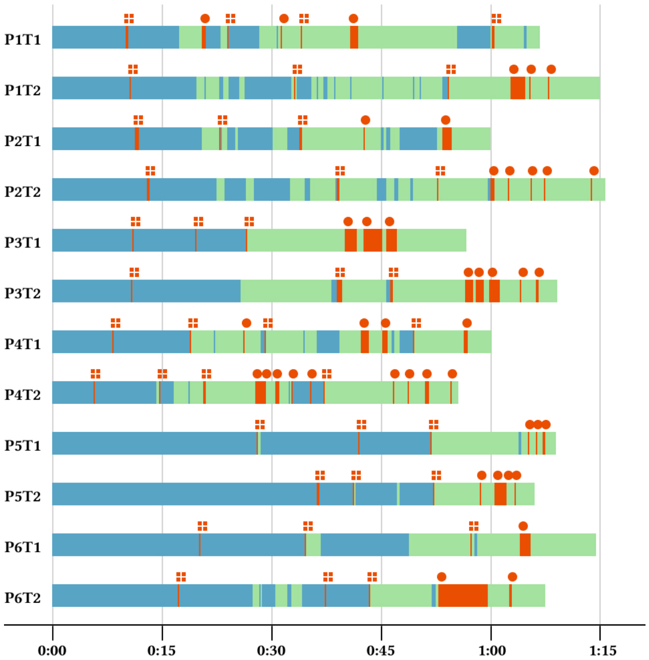

Figure 12: Timelines of the designers' activities for all 12 design tasks. Each bar represents a design activity (blue: sketching, green: composing, red: generating), with the length proportional to the time spent. Red icons above the red bars indicate types of generation (four squares: generating components, circle: generating cabin). The designers demonstrated various patterns of progression and iteration.

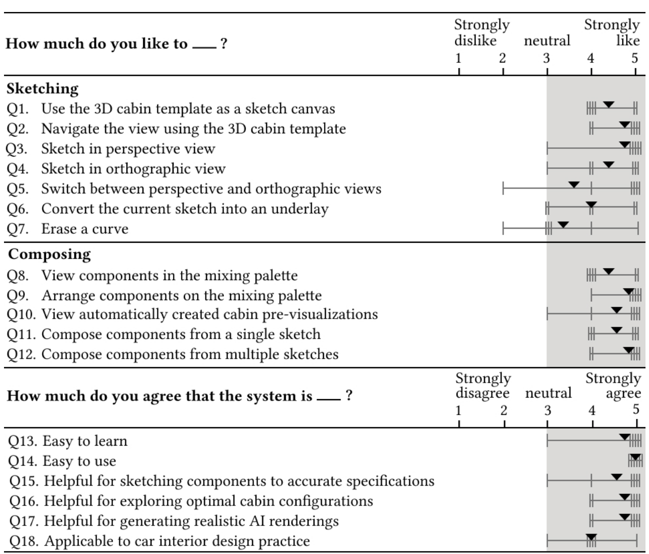

Figure 13: The 5-point Likert scale scores on the system's usability (Q1-12) and usefulness (Q13-18). Each tick corresponds to a designer's response, and each triangle to the average score. An average score of 4.4 out of 5 (±2 SE: 0.1) across all questions indicates a satisfying overall experience.

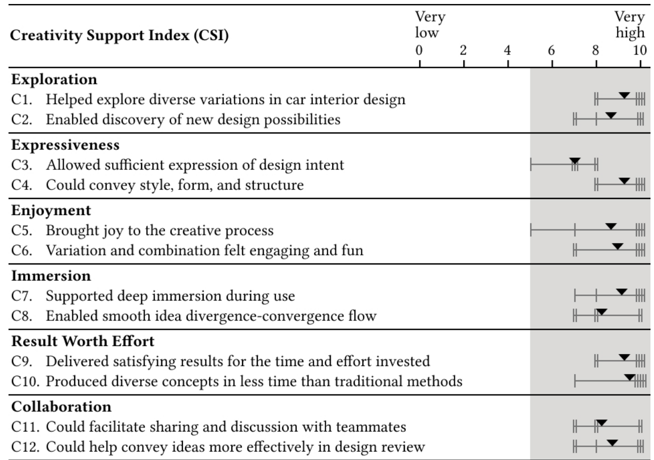

Figure 14: The Creative Support Index (CSI) [8] scores on exploration, expressiveness, enjoyment, immersion, result worth effort, and collaboration. Each tick corresponds to a designer's response, and each triangle to the average score. An average score of 8.8 out of 10 (±2 SE: 0.3) across all questions indicates a high level of creativity support.

8.1 3D Cabin Template

The designers strongly agreed that the 3D cabin template is useful for car interior design, giving an average score of 4.2 (±0.3) on Q1-Q7 (Figure 13). We discuss how the 3D cabin template helped the designers throughout their work processes.

• **Realistic design outputs.** The designers highly valued the 3D cabin template, noting that it *"accurately embedded the spatial constraints of each component"* (P4), which *"are subtle but are crucial in professional car design practices"* (P6). These spatial constraints helped the designers *"accurately position components in 3D"* (P4) from the early sketching stages. As a result, the designers observed that *"different proportions between car body types were well reflected in final results"* (P1), that *"distortions commonly seen during generation were noticeably reduced"* (P5), and that *"components landed where they should"* (P6). These findings highlight the role of the 3D cabin template as a *"solid foundation for creating realistic sketches and renderings"* (P5).

• **Immersive design experience.** The designers initially expected that the 3D cabin template *"would lack a sense of dimension"* (P2) and be *"too simple for complex car interiors"* (P6) as it is composed of flat 3D cards. However, after using our system, they reported that *"it felt natural"* (P6) and that *"it gave me the feeling of being inside the car"* (P1). One designer further noted that 3D cards were *"less distracting and cognitively lighter"* (P4). These findings show that the 3D cabin template enabled an immersive design experience, allowing the designers to view and work with their cabin designs in 3D without the need for complex 3D modeling.

• **Flexible view exploration.** The designers navigated views 20.6 times during sketching and 23.0 times during composing on average, corresponding to one view change every 97 seconds and 70 seconds, respectively. They explained that, in conventional workflows, *"I had to carefully select the starting viewpoint because it would* *take a lot of time to change it later"* (P3), and that *"if I wanted to change the view while sketching, I had to redraw from scratch"* (P1). In contrast, using our system, the designers could *"rotate to any view at any time"* (P4), which helped them *"examine whether a component worked"* (P2), and *"review the entire cabin design from different views"* (P6). These findings suggest that the 3D cabin template enabled flexible view exploration and supported the designers to make more informed design decisions.

8.2 Sketching

The designers spent 53.5% of their time on sketching, producing an average of 3.3 sketches per car, with final sketches containing an average of 238.0 curves (Table 3). The designers strongly agreed that our system is useful for sketching car interiors, giving an average score of 4.5 (±0.7) on Q15 (Figure 13). We describe how our system helped the designers fluently sketch car interiors.

• **Big picture in perspective, details in orthographic.** The designers sketched each component from the view they found most appropriate, with time distributed fairly evenly across views: 22.3% in perspective and 31.2% in orthographic (Table 3). The designers explained that they could *"rough out the big picture in perspective views and then shift to orthographic views to nail the details"* (P2), describing the transition as *"seamless and intuitive"* (P1), *"natural"* (P5), and *"easy"* (P6). This workflow supported a natural global-local-global loop, in which the designers established overall structure in perspective views, refined components in orthographic views, and returned to perspective views to assess the design as a whole.

• **Different components, different strategies.** Although the designers generally followed an iterative global-local-global loop, their specific strategies varied across different components.

For dashboards, the designers drew a similar number of curves in both views (perspective: 43.0 vs. orthographic: 51.6, Table 3). One designer explained that *"because the dashboard defines the overall impression of the interior, I began by sketching its flow and volume in perspective views, then refined the details in orthographic views, repeating this process as needed"* (P5).

For door trims, the designers drew about twice as many curves in orthographic views (15.1 vs. 31.4). The designers explained that they *"first roughly sketched connecting parts between doors and the other components in perspective"* (P4), and then *"refined them* [door trims]*"* (P4) in orthographic views, where they could *"accurately draw the beltline, armrest, and door handle"* (P2), as orthographic views *"made it easier"* (P3).

For consoles, the designers drew about 3 times as many curves in orthographic views (8.3 vs. 26.4). They explained that consoles *"are usually hidden behind the seat"* (P1) and *"include many smaller components like buttons and cupholders"* (P2). They found viewing consoles from the top orthographic view to be *"better to work with"* (P1), and *"useful for sketching all necessary elements"* (P3).

For steering wheels, the designers drew significantly more curves in orthographic views (1.3 vs. 43.2). They explained that steering wheels are *"difficult to draw from perspective views"* (P1) because *"they have the most complex curved surface"* (P4), which makes orthographic views *"much easier to work with"* (P6).

• **Quick sketches, realistic results.** The designers emphasized that interior sketching is challenging even for professionals, noting that *"without 3D models, it is difficult to accurately represent rigorous spatial dimensions for each car body type using only freehand sketches"* (P2) and that *"capturing subtle differences in layout between car body types requires a high level of expertise"* (P4). However, the designers agreed that our system helped improve both the efficiency and rigor of freehand sketching, noting that it helped *"sketch fast and accurately"* (P2), *"reduce distortion commonly seen in freehand inputs"* (P3), and *"produce reliable sketches early on"* (P6).

8.3 Composing

The designers spent 41.5% of their time on composing cabins, producing an average of 6.4 cabin pre-visualizations per car (Table 3). They strongly agreed that our system is helpful for exploring alternatives and selecting the best cabin designs, giving an average score of 4.7 (±0.4) on Q16 (Figure 13) and 9.0 (±0.7) on C1-C2 (Figure 14). Based on their usage patterns and interviews, we identified 3 distinct strategies for composing cabins (Figures 15-17).

• **Prepper.** This strategy was observed in 3 out of 12 tasks (P3T1, P5T1, P5T2). The designers following this strategy first concentrated on sketching and generating all necessary components, and once their *"resources"* (P5) were prepared, they explored various combinations without returning to sketching (Figure 15). The designers explained that they *"first focused on securing good materials"* (P5), and that *"once all assets were there, mixing them became easy"* (P3). These examples illustrate that the 3D cabin template and the mixing palette were each capable of effectively supporting focused sketching and composing when the designers chose to concentrate on those activities.

• **Cycler.** This strategy was observed in 2 out of 12 tasks (P1T1, P4T1). The designers following this strategy repeatedly cycled through the four stages of sketching components, generating components, composing cabin, and generating cabin to create a variety of cabin designs (Figure 16). As the designers explained, *"I completed different versions of designs and compared them later"* (P1) and *"I did not start with a clear idea, so I created multiple variations to see what might work"* (P4). These examples illustrate that the system supported a flexible and uninterrupted workflow, allowing the designers to quickly expand design space and compare a wide range of high-quality alternatives.

• **Refiner.** This strategy was observed in 7 out of 12 tasks (P1T2, P2T1, P2T2, P3T2, P4T2, P6T1, P6T2). The designers following this strategy freely transitioned between sketching and composing, with insights gained from cabin pre-visualizations reflected back into sketches (Figure 17). The designers explained that *"unexpected ideas often emerged during cabin composition, and remixing them allowed me to see new possibilities"* (P3), that *"even while generating components or cabins, I could sketch new ideas, and even while sketching, I could always check generated results"* (P4), and that *"I could draw new sketches based on ideas that arose while composing cabins"* (P6). These examples illustrate that the seamless interplay between sketching and composing sparked creative insights.

8.4 Integrated Workflow

The designers successfully completed tasks using all system features involving sketching, composing, and generating. We discuss how our tightly integrated workflow benefited their design processes.

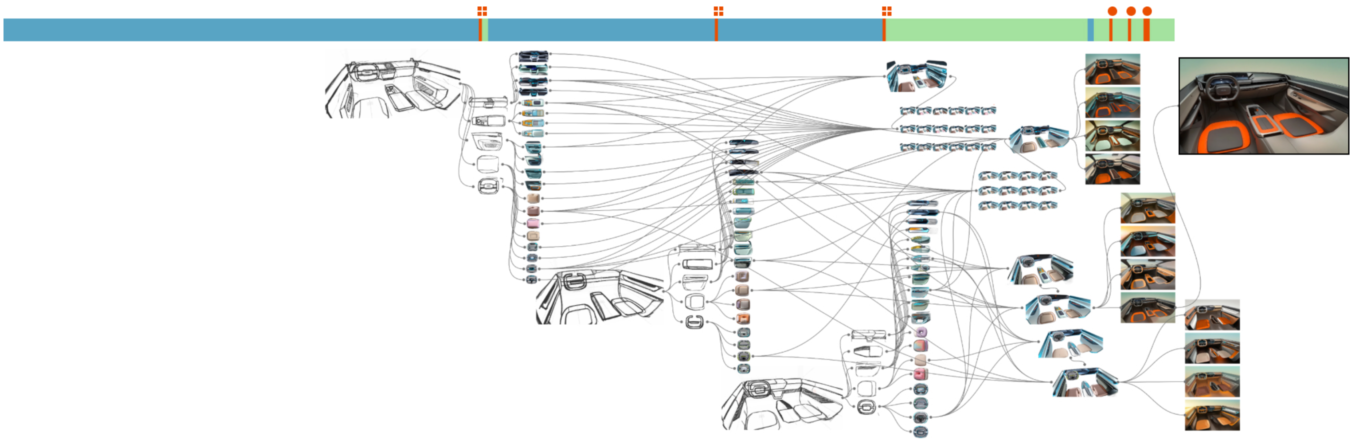

Figure 15: A task that showed cabin composing strategy 1: *prepper* (P5T1). Each bar represents a design activity (blue: sketching, green: composing, red: generating) and red icons indicate types of generation (four squares: generating components, circle: generating cabin). P5 spent most of the early time sketching different ideas, triggering generation after completing each sketch and proceeding to the next one in parallel. Once all components for every sketch had been generated, P5 spent the remaining time composing cabins and generating the final rendering.

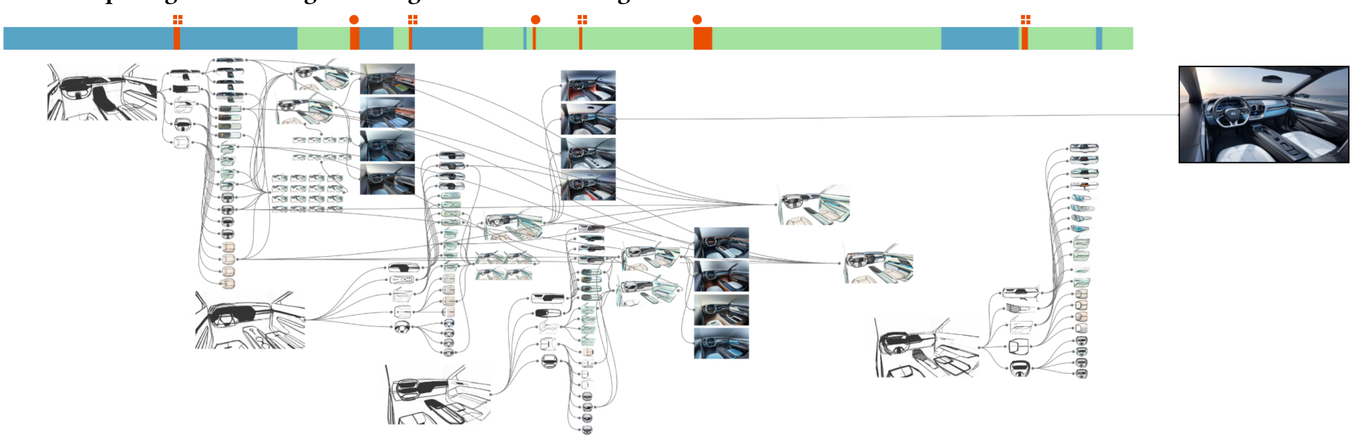

Figure 16: A task that showed cabin composing strategy 2: *cycler* (P1T1). P1 repeatedly cycled through the four stages of sketching components, generating components, composing cabin, and generating cabin, producing multiple renderings of different cabin designs early in the process. He then spent substantial time comparing these renderings to identify the most satisfactory design.

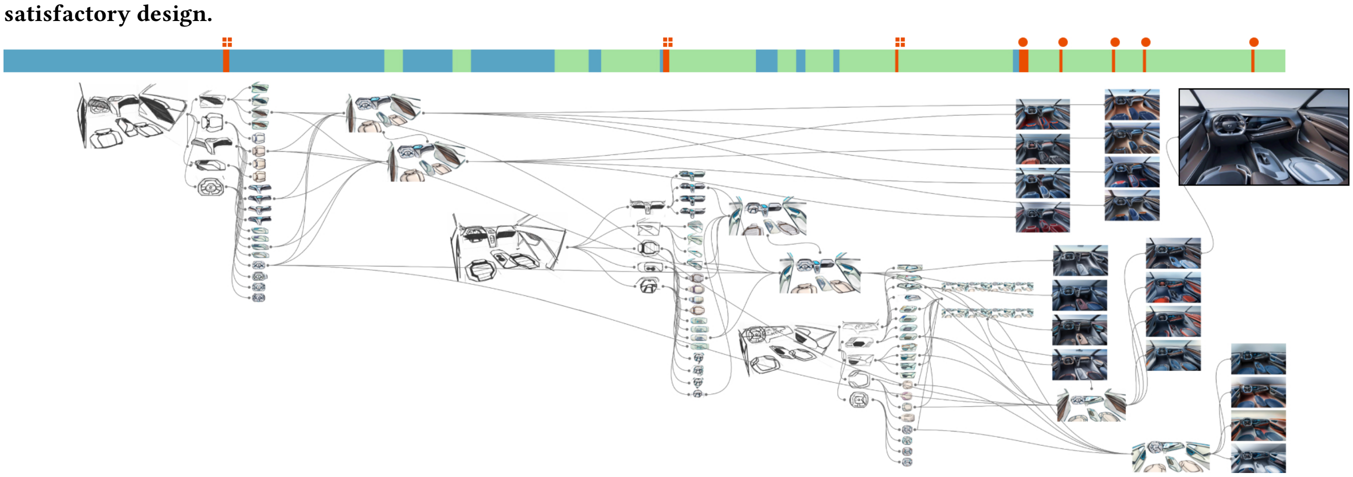

Figure 17: A task that showed cabin composing strategy 3: *refiner* (P2T2). P2 iteratively developed the design by obtaining new ideas from cabin pre-visualizations, and integrating them into subsequent sketches, and repeating this process until a satisfactory cabin configuration was found, from which the final cabin rendering was generated.

• **Seamless transition.** The designers reported becoming deeply immersed in their tasks while using our system. They explained that, in conventional workflows, they had to *"hop between multiple tools"* (P2), as in *"creating 2D sketches in one program, passing them through generative AI tools, and collecting results in another program for comparison"* (P4), or even *"arranging printouts on desks to compare options"* (P6). In contrast, our system enabled the designers to seamlessly transition between sketching, composing, and generating within a single environment, helping them *"stay immersed in tasks without disruptions"* (P3).

• **Efficient decision-making.** The designers expressed high satisfaction with the mixing palette, giving an average score of 4.6 (±0.2) on Q8-Q12 (Figure 13). They agreed that the mixing palette enabled efficient exploration and organization of the design space, noting that it was useful for *"grouping"* (P2, P5) and *"comparing"* (P4) many interior components originating from the same or different sketches, while *"seeing everything at a glance"* (P6). This helped the designers *"prevent being overwhelmed with too many alternatives to compare"* (P3). As a result, the designers were able to narrow the vast design space of potential cabin configurations to an average of 6.4 cabin pre-visualizations per car (Table 3).

• **Focus on creativity.** The designers spent only 5% of their time on generating components or cabins and devoted the vast majority of their time to sketching and combining (Table 3). They reported a high level of enjoyment and immersion, giving an average score of 8.8 (±1.0) on C5-C6 and 8.8 (±0.8) on C7-C8 (Figure 14). The designers explained that, in conventional workflows, they often *"just wait idly during generation"* (P2) and *"lose context while doing other tasks"* (P4). In contrast, they agreed that our integrated workflow helped preserve focus and creative momentum, noting that *"I could immediately move on to the next sketch while generation was running"* (P1), that *"the mental fatigue of waiting for generation to finish was reduced"* (P3), and that *"everything flowed naturally, so I could just keep designing"* (P5).

8.5 Applicability

The designers agreed that our workflow is applicable to professional car interior design practice, giving an average score of 4.0 (±0.5) on Q18 (Figure 13). We discuss the key factors underlying this positive evaluation and examine how our system could be integrated into real-world car design practices.

• **Easy.** After the 60-minute tutorial session, the designers were able to use all system features and produce highly satisfactory results (Figure 11), giving an average score of 4.7 (±0.4) on Q17 (Figure 13) and 8.2 (±0.9) on C3-C4 (Figure 14). They agreed that our system was easy to learn and use, giving an average score of 4.8 (±0.2) on Q13-Q14 (Figure 13), and described the system as *"easy"* (P1, P3, P4, P6) and *"intuitive"* (P1, P2, P5, P6), and noted that *"it highly resembled what we actually do in the studio"* (P3).

• **Fast.** The designers expressed strong satisfaction with the system's support for productivity, giving an average score of 9.4 (±0.6) on C9-C10 (Figure 14) and described our system as *"fast"* (P1, P3, P4) and *"efficient"* (P1, P2, P5, P6). They explained that in conventional workflows, it typically takes around 2 weeks to progress from rough ideas to visualizing multiple combinations and selecting a final concept (P1, P3, P6). In contrast, using our system, the designers produced an average of 3.3 sketches, 6.4 cabin pre-visualizations, and 14.7 realistic cabin renderings per car in approximately 1 hour (Table 3), enabling them to explore a broad design space and obtain high-quality results that are *"reliable"* (P2), *"solid"* (P5), and *"ready for immediate use in real work"* (P6) within a short timeframe.

• **Versatile.** The designers suggested that our system could be applied to a wide range of design projects, including both major *"model changes"* (P1, P4, P5) and minor *"facelifts"* (P1, P2, P3, P6). Some designers also emphasized that the system could *"reduce quality disparities between designers with different skill levels"* (P1), thus *"helping junior designers with less experience"* (P3). In addition, the designers evaluated our system as highly useful for communication and design reviews, giving an average score of 8.5 (±0.8) on C11-C12 (Figure 14). The designers explained that the system *"captured much of the intended design while offering new interpretations"* (P5), allowing them to *"review designs in 3D from different perspectives"* (P4) and *"create new combinations on site when needed"* (P1). As one designer summarized, these qualities made the system *"useful for early-stage idea exploration and beyond"* (P1).

9 LIMITATIONS & FUTURE WORK

In this section, we discuss the limitations identified in the user study, along with opportunities for future research.

• **Supporting hierarchical modularity.** This study focused on key components of car interiors including dashboards, doors, consoles, steering wheels, and seats. Each of these components comprises subcomponents such as buttons, displays, and storage elements. Supporting hierarchical modularity, together with a library of reusable components, could enable more detailed work.

• **Expanding to other domains.** While this study focused on validating the system's effectiveness within car interior design, the need for 2D renderings that respect rigorous spatial constraint exists in many other design fields. The proposed workflow is broadly applicable to various modes of transportation, and can be combined with different 2D-to-2D models to better satisfy domain-specific requirements (Figure 18). Future collaborations with designers across diverse industries could further enhance the generality and flexibility of the proposed workflow.

• **Integrating 3D generation and VR.** 3D cards can be captured from multiple viewpoints and used as input for 3D generative AI to produce meshes [6, 46]. By placing the resulting meshes at real scale within VR and projection-mapping realistic 2D renderings onto them, designers could quickly and affordably conduct immersive design reviews in 3D. This capability could significantly accelerate car interior design workflows, which still heavily rely on physical clay modeling for real-scale design iteration.

10 CONCLUSION

This study proposed a simple yet effective component-wise workflow for car interior design, in which designers sketch components individually, generate refined component renderings, compose them into a cabin pre-visualization, and generate high-quality cabin renderings using the pre-visualization as input.

We first interviewed 10 professional car designers to identify key challenges in applying 2D generative AI in practice, as well

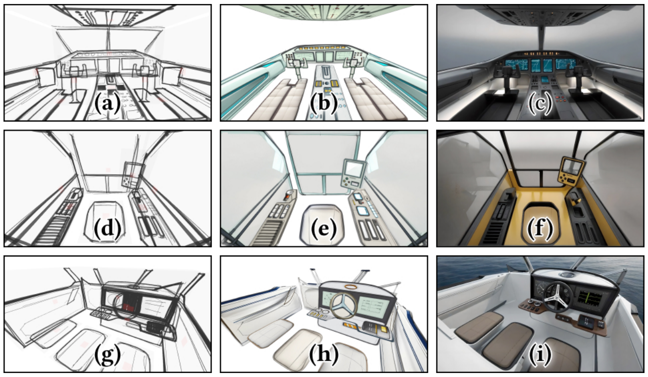

Figure 18: One of the authors used our system to sketch, pre-visualize, and generate cabins for various modes of transportation, including (a-c) an aircraft, (d-f) heavy equipment, and (g-i) a marine vessel.

as insights into how these challenges might be addressed. Based on these findings, we designed the component-wise workflow and conducted a pilot study with 4 designers, which resulted in 6 design requirements for professional applicability. We then refined the system by introducing the 3D cabin template and the mixing palette to better support sketching and composing within the workflow.

We conducted a user study with 6 professional car designers averaging 9.2 years of work experience to evaluate the practicality and effectiveness of the system. Over a total of 13.0 hours, the designers successfully created interior design concepts for all 12 major car body types using our system. They fluently sketched complex car interiors, efficiently explored design alternatives, and rapidly produced high-quality design outputs, at a level of quality suitable for professional use. Throughout the design process, the designers demonstrated 3 distinct patterns of design development: prepper, cycler, and refiner. The designers responded positively to the prospect of the system being adopted within professional car interior design workflows.

As generative AI tools become increasingly adopted in car design studios, our sketch-based workflow highlights that the true strength of sketching lies not in producing a perfect rendering in a single step, but in developing ideas through iteration, ultimately leading to better design outcomes. We believe that tools integrating sketching and generative AI in a harmonious and complementary manner will offer further practical solutions for car design and other industrial design processes.

Acknowledgments

This research was supported by the DRB-KAIST SketchTheFuture Research Center, and the InnoCORE Program of the Ministry of Science and ICT (N10260008). We thank Jaeseob Yeon, Junghwan Kwak, Jamin Koo, Guenha Ryu, and the designers who wished to remain anonymous, for participating in our studies.

References

[1] Audi AG. 2024. *Reinventing the wheel: FelGAN inspires new rim designs with AI.* https://www.audi-mediacenter.com/en/press-releases/reinventing-the-wheel-felgan-inspires-new-rim-designs-with-ai-15097 Accessed: 2025-08-15.
[2] Autodesk. 2025. *BlankAI.*
[3] Vivek D. Bhise. 2024. *Ergonomics in the Automotive Design Process.* CRC Press.
[4] Luigi Bandini Buti. 2001. Design of automobile interiors. In *International Encyclopedia of Ergonomics and Human Factors.* Taylor & Francis, 920–924.
[5] Liuqing Chen, Qianzhi Jing, Yixin Tsang, Qianyi Wang, Ruocong Liu, Duowei Xia, Yunzhan Zhou, and Lingyun Sun. 2024. AutoSpark: supporting automobile appearance design ideation with Kansei Engineering and generative AI. In *Proc. UIST '24.* Article 108, 19 pages.
[6] Minglin Chen, Weihao Yuan, Yukun Wang, Zhe Sheng, Yisheng He, Zilong Dong, Liefeng Bo, and Yulan Guo. 2024. Sketch2NeRF: multi-view sketch-guided text-to-3D generation. arXiv:2401.14257
[7] Wengling Chen and James Hays. 2018. SketchyGAN: towards diverse and realistic sketch to image synthesis. In *Proc. CVPR '18.* 9416–9425.
[8] Erin Cherry and Celine Latulipe. 2014. Quantifying the creativity support of digital tools through the Creativity Support Index. *TOCHI* 21, 4, Article 21 (2014), 25 pages.
[9] European Commission. 2025. *EU classification of vehicle types.* https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types Accessed: 2025-04-08.
[10] Julie Dorsey, Songhua Xu, Gabe Smedresman, Holly Rushmeier, and Leonard McMillan. 2007. The mental canvas: a tool for conceptual architectural design and analysis. In *Proc. PG '07.* 201–210.
[11] Runlin Duan, Chenfei Zhu, Yuzhao Chen, Dizhi Ma, Jingyu Shi, Ziyi Liu, and Karthik Ramani. 2025. SketchConcept: sketching-based concept recomposition for product design using generative AI. arXiv:2508.07141
[12] Koos Eissen and Roselien Steur. 2008. *Sketching: Drawing Techniques for Product Designers.* Bis Publishers.
[13] Fabio Filippini and Gabriele Ferraresi. 2021. *Curve: 15 lezioni sul car design.* Rizzoli Lizard.
[14] Daniel Gatis. 2025. Rembg. https://github.com/danielgatis/rembg. GitHub repository, MIT License.
[15] Tao Geng and Yuxuan Yang. 2025. DiffDesign: controllable diffusion with meta prior for efficient interior design generation. *PloS one* 20, 9 (2025), e0331240.
[16] José Manuel Aznar Gragera. 2024. *How to Design Cars: Design from Scratch with this Step-by-step Guide.* Verlag Nicht Ermittelbar.
[17] Tovi Grossman, Ravin Balakrishnan, Gordon Kurtenbach, George Fitzmaurice, Azam Khan, and Bill Buxton. 2002. Creating principal 3D curves with digital tape drawing. In *Proc. CHI '02.* 121–128.
[18] Toyota Research Institute. 2023. *Toyota Research Institute Unveils New Generative AI Technique for Vehicle Design.* https://pressroom.toyota.com/toyota-research-institute-unveils-new-generative-ai-technique-for-vehicle-design/ Accessed: 2025-08-15.
[19] SAE International. 2001. Motor Vehicle Dimensions (SAE Standard J1100_200102, Revised February 2001).
[20] TKiia Kallio. 2005. 3D6B editor: projective 3D sketching with line-based rendering. In *Proc. SBIM '05.* 73–79.
[21] Levent Burak Kara and Kenji Shimada. 2008. Supporting early styling design of automobiles using sketch-based 3D shape construction. *CAD. Appl.* 5, 6 (2008), 867–876.
[22] Yongkwan Kim, Sang-Gyun An, Joon Hyub Lee, and Seok-Hyung Bae. 2018. Agile 3D sketching with air scaffolding. In *Proc. CHI '18.* Article 238, 12 pages.
[23] Yongkwan Kim and Seok-Hyung Bae. 2016. SketchingWithHands: 3D sketching handheld products with first-person hand posture. In *Proc. UIST '16.* 797–808.
[24] Subhadeep Koley, Ayan Kumar Bhunia, Deeptanshu Sekhri, Aneeshan Sain, Pinaki Nath Chowdhury, Tao Xiang, and Yi-Zhe Song. 2024. It's all about your sketch: democratising sketch control in diffusion models. In *Proc. CVPR '24.* 7204–7214.
[25] Joon Hyub Lee, Hanbit Kim, and Seok-Hyung Bae. 2022. Rapid design of articulated objects. *Trans. Graph.* 41, 4, Article 89 (2022), 8 pages.
[26] Kijun Lee. 2024. *Between inspiration and conceptual design: Kia Global Design explores generative AI for automotive design.* https://www.autodesk.com/kr/design-make/articles/kia-generative-ai-for-automotive-design Accessed: 2025-8-15.
[27] Seung-Jun Lee, Jeongche Yoon, Sang-Hyun Lee, Joon Hyub Lee, and Seok-Hyung Bae. 2025. 3D sketching + 2D generative AI for car exterior design. In *Proc. UIST '25.* 1–14.
[28] Yuheng Li, Haotian Liu, Qingyang Wu, Fangzhou Mu, Jianwei Yang, Jianfeng Gao, Chunyuan Li, and Yong Jae Lee. 2023. GLIGEN: open-set grounded text-to-image generation. In *Proc. CVPR '23.* 22511–22521.
[29] Vivian Liu, Jo Vermeulen, George Fitzmaurice, and Justin Matejka. 2023. 3DALL-E: integrating text-to-image AI in 3D design workflows. In *Proc. DIS '23.* 1955–1977.
[30] Stuart Macey and Geoff Wardle. 2014. *H-Point: The Fundamentals of Car Design & Packaging.* Design Studio Press.
[31] Chenlin Meng, Yutong He, Yang Song, Jiaming Song, Jiajun Wu, Jun-Yan Zhu, and Stefano Ermon. 2021. SDEdit: guided image synthesis and editing with stochastic differential equations. arXiv:2108.01073
[32] Midjourney. 2025. *Midjourney.*
[33] Car Design News. 2025. *AI is an implement: it's about how you use it.* https://www.cardesignnews.com/design-tools/ai-is-an-implement-its-about-how-you-use-it/455132 Accessed: 2025-12-05.

[34] OpenAI. 2025. *DALL-E*.

[35] Xiaohan Peng, Janin Koch, and Wendy E. Mackay. 2025. FusAIn: composing generative AI visual prompts using pen-based interaction. In *Proc. CHI '25'*. Article 874, 20 pages.

[36] Moreno Attilio Piccolotto. 1998. *Sketchpad+: Architectural Modeling through Perspective Sketching on a Pen-Based Display*. Master's thesis. Cornell University.

[37] Corrado Poli. 2001. *Design for Manufacturing: A Structured Approach*. Butterworth-Heinemann.

[38] Nicolas Rosset, Guillaume Cordonnier, Regis Duvigneau, and Adrien Bousseau. 2014. Interactive design of 2D car profiles with aerodynamic feedback. *Comput. Graph. Forum* 42, 2 (2014), 427–437.

[39] Patsorn Sangkloy, Jingwan Lu, Chen Fang, Fisher Yu, and James Hays. 2017. Scribbler: controlling deep image synthesis with sketch and color. In *Proc. CVPR '17*. 5400–5409.

[40] Yulin Shen, Yifei Shen, Jiawen Cheng, Chutian Jiang, Mingming Fan, and Zeyu Wang. 2024. Neural canvas: supporting scenic design prototyping by integrating 3D sketching and generative AI. In *Proc. CHI '24*. Article 1056, 18 pages.

[41] Michael Tovey, S. Porter, and Robert Newman. 2003. Sketching, concept development and automotive design. *Design Studies* 24, 2 (2003), 135–153.

[42] Udin. 2025. *Optic*.

[43] Karl T. Ulrich, Steven D. Eppinger, and Maria C. Yang. 1995. *Product Design and Development*. McGraw-Hill.

[44] Vizcom. 2025. *Vizcom*.

[45] Min Xin, Ehud Sharlin, and Mario Costa Sousa. 2008. Napkin sketch: handheld mixed reality 3D sketching. In *Proc. VRST '08*. 223–226.

[46] Jiale Xu, Weihao Cheng, Yiming Gao, Xintao Wang, Shenghua Gao, and Ying Shan. 2024. InstantMesh: efficient 3D mesh generation from a single image with sparse-view large reconstruction models. arXiv:2404.07191

[47] Hongbo Zhang, Pei Chen, Xuelong Xie, Zhaoqu Jiang, Yifei Wu, Zejian Li, Xiaoyu Chen, and Lingyun Sun. 2025. FusionProtor: a mixed-prototype tool for component-level physical-to-virtual 3D transition and simulation. In *Proc. CHI '25*. Article 685, 19 pages.

[48] Hongbo Zhang, Pei Chen, Xuelong Xie, Chaoyi Lin, Lianyan Liu, Zhuoshu Li, Weitao You, and Lingyun Sun. 2024. Protodreamer: a mixed-prototype tool combining physical model and generative AI to support conceptual design. In *Proc. UIST '24*. Article 97, 18 pages.