DESIGN AND EVALUATION OF A GENERATIVE AI-DRIVEN VR TEXTURING TOOL: A DESIGN SCIENCE APPROACH

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Hyerim Park, BMW Group, Munich, Germany / University of Stuttgart, Germany, hyerim.park@bmw.de

Joscha Eirich, BMW Group, Munich, Germany, joscha.eirich@bmw.de

Andre Luckow, BMW Group, Munich, Germany, andre.luckow@bmwgroup.com

Michael Sedlmair, University of Stuttgart, Germany, michael.sedlmair@visus.uni-stuttgart.de

Abstract

The integration of generative AI (GenAI) with virtual reality (VR) offers new opportunities for the automotive industry to enhance customer engagement by enabling customizable textures for 3D car models and sharing them within VR. However, creating textures for VR platforms remains challenging due to the expertise required for traditional texturing tools and the limited customization options VR platforms provide. This study introduces GenVRTex, a GenAI-driven VR texturing tool that helps novice users generate high-quality textures through text prompts and drawings. Developed through a Design Science Research approach in collaboration with an industrial partner, GenVRTex incorporates ten design guidelines addressing user interaction, prompt control, and texture creation. A qualitative evaluation with nine designers inexperienced in VR texturing confirmed the tool's usability and effectiveness while highlighting potential improvements, including multimodal inputs and iterative GenAI input-output management. This research provides insights into GenAI-VR integration from an HCI perspective and outlines future research directions.

Keywords: Virtual Reality, Generative AI, 3D Texture Design, Human-Computer Interaction, Design Science Research.

1 Introduction

Advancements in VR technology and user interfaces have transformed VR into a highly immersive and engaging medium, now integrated into daily life across domains such as entertainment, education, and productivity (Barrow et al., 2023; Chheang et al., 2023; Rieuf et al., 2017). This evolution has shifted users from passive consumers to active creators, enabling them to design and generate digital assets. Platforms like Roblox Creator Hub, ShapesXR, and SculptrVR facilitate the creation and sharing of virtual content.

In the automotive industry, VR enables users to customize the surface textures of 3D car models and share their designs in immersive environments. Such customization can enhance brand engagement and strengthen customer relationships by providing interactive, sensory-rich experiences (Bogicevic et al., 2024; Bousba & Arya, 2022). Personalizing vehicle models, such as favorite real-world cars, to reflect individual identities and preferences fosters emotional connections and increases perceived brand value (Choi et al., 2016; Cowan & Ketron, 2019). However, customization is often limited to pre-designed skins, restricting users—especially novices—from fully expressing their creative ideas or engaging meaningfully with digital representations of familiar vehicles.

While some VR platforms offer in-app texture customization features, they often lack the granularity needed for detailed, user-driven design. Creating personalized textures remains particularly challenging for users unfamiliar with VR interaction or 3D design tools. Traditional software such as Blender and Maya requires advanced texturing skills, resulting in a steep learning curve that makes texture generation, editing, and importing into VR largely inaccessible to novice users.

Generative AI (GenAI) technologies, such as text-to-image and image-to-image models, offer promising solutions to these challenges when integrated into VR. Tools like Midjourney, DALL-E, and Stable Diffusion-based platforms like DreamStudio simplify texture creation by enabling users to generate unique images from text or sketches, reducing reliance on manual design skills. These tools significantly lower barriers for novices, making the creation of personalized textures more accessible and intuitive.

However, while GenAI tools have seen growing exploration in 2D workflows (Suzuki et al., 2023), research on their integration into immersive VR environments remains limited, particularly from a Human-Computer Interaction (HCI) perspective. Existing research on AI-Extended Reality (XR) integration has primarily focused on enhancing realism, including tracking, geometry reconstruction (Huang & Ling, 2021; Tone et al., 2020), and illumination optimization in VR (C. Liu et al., 2018), rather than supporting user interaction in creative workflows like real-time texture customization. Furthermore, many GenAI applications operate outside VR, requiring users to switch tools and import static outputs, which disrupts creative flow and adds complexity, especially for those unfamiliar with 3D modeling or VR design conventions. This lack of HCI research on GenAI integration in immersive VR presents a key design challenge: how to support novice users in creating and editing textures within VR without requiring expert-level skills or switching tools.

This study addresses that challenge by introducing *GenVRTex*, a GenAI-based VR texturing tool designed for users with little or no experience in 3D texture creation in VR. The tool enables users to generate high-quality textures for 3D objects using simple text prompts and basic drawing inputs. By employing a Design Science Research (DSR) methodology (Gregor & Hevner, 2013; Hevner et al., 2004; Vaishnavi & Kuechler, 2015) and collaborating with an automotive industry partner, we aimed to answer the following research question:

***RQ**: How should a GenAI-based VR texturing artifact be designed to support novice users in creating textures (images) for 3D objects within VR environments?*

To evaluate *GenVRTex*, we conducted a qualitative study with nine designers experienced in traditional design but unfamiliar with VR-based texturing or GenAI tools. Participants provided insights into the tool's usability, input preferences (e.g., speech vs. virtual keyboards), and challenges related to prompt formulation, iterative refinement, and output management within the constraints of a VR environment. This study contributes to both theory and practice. It advances the understanding of GenAI integration in VR for novice users, highlighting the importance of user-friendly inputs, smooth transitions between input methods, and spatial navigation for iterative prompt workflows. These insights provide guidance for designing GenAI-supported tools in immersive environments within HCI and DSR contexts. Practically, the study demonstrates the tool's applicability to automotive design, where there is a growing demand for user-driven customization. By simplifying texture creation for users with limited VR and 3D design experience, *GenVRTex* shows potential for broader use across industries. Future work should focus on enhancing sketching precision, enabling seamless multimodal transitions, and leveraging VR's spatial affordances for refining inputs and managing outputs in GenAI. Longitudinal studies with diverse user groups could further validate usability and creative support across contexts.

2 Related Work

This section reviews (1) GenAI tools for image generation, (2) VR interaction methods with a focus on text entry, (3) texture and 3D object creation in VR, and (4) GenAI integration into immersive authoring. We highlight how our work differs, particularly in enabling surface-level customization for novice users.

2.1 Generative AI Image Generation Tools

GenAI technologies specialize in generating new content, like images, text, videos, and music. Unlike traditional AI models, which often focus on prediction, classification, or optimization, GenAI produces human-like outputs using models such as Generative Adversarial Networks (Goodfellow et al., 2014), Variational Autoencoders (Kingma & Welling, 2022), Generative Pretrained Transformers (Radford et al., 2021), and Denoising Diffusion Probabilistic Models (Ho et al., 2020). These technologies are particularly valuable in creative domains, supporting ideation, streamlining workflows, and enabling novel outcomes. Tools like Midjourney and DALL-E generate images from text, sketches, or images but primarily rely on text-based input. However, studies with professional designers show that crafting effective prompts can be challenging, especially for visually oriented users (Park et al., 2024).

Efficient GenAI use requires precise prompt control, often achieved through iterative refinement. Oppenlaender (2023) proposed a five-step iterative optimization process (*define, modify, solidify, vary, and mix/exclude*) and six prompt modifier types, reflecting common practices in online text-to-image communities. Liu et al. (2022) analyzed over 5,000 generations, demonstrating how prompt keywords and parameters influence image coherence and offering practical design guidelines. Similarly, Pavlichenko et al. (2023) emphasized human-in-the-loop refinement by employing genetic algorithms to improve output quality.

Recent studies have explored visual interaction interfaces to reduce reliance on text. Chung et al. (2023) introduced slider-based controls to adjust prompts and parameters, improving intuitiveness. Feng et al. (2024) developed a visual prompt analysis tool to support refinement. These approaches highlight the challenge faced by less experienced users in text-centric GenAI tools, which often require trial and error. In response, this study adopts alternative interaction methods, such as sketch-based input for visually expressing design ideas and a text-prompt assistant powered by large language models (LLMs) to ease the difficulty of prompt crafting for novices.

2.2 Text Entry Interaction Methods in VR

Text entry in VR remains a significant challenge, particularly for GenAI systems that rely heavily on textual prompts. Despite advances in head-mounted displays (HMDs), VR still lags behind 2D interfaces in terms of text input efficiency and accuracy. While platforms like Meta offer physical keyboard integration, these setups are often stationary and can disrupt immersion. Research has examined various VR text entry methods. Speicher et al. (2018) compared head pointing, ray casting, tapping, and freehand tracking, finding that handheld controllers generally performed best, though effectiveness varied with user experience and task type. They also noted that most VR input guidelines are adapted from non-VR contexts with limited validation.

Speech recognition has emerged as a faster, more natural alternative. However, studies have identified frequent issues with accuracy, system delays, and user discomfort (Bowman et al., 2002). Users often adjust their speech to match the system response, reducing fluency. Still, speech interfaces are considered effective for learning-focused or long-form input tasks (WeiB et al., 2018).

To address the limitations of single-modal input, researchers have explored multimodal systems combining input methods such as speech, gestures, and controller-based input. These approaches aim to improve performance, usability, and user satisfaction by reducing cognitive workload (Bowman et al., 2004; Dumas et al., 2009; Oviatt, 2003). Studies show that combining speech with gestures can reduce perceived task duration and mental effort, especially in creative workflows (Wolf et al., 2019). Building on this prior work, we integrate speech input with both direct and ray-casting text entry to reduce reliance on typing. We also include sketch-based input to support visual thinkers and lower the cognitive and physical burden of text entry in VR, enabling more intuitive interaction with GenAI tools.

2.3 Texture Creation in VR

VR has emerged as a promising environment for design, offering immersive alternatives to traditional 2D workflows (Y. Wang et al., 2023; Wolf et al., 2019). It enhances enjoyment, immersion, and creative engagement through real-time interaction with full-scale 3D models (Bourgeois-Bougrine et al., 2022; Hagedorn et al., 2023). Unlike 2D tools such as mice or styluses, VR allows direct interaction, improving spatial awareness and creative flow (Y. Wang et al., 2023).

Previous research has explored 3D sketching (Jiang et al., 2021), mid-air sculpting (Fu et al., 2022), and transferring geometry or textures between objects (Yin et al., 2021). While these studies focus on creating and manipulating 3D forms, our work centers on designing 2D textures for pre-existing 3D models, especially for novice users with limited modeling experience. Unlike studies that emphasize system-level innovation or geometry editing, our research provides insights into immersive workflows for surface-level customization and proposes user-centered design guidelines to support intuitive texture creation in VR.

2.4 GenAI-Driven VR Authoring Tools

Recent research has explored integrating GenAI into VR authoring tools, enabling real-time content creation through multimodal inputs such as speech, typing, sketching, and gestures. Some studies focus on scene layout and object generation, supporting novice users in controlling object placement through these input methods (Aghel Manesh et al., 2024; Zhang et al., 2024). Others have examined GenAI-enabled workflows for terrain and object prototyping using sketches, gestures, or reference images (Wong et al., 2022). These approaches facilitate rapid prototyping by combining manual input with AI-generated suggestions and are particularly useful in early-stage design. While these studies demonstrate the potential of GenAI-VR integration, challenges remain in real-time performance, prompt effectiveness, and interaction fluidity—especially for detailed customization tasks.

Recent work has also begun to explore surface-level design. For example, one study (Watanabe & Cohen, 2024) applied AI-generated textures to furniture using text-to-image models and multimodal inputs such as speech and hand gestures, though it did not support visual inputs like sketching. To our knowledge, few systems have directly addressed texture-level customization in immersive VR with rich multimodal input designed for novice users. To address this gap, we present a GenAI-powered VR tool for surface-level customization of 3D car models. The system supports speech, sketching, and controller-based text input and includes an LLM-powered assistant for prompt creation. Unlike prior work focused on object modeling, layout, or early-stage design, our tool moves toward enabling relatively fine-grained texture creation and supports iterative workflows tailored to novice users in immersive environments.

3 Methodology

Our study employed a DSR approach to address a significant, unresolved problem by designing and developing a novel artifact (Hevner et al., 2004). DSR emphasizes both scientific rigor and practical relevance, using iterative cycles of design, evaluation, and refinement (Hevner et al., 2004; Jones & Gregor, 2007). We followed the five-phase DSR framework outlined by Kuechler and Vaishnavi (2008) (illustrated in Figure 1), which we applied in a user-centered and iterative manner. Each phase built on the outputs of the previous one, with development guided by domain expert input, relevant literature, and existing tools. The artifact was later evaluated with novice users to ensure it aligned with the practical interaction design needs and capabilities of users unfamiliar with VR-based texture creation.

Our research spanned eight months in collaboration with an automotive manufacturer based in Germany. Initial interviews with VR product managers and AI/data experts from the IT department helped us define the problem and guided the iterative development and evaluation of the artifact.

The **(1) Awareness of the Problem** phase began with a literature review on VR creation tools, interaction techniques, and GenAI models to identify current gaps. We supplemented this by analyzing existing GenAI-powered image generation tools, both within and outside VR. To further contextualize the problem, we conducted open-ended interviews with two VR product managers and four AI/data experts from the automotive sector to explore user needs, functional requirements, and potential use cases for GenAI in VR-based texture creation. While these experts provided advanced insights into the capabilities and limitations of current tools, they were also well-versed in the needs of novice users.

Their input informed design decisions aimed at making the tool more usable and accessible to non-experts.

During the **(2) Suggestion** phase, we formulated ten design guidelines (DGs), detailed in Table 1, based on insights from the literature, expert input, and evaluations of existing applications. These DGs formed the foundation of our tool, with the goal of enabling novice users to create high-quality, customized textures in VR. We distilled expert feedback into novice-oriented design principles that emphasize ease of use, intuitive interaction, and low learning effort. These guidelines informed the design of *GenVRTex*, with features adapted to meet the expectations of non-expert users.

In the **(3) Development** phase, the DGs from the previous stage guided the creation of *GenVRTex*, a GenAI-integrated VR texturing tool that incorporates both image generation and LLMs support. We engaged in an iterative refinement process, prioritizing usability and functionality for novice users in VR texturing. Throughout development, we actively collaborated with the industry experts involved in the Awareness of the Problem phase, organizing multiple review sessions to explore alternative design directions and drive continuous improvement. While the design was informed by expert input, we maintained our focus on ensuring that all features remained intuitive and accessible for novices.

During the **(4) Evaluation** phase, we conducted a qualitative study with nine professional designers (five female, four male) from the automotive industry, with 1 to 20 years of experience in UI/UX, graphic, and interior design. Although experienced in traditional design, participants had limited exposure to VR-based texture creation and GenAI tools, positioning them as novice users in this context. The study assessed the accessibility and usability of *GenVRTex* for its intended audience. Participants engaged in open-ended interviews to share their experiences with the tool. Their responses provided insights into usability challenges, including navigating VR interfaces, managing input methods, iterating with GenAI prompts, and interpreting generated outputs. Despite limited prior experience with GenAI and VR texturing, participants emphasized *GenVRTex*'s effectiveness in simplifying the process of texture creation for non-experts.

In the **(5) Conclusion** phase, we synthesized evaluation findings to assess the tool's effectiveness and the relevance of the design guidelines. We also reflected on broader implications for GenAI-VR integration and identified directions for improvement. Finally, we discussed the study's implications for research and industry, highlighting key contributions and opportunities for future work.

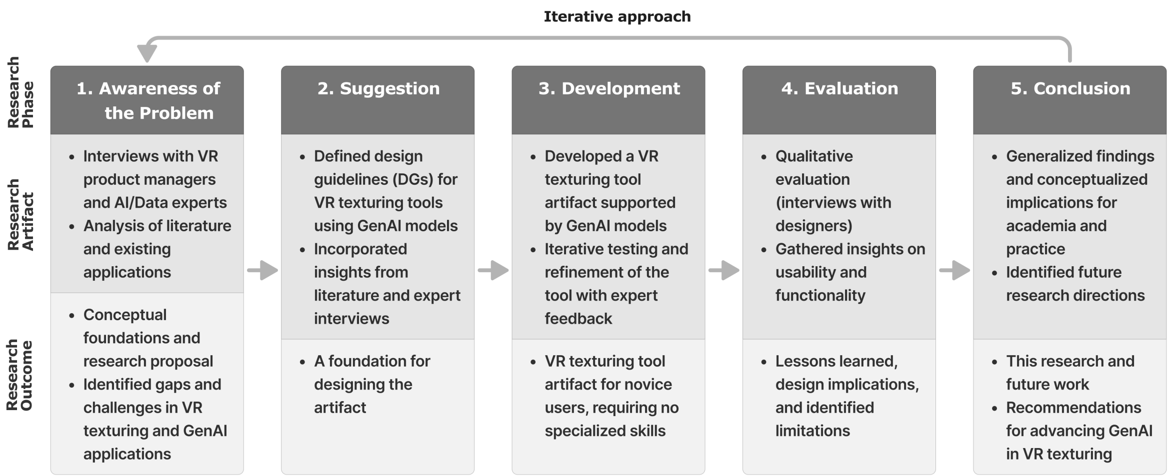

Figure 1. ***Design Science Research (DSR) Model Adopted from Kuechler & Vaishnavi (2008):*** *This model illustrates an iterative approach encompassing problem definition, suggestion, development, evaluation, and conclusion phases.*

4 Design Guidelines for a GenAI-Based VR Texturing Artifact

Based on interviews, literature, and analysis of existing tools, we defined ten design guidelines (DGs) across three categories to guide the development of *GenVRTex*. As detailed in Table 1, these DGs served as the foundation during the Development phase. The proposed guidelines synthesize insights from HCI, GenAI prompting, and VR interaction studies tailored to image generation in immersive environments. Designed for novice users, they support spatial, multimodal workflows and offer transferable design knowledge for future GenAI-VR tools.

Category	ID	Design Guidelines (DGs)
User Interaction in VR	DG1	Enable Multimodal Input in VR Environments
	DG2	Provide Options for Direct Interaction with 3D Objects
Prompt Control	DG3	Incorporate Predefined Modifiers, such as Art or Artist Styles
	DG4	Facilitate Prompt Refinement with a LLM (Magic Prompts)
	DG5	Integrate Drawing Input for Visual Thinkers
	DG6	Enable Review and Management of Past Work (History Tracking)
	DG7	Support Iterative Image Generation from Previous Results
Texture Creation	DG8	Enable Real-Time Texture Projection on 3D Objects
	DG9	Support Texture Positioning and Rotation
	DG10	Provide an Overview of Created Textures

Table 1. ***Ten Design Guidelines (DGs) for Our GenAI-Based VR Texturing Artifact:*** *This table provides a concise overview of DGs across three categories: User Interaction in VR, Prompt Control, and Texture Creation.*

4.1 User Interaction in VR

DG1: Enable Multimodal Input in VR Environments: To address the text input demands of GenAI, we support multimodal input, including virtual keyboards, speech, and sketching. Speech offers efficient, natural communication, while drawing improves accessibility for visually oriented users. This aligns with multimodal research showing that combined input methods enhance usability and reduce cognitive load in immersive environments (Martin et al., 2022; Oviatt, 2020).

DG2: Provide Options for Direct Interaction with 3D Objects: We implemented image-to-image models that allow users to create textures from drawings directly within VR. Users can interact with and modify real-scale 3D objects, enhancing spatial awareness for accurate texture placement. Handheld drawing tools, color palettes, and repositionable menus support intuitive interaction and control. This reflects HCI principles of direct manipulation, which enhance spatial understanding and learnability in immersive environments (Billinghurst et al., 2015; Bowman et al., 2004; Shneiderman, 1983).

4.2 Prompt Control

DG3: Incorporate Predefined Modifiers, such as Art or Artist Styles: Predefined modifiers help simplify prompt creation and reduce typing effort for novice users (Chang et al., 2023; Oppenlaender, 2023). This approach supports the HCI principle of "recognition over recall" (Norman, 2002), which decreases cognitive load by allowing users to select rather than generate input from memory. This is particularly useful in GenAI systems that often require multiple rounds of trial and error.

DG4: Facilitate Prompt Refinement with a Large Language Model (Magic Prompts): Extending DG3, we propose using LLMs to generate refined prompts, referred to as *magic prompts*. These help align outputs with user intent while reducing the cognitive and physical effort required for text input in VR. This feature, already implemented in commercial tools like Ideogram and Visual Electric, is supported by HCI and GenAI research demonstrating its benefits for improving prompt quality, reducing trial and error, and enhancing user satisfaction (Brade et al., 2023; Park & Eiband, 2024; Z. Wang et al., 2024).

DG5: Integrate Drawing Input for Visual Thinkers: Drawing is often more intuitive than text for visually oriented users (Park et al., 2024). VR experts also recommended enabling sketching directly on 3D objects, noting that even simple sketches can convey design intent and reduce reliance on text input. Supporting this feature enhances accessibility and creative workflows for visual thinkers.

DG6: Enable Review and Management of Past Work (History Tracking): GenAI workflows often involve trial and error (V. Liu & Chilton, 2022; Park et al., 2024). A *history tracking* feature, as explored in recent studies (Brade et al., 2023; Z. Wang et al., 2024), allows users to review and manage previous outputs. This supports progress tracking and enables users to branch from earlier results, as further discussed in DG7.

DG7: Support Iterative Image Generation from Previous Results: Building on DG6, this functionality allows users to generate new outputs based on prior results, allowing variation without re-entering prompts. It supports exploratory workflows and aligns with HCI and creative tool principles that emphasize iterative refinement and user control (Shneiderman, 2007; Z. Wang et al., 2024).

4.3 Texture Creation

DG8: Enable Real-Time Texture Projection on 3D Objects: Real-time projection lets users preview and refine textures directly in VR, providing visual feedback that traditional 2D tools and pre-designed skins often lack. This supports efficient evaluation and aligns with usability heuristics emphasizing immediate feedback and visual confirmation (Nielsen, 1994; Norman, 2002; Shneiderman, 2007).

DG9: Support Texture Positioning and Rotation: Adjusting the position and rotation of textures is essential for creative flexibility, allowing users to fine-tune placement without regenerating outputs. This approach is grounded in direct manipulation principles that emphasize continuous feedback and reversible actions to support exploration (Shneiderman, 1983) and reflects the importance of fine-grained spatial control in 3D user interfaces (Bowman et al., 2004).

DG10: Provide an Overview of Created Textures: Efficient VR texturing requires quick access to prior outputs. We propose a visual catalog to browse, organize, and manage textures, with options to favorite or delete. This streamlines workflows and reduces cognitive load by enabling quick retrieval, consistent with research on workspace organization in immersive tools (Bowman et al., 2004; Shneiderman, 2007). It also supports versioning practices, allowing users to revisit and build on previous results.

5 Instantiation of *GenVRTex*: A GenAI-Driven VR Texturing Tool

Guided by our DGs and developed through an iterative design process, we created *GenVRTex*, a VR texturing tool powered by GenAI models, including text-to-image, image-to-image, and LLMs. This section presents the tool's interface and explains how its features align with corresponding DGs.

5.1 User Interface Overview

GenVRTex enables users to create customized textures for 3D objects using GenAI. Textures can be generated through text prompts, sketches, or a combination of both. The interface includes a VR keyboard, accessible via ray interaction or speech input, and supports sketching directly on 3D models or a virtual 2D canvas using ray or handheld tools. As illustrated in Figure 2, the interface includes (1) the image panel view, (2) the prompt input field view, (3) the advanced menu view, and (4) the expandable 2D canvas panel. Additional features include an assistant menu for (5) drawing tool selection with color and brush-width options, (6) new canvas creation, (7) texture position adjustment tools, (8) texture rotation options, and (9) a handheld menu for quick color and brush-width adjustments. The following sections detail each menu and its functionality.

(1) Image Panel View: Displays generated images with navigation controls for browsing, favoriting, deleting, or creating variations (DG6, DG7).

(2) Prompt Input Field View: Allows text input through a virtual keyboard or voice commands (DG1). The *Create* button generates textures, while *Create from Images* combines text and sketches.

(3) Advanced Menu View: Offers extended features, including:

- ***ChatGPT*:** Refines and expands prompts (DG4).
- ***Style*:** Applies predefined modifiers such as art styles or artist names (DG3).
- ***Favorites*:** Stores selected images for reuse, review, or inspiration (DG10, DG7).

(4) 2D Canvas: Enables sketching on a virtual canvas that simulates real-world drawing (DG5). Users can combine sketches with prompts and preview textures with position and rotation controls (DG9).

Figure 2. ***User Interface Overview of GenVRTex:*** *The menu panel is structured into several sections, each serving distinct functions: (1) the image panel, (2) the prompt input field, (3) the advanced menu, which includes ChatGPT, style selection, and the favorite collection, (4) the 2D canvas, (5) the color and brush-width menu, (6) the new canvas menu, (7) texture movement, (8) rotation, and (9) the handheld color and brush-width menu for direct drawing on 3D objects.*

(5) Color and Brush Menu: Features a color-picker and adjustable brush widths for precise drawing.

(6) New Canvas Menu: Clears the current canvas, allowing users to start fresh with a blank workspace.

(7) Texture Movement and (8) Rotation: Enable users to adjust texture positioning on 3D models by moving them vertically or horizontally and rotating them using sliders and arrow icons (DG9).

(9) Handheld Color and Brush Menu for Direct Drawing Interaction: Enables real-time texture projection (DG8). Users can adjust color and brush width while drawing directly on 3D models (DG2).

5.2 System Implementation

The system was built using Unity 2022.3.17 and supports Oculus Quest 2 and Quest Pro, providing a fully immersive experience for VR-based texture design. GenAI features are powered by the Stable Diffusion API (v3), supporting text-to-image and image-to-image generation. ControlNet models, including segmentation, lineart, and scribble, further enhance the image-to-image process. The segmentation model targets specific object areas, such as a car's hood or side mirrors, for precise texture application. The lineart model processes detailed sketches, while the scribble model transforms rough drawings into stylized textures. Prompt refinement is supported through OpenAI's GPT-3.5 Turbo API, labeled *ChatGPT*, for user familiarity. This helps users iteratively enhance textual descriptions, enabling more detailed and specific prompts. Voice input is enabled via the OpenAI Whisper API, allowing hands-free operation and easing text entry in VR environments.

6 Evaluation

We conducted a qualitative evaluation to assess the usability and effectiveness of *GenVRTex*. The study involved nine designers from the automotive industry (five female and four male) with expertise in UI/UX, graphic design, and interior design and between 1 and 20 years of experience. While participants were skilled in traditional design, most had little or no experience with VR texturing or GenAI tools, positioning them as relevant users for evaluating the tool's accessibility and usability in this context. Participants were introduced to the system, its interfaces, and basic GenAI prompting. They were guided through using the VR headsets and controllers and navigating the VR environment. During the session, participants were free to ask questions or request clarification, and their behaviors were observed. Each session concluded with an open-ended interview to gather in-depth feedback.

6.1 Text Entry Methods

Participants explored two text input methods: the VR keyboard and speech input. Most preferred voice commands during use, citing greater efficiency and reduced physical effort. However, for real-world GenAI use on 2D interfaces, many favored keyboard input due to familiarity and faster typing speed. Although typing on a virtual keyboard was generally slower and more effortful, some participants still preferred it for reasons such as privacy, particularly when others were present, and the ability to revise inputs before submission. One participant remarked, *"With voice input, I feel pressured to get the entire prompt right in one go, which isn't always easy."* This feedback supports DG1 by confirming that multimodal input options are valued for accommodating different usage contexts and balancing efficiency with control, comfort, and privacy.

6.2 Drawing vs. Textual Prompts

Initially, most participants relied on textual prompts using the virtual keyboard or voice commands, finding them more straightforward while adjusting to the VR interface. In contrast, drawing required more precise coordination, including brush and color selection, as well as familiarity with VR menu controls and navigation, which increased the learning curve. One participant noted, *"This is my first VR experience. I needed time to learn to use the controller to move around the car and draw on it."*

Drawing directly on the large, curved 3D car model presented further challenges. Participants suggested features such as model resizing and rotation to improve focus and control. One participant stated, *"I would like to resize it and place it on a virtual desk so I can work on it as I do in the real world."* Several also requested more granular drawing tools, including brush types, sizes, and texture presets. One designer remarked, *"It feels harder to be precise here than using traditional drawing tools."* These findings affirm the value of DG2 and DG5 while highlighting the need for improved spatial flexibility and more precise, easily controllable drawing tools to better support novice users in VR-based drawing interactions.

6.3 Prompt Creation

Seven participants had some prior experience with GenAI tools such as Midjourney, DALL-E, or Adobe Firefly but often felt that the images generated did not fully meet their expectations. Most relied on short, simple prompts due to difficulties in crafting detailed inputs, which were further compounded by the limitations of VR text entry. A few participants experimented with longer, more complex prompts using the *ChatGPT* menu, though their satisfaction with the results varied and was not consistently tied to prompt complexity. While predefined modifiers were considered helpful, they did not always align with participants' creative intent, echoing challenges observed in non-VR GenAI tools (V. Liu & Chilton, 2022; Oppenlaender, 2023). Participants also valued the ability to revisit previously generated images, noting that it helped them track progress and explore variations without starting over. These observations support DG3 and DG4, demonstrating the value of prompt-assistance features but also highlighting the need for more adaptive refinement tools, particularly for users unfamiliar with GenAI or lacking confidence in textual expression. They also underscore the relevance of DG6, showing that history tracking plays a key role in supporting iterative creative workflows.

6.4 Texturing in VR

Participants raised concerns about applying large, single images as textures on 3D car models, as distortions frequently occurred on curved surfaces. For example, displaying a Barbie doll image led to a noticeable warping of facial features such as the eyes and nose. To address this, one participant suggested using smaller, repeated patterns (e.g., wallpaper-style textures), which were perceived as a more visually coherent solution for covering large areas. Image distortion remains a common challenge when applying textures to curved 3D surfaces in VR. Techniques such as adaptive UV mapping or custom projection methods could help reduce distortion and are considered for future development. Participant feedback underscores the relevance of DG8 and DG9 and highlights the need for improved texture handling, especially for complex surface geometries.

6.5 Summary of Findings

Participants appreciated the tool's multimodal input options. Voice input was preferred for efficiency, while the keyboard was favored in contexts requiring greater control or privacy. Text prompts were initially more accessible, particularly for those new to VR, while drawing features were limited by navigation complexity and a lack of precision. Predefined modifiers were helpful for getting started, but participants expressed a need for more flexible and adaptive prompt refinement. The ability to revisit generated images was also valued, supporting an iterative workflow. For texturing, participants noted distortion issues when applying large images to curved surfaces and suggested repeated patterns as a more visually consistent alternative.

These findings validate key design guidelines while also revealing areas for improvement. On the GenAI side, enhancements should support more accessible prompt entry, improved output management, smoother iterative refinement, and better ways to express intent beyond text input. VR-specific capabilities, such as spatial interfaces for history tracking, visual feedback, and intuitive control through gestures, eye gaze, or sketching, could help address these challenges. On the VR side, improvements in spatial navigation, drawing precision (through controller or hand tracking), and texture handling on complex surfaces are needed. Overall, these insights emphasize the need for integrated, user-centered systems that seamlessly bridge GenAI content generation and immersive VR interaction.

7 Discussion

This study focused on designing and evaluating a GenAI-based VR texturing tool to assist novice users in customizing 3D objects in immersive environments. Using a Design Science Research methodology, we developed and evaluated *GenVRTex* with feedback from nine automotive industry designers. The results demonstrated that the tool is usable and effective, helping users with limited VR or texturing experience complete complex tasks.

Key insights from development and evaluation highlight strategies for integrating GenAI into VR workflows, including drawing directly on 3D objects, managing text input, and refining prompts iteratively. Unlike prior VR creation tools (Fu et al., 2022; Jiang et al., 2021), our system integrates 3D object interaction with GenAI-driven text and image generation, supporting diverse input methods, including voice, keyboard, and sketching on both 3D models and 2D canvases. The design guidelines accommodate these modalities with a focus on supporting iterative workflows in immersive contexts.

This work contributes to theoretical frameworks in HCI and DSR by integrating iterative GenAI prompting with multimodal VR inputs specifically tailored for novice users. Our study extends existing theory by addressing the practical challenges novices face when using multiple input modalities—drawing, speech, and keyboard—in immersive environments, along with the complexity of text-prompted content creation and iterative refinement. The resulting principles offer concrete guidance for building GenAI-supported creative tools in VR and contribute to theory in immersive interaction and novice-centered GenAI design.

7.1 Insights from User Interaction with GenAI in VR

Participants strongly favored speech input over virtual keyboards for its efficiency and reduced physical effort, aligning with GenAI's reliance on text-based prompts. However, keyboards were preferred in situations requiring privacy or more precise editing. Future research could explore alternatives such as handwriting recognition, physical keyboard support, or AI-assisted interpretation of incomplete prompts to improve accessibility. Managing prompt histories and iterative outputs was another common challenge. VR's spatial affordances offer promising solutions, such as allowing users to organize and compare outputs in virtual space (Zhang et al., 2023). Features that support spatial arrangement and visual review could enhance exploratory workflows. Additionally, collaborative features that enable co-creation and shared refinement may further improve usability and creative potential (Nebeling et al., 2020).

7.2 Challenges in Texture Creation in VR

Creating textures on large, curved 3D surfaces, such as car models, remains challenging. Participants noted that ray-casting controllers limit precision and suggested features such as adjustable brush types, sizes, and texture options. They also recommended integrating handheld brush tools or hand tracking for more precise control. Features like resizing, rotating, and zooming 3D objects were viewed as essential for detailed work. To avoid distortion on curved surfaces, participants preferred smaller, repeated patterns, which offered a more cohesive aesthetic than single large images. Customizable pattern layouts and scaling were also recommended for greater design flexibility. Some participants observed that VR offers distinct advantages over traditional 2D interfaces, particularly for spatial tasks involving 3D objects. The immersive nature and intuitive interactions in VR support detailed design work that is less feasible in 2D environments. Integrating multimodal inputs, such as sketching and gestures, into GenAI workflows was viewed as a way to increase usability and creative potential. As GenAI evolves to better support multimodal interaction, these integrations could significantly enhance VR-based texture creation.

8 Limitations and Future Research

This study has several limitations that inform directions for future research. First, *GenVRTex* was evaluated within the IT department of a single automotive company. While this provided relevant use cases for vehicle customization, the findings may not fully generalize to other industries or user groups. Future research should explore broader domains, such as gaming, architecture, or fashion, to assess broader applicability. Second, all evaluation feedback was collected immediately after use. While this captured valuable first impressions, it did not account for long-term learning or sustained usage. Longitudinal studies could provide deeper insights into learning curves, sustained usability, and the tool's long-term impact on workflows. Third, although designed for novice users, participants were professional designers with limited experience in VR or GenAI. While they reflected the target audience to some extent, future studies should include more diverse participants, including those from non-design and non-technical backgrounds, to evaluate accessibility and usability across broader user groups. Additionally, domain experts were recruited from the same organization, which may introduce contextual bias. While this ensured relevance to domain-specific workflows, it may limit generalizability. Future evaluations should involve participants from diverse organizational and cultural settings to strengthen broader applicability. We also acknowledge the difference in participant roles across phases: industry experts contributed to early design, while novice users participated in the evaluation. Expert input helped define system goals, and novice needs were addressed through design abstraction and literature-informed translation. Future work could involve both groups throughout development to enable more iterative, user-centered refinement. Lastly, the study relied on qualitative methods, such as interviews and observations, which provided rich insights but limited statistical generalizability. Incorporating quantitative metrics, such as task completion time, interaction accuracy, and satisfaction scores, would allow for more robust evaluation and broader comparisons.

Future research should focus on improving GenAI interaction in immersive environments. Key areas include refining prompt control, enhancing output management, and supporting more seamless iterative workflows. Leveraging VR's spatial affordances for visualizing input/output history and enabling fluid transitions between text, sketch, and gesture input could further improve usability and creative expression. As GenAI continues to evolve, tools like *GenVRTex* can be extended to support more personalized and adaptable design workflows across domains.

9 Conclusion

This study introduced *GenVRTex*, a GenAI-driven VR texturing tool developed using the Design Science Research approach. The system enables users to generate textures through text prompts, entered via virtual keyboard or voice, and drawing inputs applied either directly on full-scale 3D objects or on a 2D canvas-style interface. To explore user interaction with text input, sketching on 3D objects, and control over GenAI models, we outlined ten design guidelines spanning user interaction, prompt control, and texture creation in VR. Developed in collaboration with an industrial partner, the tool incorporated expert input in VR and AI/data. A qualitative evaluation with nine designers who had limited experience with VR texturing or GenAI confirmed the tool's usability and practicality while also identifying areas for improvement. Overall, the feedback validated *GenVRTex*'s effectiveness in supporting texture creation in VR. Theoretically, this study contributes design guidelines that integrate iterative GenAI prompting with multimodal interaction in VR, specifically tailored for novice users. These guidelines extend existing frameworks in HCI and VR by addressing gaps in input diversity, prompt refinement, and support for creative workflows. *GenVRTex* demonstrates how GenAI can assist novice users in immersive design contexts, contributing to theories of multimodal interaction, user-centered creativity, and iterative content generation. Although developed for automotive design, the tool shows potential for broader application in domains such as gaming, architecture, and education.

Future research should expand *GenVRTex's* applicability by involving more diverse user groups and evaluating it across various industries. Enhancements such as gesture-based controls, smoother transitions between input modes, and improved multimodal support could further reduce cognitive load and enhance creative expression. Continued exploration of GenAI-VR integration may improve prompt refinement, output visualization and management, and history tracking by leveraging VR's spatial and immersive capabilities. These advancements could strengthen *GenVRTex*'s value as a tool for researchers and practitioners in VR texturing, GenAI, HCI, and related fields.

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