Designing External Automotive Displays: VR Prototypes and Analysis

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Figure 1: External automotive display design: sketches from design study, and example of VR prototypes

ABSTRACT

Our work extends contemporary research into visualizations and related applications for automobiles. Focusing on external car bodies as a design space we introduce the External Automotive Displays (EADs), to provide visualizations that can share context and user-specific information as well as offer opportunities for direct and mediated interaction between users and automobiles. We conducted a design study with interaction designers to explore design opportunities on EADs to provide services to different road users; pedestrians, passengers, and drivers of other vehicles. Based on the design study, we prototyped four EADs in virtual reality (VR) to demonstrate the potential of our approach. This paper contributes our vision for EADs, the design and VR implementation of a few EAD prototypes, a preliminary design critique of the prototypes, and a discussion of the possible impact and future usage of external automotive displays.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

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1 INTRODUCTION

Progress in automotive display technology offers opportunities for innovative designs. Researchers and manufacturers have explored different in-car display technologies such as stereoscopic 3D displays [26], heads-up displays [13], interactive dashboards [2], and windshield displays [8]. Vehicles' exterior surfaces are also considered as potential design spaces [3, 4]. In our research, we explore automotive displays, which include informative visualizations and interactive designs for use on the external surfaces of automobiles.

Currently, the external surfaces of cars share visual information through vehicle lights, license plates, promotional decals, and custom detailing [22]. Research comparing information sharing between manually driven cars and autonomous vehicles (AVs) provides new information about the operation of visual information between cars, and from vehicles to users and pedestrians [4, 7]. The automotive industry is interested in new applications in the area as indicated by the Mercedes F015 and Nissan IDS which use simple external visualizations to take advantage of this new design space [1]. The former uses displays mounted in the rear and sidewalls of the car to exchange information between vehicles, passengers, and the outside world, while the latter uses an LED display to send visual cues to provide awareness and intent to the pedestrians while crossing the roads in an approach called the "smiling car concept" [1]. Much of this work focuses on AVs where information sharing between cars and pedestrians is crucial, but our research suggests that external automotive displays (EADs) may provide opportunities for all types of vehicles and traffic conditions.

Across the automotive sector, researchers and industry professionals are exploring window displays for use in applications that provide location-specific advertising, general information, vehicle to pedestrian communication, and informal greetings [6]. Recently, the location-based digital advertising platform called "Grabb-It" played advertisements on cars' rear windows [15]. Toyota's interactive window displays content such as weather, calendars, to-do lists, and vehicle status [21]. Some works [4, 8] have studied information transmission between cars, drivers, passengers, and pedestrians and have presented design spaces for external displays on cars where windshield-based applications were focused on [8]. Our work builds on these current research by explicitly focusing on the external side bodies of the car as a design space. In our work, we design and prototype interactive visualizations for external car bodies including the side windows. Using a participatory design study with 5 interaction designers, we conducted a qualitative analysis of our design studies, using those results to create 4 prototypes for exploration in VR environments that test variables in-vehicle state (moving or parked), vehicle type (private or publicly owned), and user experience.

This paper contributes: (1) a design study exploring the EADs' usage cases; (2) VR prototypes demonstrating and implementing several of our EAD approaches, supporting potential services to pedestrians, passengers, and drivers of other vehicles in a variety of traffic conditions; and, (3) findings from a preliminary design critique of the EADs VR prototypes.

2 RELATED WORKS

Our work draws on research from three domains: 1) interactive window designs targeting passengers' in-car experience produced by the automotive industry; 2) scholarly research into windshield applications for passengers and drivers; and, 3) studies dedicated to external car displays for drivers and pedestrians in traffic. Each area offers distinct contributions, but all share a commitment to balancing improved experiences with the safety implications of user distraction.

Automotive and related industries continue to explore innovative concepts for windows (internal), windshields (external), and external autobody displays. In 2011, Microsoft promoted the idea of a smart taxi with a side-window display that shares contextual information such as time and destination [17]. In the same year, Toyota's "Window to the World" concept envisioned an interactive car window that allows passengers to interact with passing scenery [11]. The window is a touchscreen, allowing riders to trace the outdoor scenes with the option to zoom in on distant objects. In 2012, General Motors, in conjunction with Israel's Bezalel Academy of Art and Design presented the "Window of Opportunity" [24]. Their project aims to connect passengers with the external environment through the window by providing the ability to draw on the screen, download and share music, and view other users' windows in real-time. A static prototype with two external projectors displaying outdoor scenes and projecting content illustrates their concept.

Scholarly research such as Li et al. [16] presented a concept iWindow that explores internal interfaces testing for engagement and distraction. iWindow's three interaction phases provide: 1) calendar notifications; 2) always-on widgets for elements such as time and weather; and, 3) interactive contextual applications with information about external surroundings. Additional work, such as that by Chou et al. at Toyota Motors, investigates the use of windshields for vehicle and user identification [21]. A study on mixed-reality screens produced a prototype that offers a rich experience focused on passengers [9]. Extending the windshield's design space to provide services to drivers, passengers, and pedestrians, Haeuslschmid et al. [8] include applications inside and outside the vehicle offering applications such as driver-monitoring, vehicle status, navigation, public displays, and social interaction.

Moving beyond glass surfaces and vehicle-specific users, external autobody applications extend the potential for visualization with an emphasis on safety. Much of this work comes from research on autonomous vehicles where public engagement is crucial. Dey et al. use elements such as light strips, trackers, and countdown timers on bumper and body displays to communicate intent to pedestrians [5]. Mahadevan et al. deploy LED strips on windshields to support pedestrians wishing to cross the road [19]. Their PICTIVE method studies different interfaces that communicate awareness and intent to inform decision-making. This work informs our approach to design sessions used to ideate and sketch concepts for external automotive displays for different purposes and contexts. Recent work using VR to design external interfaces for AVs provided us with models for prototyping and testing our work. Mahadevan et al's VR pedestrian simulator studies AV-pedestrian interaction in mixed traffic conditions by varying traffic and street characteristics and studying the behavior of virtual pedestrians [18]. Their findings indicated that VR simulators can be a powerful tool to evaluate interfaces for communication between vehicles and pedestrians. In their work on external car displays (ECDs), Holländer et al. [10] use three visualization concepts to inform pedestrians: 1) a smiling grille; 2) traffic light indicators; and, 3) a gesturing robotic driver. By implementing visual cues to instruct and communicate the vehicle's intent with pedestrians while crossing this work productively studies the influence of ECDs using VR. Following this model, our designs and prototypes for EADs are tested in VR. The work presented by Colley et al. [4] informs our approach to the research environment by developing a design space for external car surfaces that includes display areas, interaction methods, and contextual factors designed to improve pedestrian safety through communication between AVs and pedestrians. Later they [3] extended their conceptual design work with evaluations of use cases of exterior

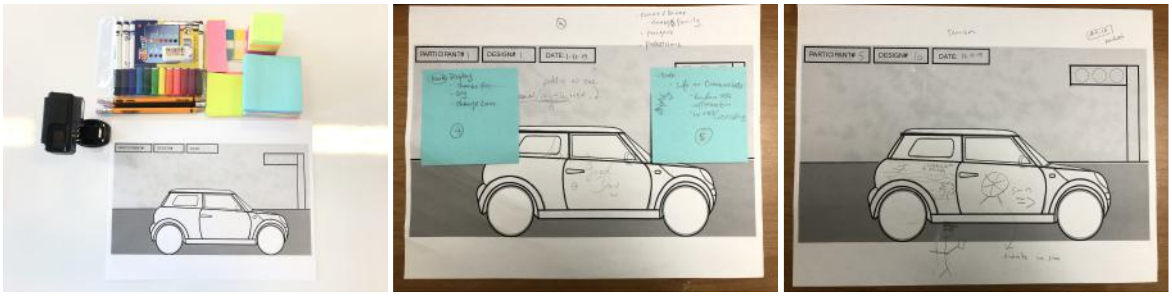

Figure 2: Study environment with the initial sketch showing vehicle's side body (left), example sketches of participant-created designs on vehicle's external display: (middle) displaying public services (P1), (right) displaying contents to tourists (P5).

displays on cars based on the design space they develop in their previous work. Handheld projectors provide sample content on the surface of a car. Participants in two focus groups positively responded when offered information such as notifications about nearby pedestrians or cars, navigation guidelines, vehicle emissions, and fuel consumption.

Our work builds on these works by testing different interfaces on EADs to provide visualization and interaction experience to different road users. We explicitly consider external side displays primarily for the benefit of the road users- pedestrians, passengers, etc. Our research contributes to this growing body of work through a systematic exploration of new interactive design opportunities on car's EADs. We first explore what interactive visualizations can be designed on EADs to provide services to the road users. Then, we implement a few prototypes of both visual and interactive interfaces in a VR environment with driving and parked car scenes. We present a design critique to assess the importance of these interfaces in improving the road user's experience with vehicles by providing interactivity and information richness.

3 EXTERNAL AUTOMOTIVE DISPLAY STUDY

We conducted a preliminary design session exploring external visual and interactive displays to understand how users might engage with them. We recruited five participants (2 male, 3 female) with an age range between 20 and 35. Education levels varied from senior undergraduate to doctoral students, all with interaction design experience. We adapted the PICTIVE (Plastic Interface for Collaborative Technology) participatory design method to conduct the study [20]. We chose PICTIVE because it enables participants to express ideas visually through simple sketches and or textually with labels. Each participant received a design sheet with an initial sketch of a vehicle's side body to support their designs. We also supplied pens, pencils, tape, and sticky notes (see Figure 2, left). Sessions were conducted with each participant individually and lasted approximately 60 minutes. At the beginning of each study, we briefly explained our proposed concept by sharing some ideas of interactive vehicle windows from the relevant literature. Each session was divided into two phases; a design phase for sketching interfaces, and an interview for discussion and reflection. In both sessions, participants were asked to ideate the interfaces from the perspective of different road users such as pedestrians, passengers, drivers, or vehicle owners.

3.1 Study Procedure

In the initial design phase, participants were asked to reflect on what they wanted from external automotive displays and given 30 minutes to sketch simple interfaces on a design sheet we provided. Participants were invited to create labels and/or sketch directly on the sheet. We suggested that participants consider the vehicle's external surfaces as passive or interactive display surfaces which might sense gesture or touch. Participants were free to draw interface designs on any part of the car. We encouraged participants to add notes that captured their process by using Riitta Jääskeläinen's "think-aloud protocol" [12].

In the first phase, no specific scenarios or conceptual labels were provided to enable open-ended exploration and ideation without restricting or biasing the participant. However, in the second phase (interview session), we decided to provide a set of limited scenarios generated during our brainstorming session to collect more focused design ideas. During an interview session, we presented participants with six scenarios where different users might interact with the EADs on a vehicle: 1) a pedestrian is crossing the road in presence of AVs; 2) the vehicle is driving through a location (e.g., city, tourist area, beach, etc.) with pedestrians on a nearby sidewalk; 3) the car is parked in a parking lot; 4) a passenger is riding in a car and can see the target car's external display; 5) different types of vehicles (private car, taxi, truck, bus, EMS) are in surrounding traffic; and, 6) multiple cars are on the street and have integrated displays. Though exploratory in nature and limited in scope, these example scenarios were chosen to enable reflections on diverse EADs usage cases. We asked participants to discuss how the interfaces they designed in the earlier phase would handle each scenario. They could then modify their designs or create new ones if they wished. We suggested conceptual labels to see how our participants might incorporate them into their designs. These concepts included visual cues to a pedestrian crossing the street, basic information (e.g., time, weather), maps of possible destinations, stylistic themes (video, animation, or other content related to points of interest), tourist help, emergency help, and communication with other vehicles.

We collected both the participant-created initial sketches from the design phase and the adjusted or newly created sketches from

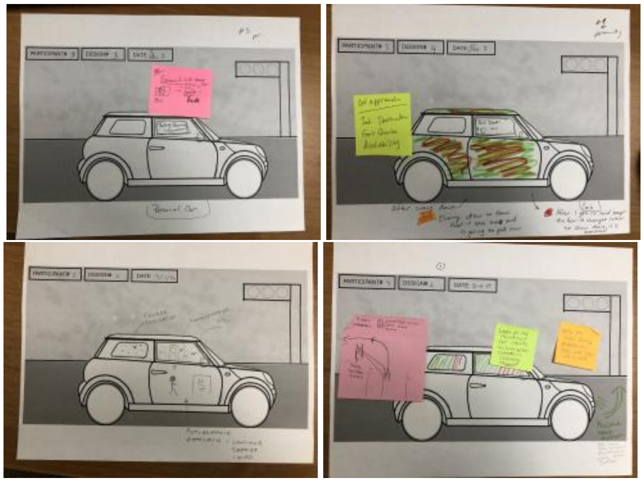

Figure 3: Example sketches of participant-created designs on vehicle's external display: (top-left) displaying car diagnosis, security information to owner (P3), (top-right) an app interface for taxi (P3), (bottom-left) displaying a pictographic approach to interaction with outside road users (P2), and (bottom-right) a sketch showing the visual cues for a 4-way intersection in presence of AVs (P4).

the interview phase of the study. We also collected video recordings of the study sessions. An open-coding method [14] was used to conduct a qualitative analysis of the material. Some of the common threads we identified were "providing public services," "identifying rides," and, "services for passengers."

3.2 Results

We collected in total of 31 separate designs. Most designs present different services for pedestrians, passengers, vehicle owners, or drivers. Interfaces came in two kinds - i.e., visualization of information or interactive external displays cars. Most favored location-based contents for public service. In total, 11 designs out of 31 featured public services for pedestrians on the sidewalk. In these designs, the followings were most common: displaying weather, current time, announcements/breaking news, general advertising, localized offers for restaurants or grocery stores, current location display, and maps of nearby attractions, event sites or, parks. Some suggested personalized displays such as greetings or emojis. According to most participants, tourists or new arrivals might benefit from visualizations designed to help find nearby attractions or events, offer food suggestions, and maps designed to help navigate from the vehicle's current location to their destination. Figure 2 shows sample sketches, with the middle image showing an interface created by P1 displaying public services (random greetings, announcements), and an interface sketch by P5 on the right targeting tourists with event information, and images of local attractions.

When designing visual interfaces for cars, participants preferred using images, text, and video. While ideating, participants considered the vehicle's state (moving/at rest) as an essential factor in what and when to display. They preferred large text and icons for visual interfaces on moving cars indicating this approach would be both more aesthetically pleasing and more accessible for pedestrian to comprehend. Interactive interfaces were only suggested for cars that were not in motion. When considering touch displays for interacting with items such as maps or public services, participants suggested visualizations should appear on public rather than private vehicles. P3 said, *"As an owner, I wouldn't want other people to come up and touch my car"*. These outcomes of our study aligned with Colley et al.'s work on the contextual design for such visualizations [4].

Participants suggested interactive interfaces for personal cars to enrich user-experience with Figure 3 (top-left) illustrating a side body example. Most suggested this approach could provide useful diagnostics such as the need for oil, fuel or recharging. Additionally, they suggested an authentication interface that could replace a physical key, and a location-recording function to improve local navigation and personal safety. For users inside the car, P3 added, *"displaying some info inside makes more sense"*. We also gathered design interfaces for public fleets such as taxis, Uber, or other ride-sharing services. Participants wanted to display red (reserved) and green (available) on the sides of the vehicles to indicate availability. Two participants suggested an app interface that could synchronize the car's display with personal mobile device for ride-share verification. Figure 3 (top-right) shows P3's example of such a solution for taxis.

The participants designed 11 EADs interfaces that were aimed at helping passengers. Participants suggested casual interactions such as symbols that reduce language barriers (Figure 3, bottom-left), virtual gestures, and simple text. Two participants wanted to display "danger alert"(flashing red) for emergencies. When considering scenario 4, where the passenger is riding in a car and sees another car's display, some mentioned public services such as location-based ads; however, two participants spoke against such an approach with P1 saying, *"I would not like to see other car's display as maybe they are not driving at the same speed"*.

Finally, for scenario 1 where pedestrians interact with the vehicle's EADs while crossing roads in presence of autonomous vehicle, we received designs featuring visual cues to support this action. We considered this scenario to explore explicit use cases of EADs for AVs. Simple visualizations such as red/green color, approach/do not approach messages, time remaining to cross, and common walk/stop symbols were identified. Participants also pointed out that the timing of such messages would be critical since they could be difficult to see once in the crosswalk. Most participants suggested front displays when pedestrians are already crossing the road; however, P4 noted that side body displays might still be effective in 4-way intersections. P4 also suggested turn-indicating information as shown in Figure 3 (bottom-right).

4 DESIGN: INTERFACE PROTOTYPES AND VR TESTBED

In this section, we first provide a rationale for the EAD choices we made based on the design study outcomes. Then we present the VR implementations of the EAD prototypes.

Figure 4: Interfaces implemented on public display (top-left, top-right, bottom-left), warning system- red light blinking alerts AV malfunction (bottom- right).

4.1 Conceptualizing Interface Prototypes

The results of the design study provided insight into important potential EADs design elements. We conceptualized specific scenarios for different interface prototypes by incorporating the ideas from the design study in an ideation brainstorming session. We ended up selecting and slightly modifying ideas from the design study based on the following criteria: 1) preference to popular interface elements from the design sessions adapted for real-world conditions (e.g. icon, text, image, solid color, animated graphics, touch, etc.), 2) incorporating ideas that apply to diverse road users, e.g. pedestrians, passengers, etc. As we designed it became clear that implementing all the design study EADs is beyond our current scope and we decided to focus on four interface prototypes to investigate the usefulness of dynamic visualizations on external car bodies. Among the four, three are visual interpretations of different EADs on a moving vehicle, while the fourth offers direct interaction with a stationary vehicle.

The implemented design concepts are considered as applicable to both manually-driven or autonomous vehicles. We decided not to focus on windshield EADs, these certainly have potential usage (e.g. in interaction with pedestrians in street crossing scenarios) but already received considerable attention (e.g. [18, 19]). We also decided to exclude in-car displays for drivers or passengers sitting inside the car as these are already prevalent in automotive interaction design (e.g. [2, 8, 13]). We decided to focus our EAD design efforts on public services, emergency alerts and signals in a vehicle, and ride-share mechanisms (e.g. rider verification) as these design ideas were highlighted in the design study by most participants and are generally less explored in the literature. We decided to include an additional design concept called ambient display where the EAD is augmenting the vehicle's visual appearance in order to blend it into the cityscape and reduce visual pollution. We detail below the four EAD design concepts we had chosen to implement:

(1) **Public Display**: public information for nearby pedestrians. Two scenarios are used to test three use-cases where interface elements respond to the scenarios. In the first, a single car travels through an urban area visible to pedestrians. In the second, multiple cars show varying information and visibility (Figure 4, bottom-left). The first use-case presents general information such as weather, time, or greetings using icons, image, text, and animated graphics with content changing dynamically based on location (Figure 4, top-left). In the second use-case, we display a context-specific map highlighting area of interest such as parks and schools (Figure 4, top-right). In the last, displays show advertising for local businesses and familiar products (Figure 4, bottom-left) aligning with the work of Colley et al. [3];
(2) **Warning System**: EAD is used for emergency alerts by flashing solid red color through side windows with an alert symbol (Figure 4, bottom-right). A scenario has been presented in this prototype where a vehicle (with no driver) is self-driving in a road with a passenger in it and starts to display an emergency alert to provide a warning to other road users such as pedestrians and drivers of other vehicles that something had gone astray. Such alerts could be utilized in the circumstances presented by Smith et al. in their study of rogue autonomous or semi-autonomous vehicles [23], or

Figure 5: Ambient Display, cars are blending to the old city environment (top) and modern city environment (bottom)

for more general concerns such as the health of the operator, safety issues of the passengers, etc.;

(3) **Ambient Display**: this approach blends vehicles with their surroundings to reduce visual pollution in the cityscape. EADs respond to their surroundings with visualizations meant to blend into the neighborhood. We have used two types of neighborhoods here: an old city (Figure 5, top) and a modern city (Figure 5, bottom). Visuals are designed to be more aesthetically pleasing, responding to concerns about the oversaturation of public spaces with displays identified by researchers such as Haeuslschmid et al. [8] and revisiting translucent cars concept presented by Amersfoorth et al. [25].

(4) **Public Fleet Identification**: using EADs and glass surfaces as interactive authentication panels to verify users, trips, and vehicles. For our test, we designed an identification interface synchronized with a user's mobile device. The car's side mirror has a scanner, the passenger scans the verification code to confirm the ride. Successful verification results in a welcome message, then an optional visualization displaying trip-based information (Figure 6). Drawing on the results of our design session and following the work of Colley et al., we tested interaction techniques involving direct touch and indirect interaction via a mobile device [4]. This design concept could be more effective for self-driving ride sharing services as there will be no driver to interact with to verify the rides.

4.2 VR Prototypes

We implemented all the EAD discussed earlier in VR, supporting a quick, relatively realistic, and safe evaluation of the prototypes. VR is an established testing medium for pedestrian-vehicle interaction in a rapid prototyping model [10, 18]. We designed our simulations using the Unity3D game engine for deployment on the Oculus Quest VR system.

To design, prototype, and test our work we developed two urban environments in VR. The first is a more established, older looking neighborhood with unique buildings, trees, and local parking and the other is a contemporary setting with high-rise buildings reflecting more modern architectural and higher population density. While the old neighborhood was used as settings for all our EAD prototypes, the modern one was used in the ambient display prototype to test the visualizations of different neighborhoods. The test environment in all scenarios was a one-way, two-lane road presenting the regular traffic. We considered several factors while designing our VR environments including vehicle speed, number of vehicles on the street, and vehicular behavior (manually-driven or autonomous). Variables are easily manipulated in the VR simulation supporting easy refinement of the simulation variables. We kept vehicle speed slow (on average roughly 40 KM/H) to reflect movement through traffic and to support context-specific visualizations (i.e. local attractions and shopping flyers) for testing in an appropriate setting. Lower speeds also increase visibility making early testing more efficient. In the last use-case of public display scenario (Figure 4 bottom-left), we tested the simulation by deploying EADs on multiple vehicles in the street, providing a more realistic reflection on the usage scenario. All the simulated vehicles in our prototype drove in the same manner except in the public fleet identification prototype where the vehicle was parked allowing direct interaction with the user (Figure 6). This scenario allowing users to interact directly with a vehicle used the Oculus Quest hand-tracking feature (without a controller) to enhance the user experience. In the simulations, we deployed the EAD on both autonomous and manually driven vehicles as we considered that users may be more accepting novel technologies such as EADs to be incorporated as part of advanced AVs technology. To affect the perception of the autonomy level of the vehicles, we modified their visual features by adding drivers in the manually driven cars and by leaving the driver seat empty in an AV.

5 PRELIMINARY DESIGN CRITIQUE

To evaluate the implemented scenarios, we conducted a preliminary design critique to collect reflections on the designed interfaces and their potential. As we were working during the COVID-19 crisis, we could not conduct a user study with participants in person and had to limit the design critique sessions to members of our lab that have access to Oculus Quest in their homes. The evaluation of the simulated designs was done in two phases. The first phase was an online evaluation with a group of 5 participants through a zoom meeting asking for preliminary reflections on videos taken from the simulation. The exploratory approach we used in this phase attempted to validate the user experience and had led to the second phase of our design critique. In the second phase, five designers were asked to interact with our EAD prototypes in VR and to provide their reflections on the in situ interactive experience. This phase was used to collect design insight and help us form our EAD design guidelines.

Figure 6: Public fleet identification: (left) user scans the verification code with the scanner in side mirror of the car, (middle) the window next to the mirror displays the welcome message, (right) user slides through the screen to see the ride information.

5.1 Phase 1

Methodology

Phase one of our design critique involved 5 people (2 females, 3 males) ranging in age from 18 to 55. Participants were from different disciplines, including computer science, engineering, fine and performing arts, and business. 4 of 5 participants were aware of related research (particularly in the case of autonomous vehicles technology) and 4 own vehicles. A pre-study questionnaire gathered demographic information. We invited all the participants to attend a zoom meeting as a virtual focus group and a brief discussion of the research topic and scenarios used for the session was shared with them. Scenarios were illustrated using images and videos exported from the Oculus Quest and shared on-screen through Zoom. Each scenario was briefly re-introduced as its video and pictures were presented. After showing all four design concepts, participants were invited to share feedback and reflections on our design implementations. Finally, each participant filled out a post-session questionnaire. The questionnaire asked the participants to rank design concepts based on effectiveness and use-value and to explain their reasoning. Participants were also invited to share information not covered by specific questions. The session was conducted via a formal Zoom meeting with participants as a group submitting completed questionnaires individually via google forms.

Participants' Evaluation

We have analyzed the collected feedback from the questionnaires using qualitative analysis and the findings are discussed here. Among the four design concepts, participants indicated the public fleet identification scenario was most useful. The reasoning given was that as ride-sharing becomes more popular better ways to match drivers and passengers are required. QR code-scanning shown in the simulation was seen to ensure the passenger found the correct vehicle and moved to the next phase of the interaction. Some participants suggested attention privacy concerns during interactions with the vehicle while others such as P1 offered design suggestions, *"for these interfaces to work, they need to make sense to target users, have a clear purpose, and be easily readable"*. Participants liked the warning system use-case noting improved safety as its key contribution for the passengers inside the vehicle, pedestrians and the driver of other vehicles, etc. by alerting about the vehicle's emergency. Reflections on public display interfaces were more diverse, with some indicating displays would reduce the need for pedestrians to use mobile devices for relevant information, though one participant expressed a preference for personal devices over EADs. Participants were neutral about the use of advertising, with one suggesting commercial vehicles would be best suited for displaying ads. All expressed concerns about multiple vehicles with varying displays. P3 noted, *"I worry about too many visual aspects happening on the road becoming distracting"*. Participants were not in favor of the ambient display interface as it introduces the hurdle of not being able to see the vehicle while blending into the environment. Participants observed that ambient displays might work well as an aesthetic car surface but did not characterize the approach as essential. When discussing these ambient displays two participants suggested that attention would be required to ensure cars remained visible for pedestrian safety. Amersfoorth et al. [25] also highlighted traffic safety while exploring the influence of translucent windshield displays on driving behavior.

Finally, participants were asked to share a general evaluation of EADs. Participants highlighted the effectiveness of the interfaces when information is tailored to users and their context. Most participants believe direct interaction with vehicles' EADs offers new design opportunities for improving user experience and public safety with P1 declaring, *"the interfaces that I rated highly serve some sort of utility to a target user group"*. P2 raised a question about whether the owner would like cars covered with displays while others suggested such visualizations were most suited to public vehicles. Overall, our participants indicated that EADs would be effective in real-world scenarios, with impact tied to a user and context-specific information/interaction and strict attention to public safety.

5.2 Phase 2

Methodology

In phase 2 of the design critique, we asked five members of our lab who have direct access to the Oculus Quest to use our prototypes in the immersive simulation. Participants were provided with the APK files of the interface prototypes and they side-loaded the files onto their quest headset to test the simulation. Their individual opinion was recorded and added to provide detail about the design recommendations, visualizations, and contextual experience. Results are recorded where they add nuance too or raise questions about the above-mentioned research and/or our ideation phase, design study, and our phase one study.

Reflection on Public Display

In the first VR prototype experiment, general public information is visualized. Four of the team participants observed that icons and image combine to produce the most effective results, while animated graphics enrich the visual experience. Information was easy to read with all noting that message placement is crucial. P1 mentioned not to use text for a moving vehicle while P5 suggested scaling the text size based on the vehicle speed. Simple designs were preferred, and a general preference for static visuals while cars are in motion was expressed by most participants. When testing location-specific information updates appearing dynamically on a map that highlights points of interest all of them expressed concerns. The real-time VR experience of this approach led all to suggest the visualizations were hard to comprehend, suggesting attention to vehicle speed, and the amount of information shared as potential improvements. P3 noted, *"Map was a detail thing, not sure what to look at initially"*. Two of the participant highlighted the potential of this interface as for tourist help. One of the use cases of the public display prototype was simulated with multiple vehicles and different thoughts were highlighted by the participants. During the simulation, multiple vehicles were displaying various contents which created visual clutter as they needed to shift their focus among several vehicles to read the information. One suggestion came from the discussion that all vehicles should display unified or coordinated information when there is anything important such as emergency on the road, traffic jam, etc. Overall, all the team participants suggested to design the interfaces on EADs with refinement and mentioned design considerations to avoid the distraction of drivers and other road users in the real world.

Reflection on Warning System and Ambient Display

When turning to visual evaluations for emergency alerts and ambient displays the VR environments seemed particularly effective. In the current vehicle, hazards lights are used to indicate that the vehicle is in trouble, but the indication is quite general and its exact meaning and level of severity can be opened for interpretation. The warning system interface prototype was identified by our participants as a practical interface warning to drivers of other vehicles and other road users about the vehicle's emergency state. Flashing red signals with danger icon were easy to notice and identify the emergency situation. However, all the participants noted that the meaning of these warnings would need to be well-understood by drivers, passengers, and pedestrians to be safe and effective. P4 suggested to display less intense signal for minor issues with the vehicle such as low fuel or tire, otherwise, it might induce unnecessary worry among the road users. And P2 highlighted using informative icons to specifically display what the problem is such as engine failure or fuel problem. Participants provided diverse opinions about the ambient display interface. When testing cars carrying visualizations that blend into their surroundings some noted the impact was aesthetically pleasing and found the idea interesting. However, most participants noted the need for contextual attention. They identified a difference between ambient displays that focus on making an aesthetic contribution to the neighborhood while avoiding a "camouflage" effect that might make it hazardous for other vehicles, and particularly for pedestrians. Three of the participants suggested having a mechanism in the vehicle that can turn such interfaces off when vehicles approach crosswalks or other areas where pedestrians enter the roadway. Overall, most of them also mentioned the technical difficulty of implementing such reflective displays in practical as it might create a double mirror effect if two vehicles are in parallel with the mirror surface.

Reflection on Public Fleet Identification

All the participants experienced direct interaction with vehicles, verifying a ride. Participants reflected that touching the screen to get quick information about the ride worked well, presented the information effectively, and has the potential to enrich the engagement experience. Participants told us that the user interface for the interactive simulations was adaptable and could potentially offer interesting possibilities to enhance the interaction experience. However, participants raised concerns about using QR code's reliability and security aspects, P5 mentioned, *"the interaction seemed reasonable, but if the QR system breaks, then the person can not get into the ride that would be trouble"*. One suggested using face recognition instead.

Overall, the participants highlighted some future directions for EADs. All the simulations were tested from the perspective of external road users and participants suggested testing the interface prototypes also from the perspective of different road users such as drivers of other vehicles, passengers (inside the vehicle) so that we can better investigate aspects such as potential distractions from their perspective. Overall, and while preliminary, our design critique session suggests the potential of this approach to the design and evaluation of EADs, demonstrating that VR simulation can provide an opportunity to visualize how interfaces could look in real-world scenarios, providing a potential future medium for safe and inexpensive ideation, prototyping, and testing of EADs.

6 DISCUSSION AND CONCLUSION

While preliminary, our work suggests the potential of EADs to improve interactions with vehicles especially for pedestrians, and passengers by displaying user- and context-specific information. Our preliminary design critique findings suggest the following EAD design considerations:

(1) adjusting textual and visual information in relation to traffic speed and volume;
(2) positioning interfaces in condition-specific locations;
(3) attending to changes in context when working with public versus private vehicles;
(4) targeting information to specific users and use cases needs to be precise;
(5) recognizing the importance of a clear purpose need for contextual comprehension when working with vehicles in public spaces.

It is important to reiterate that these design considerations were formed based on the evaluation of the design critique sessions, sessions that were limited to a small set of EAD porotypes, and a small study group. While we attempted to share the insights we gained from the design critique as generic EAD design considerations, the generalization of these findings should be questioned until it is demonstrated and evaluated in further design and studies.

The limitations of our work exist in two specific domains. The first relates to the size of our design critique and is an expected part of this type of exploratory research. Our work adds to past vast work reflecting on the benefits of designing, prototyping, and analyzing automotive UI in VR. While we believe that more work in this area is warranted our findings are preliminary and will benefit from subsequent studies that could expand and refine the implications of the existing design critique. Our VR simulated environment is still crude, and real-world environmental factors were not considered such as changing lighting conditions, weather conditions, pedestrians, etc. The second domain of limitations was introduced by the COVID-19 pandemic. Midway through our research meetings moved from lab-based sessions to Zoom meetings and our user recruitment and studies had to be altered, however, five of our team members were able to test the prototypes directly in VR. We look forward to addressing these limitations in the near future by conducting a proper user study with a large group of participants to revisit the uses of EADs.

Despite these shortcomings, our work provides preliminary reflections on new conceptual and practical suggestions for designing external automotive displays (EADs), to potentially improve user experiences for passengers, pedestrians, and drivers of other vehicles.

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