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USING MULTI-LEVEL PROTOTYPING TO SHOWCASE STUDENT MOBILITY DESIGN CONCEPTS IN URBAN CONTEXTS

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ABSTRACT

The emergence of new vehicle designs that fall outside the traditional urban mobility ecosystem, and recent paradigm-changing approaches to street layout design, require input from both urbanists and designers of mobility solutions. However, vehicle design concept showcases in academia have traditionally been vehicle-centric, using 2D materials and prototypes at the physical level (low-fidelity or small-scale) with little to no representation of the urban context. The emerging use of prototypes at the immersive level (AR/VR) in conjunction to the traditional materials provides an opportunity to represent both the vehicle and the urban context at full-scale, facilitating the input of urbanists as showcase participants. In this paper we provide a brief account of the use of prototypes in the discipline of mobility design at different levels (physical and immersive) and at varying degrees of fidelity, as well as prior work integrating the different prototyping levels. We then use a case study to propose our own multi-level prototyping approach for final showcases to present vehicle concepts.

Keywords: Future mobility design, virtual reality, augmented reality, immersive technologies, urban planning, transportation design, automotive design, vehicle design

1 INTRODUCTION

For decades, stable street layouts and vehicle ecosystems permitted urbanists and vehicle designers (also referred as automotive, transportation, and in this paper mobility designers) to work independently from one-another. However, with street layouts transitioning to multi-modality and new types of vehicles appearing on the mobility ecosystem [1], urbanists and mobility designers need new tools that facilitate their multidisciplinary collaboration. To this aim, we propose augmenting the final design showcases of mobility design projects in academia to show the integration of new vehicles with the urban context.

In academia, showcasing final mobility designs has traditionally been vehicle-centric, using 2D representations and 3D physical prototypes to explain the vehicle. The audience (usually other mobility designers) provides vehicle-centric feedback. Now that both the urban environment and the vehicle need to be in the equation, it becomes crucial to add urbanists. However, representing that scenario in 2D is inaccurate (off scale) or impractical if using 3D physical prototypes. An emerging solution in the field of mobility design education is immersion using Virtual Reality (VR) prototypes [2]. Immersion permits experiencing and interacting with both the vehicle and the city in full-scale. Additionally, Augmented Reality (AR) can serve as a bridge between the virtual and physical worlds by overlaying virtual geometry over physical prototypes without losing sight of other attendees and the showcase environment.

In this paper, the background (section 2) first addresses the changing urban fabric and new vehicle paradigms that make the enhancement of final mobility design showcases relevant to better include urbanists. Second, we present an overview of prototypes, their objectives, their physical and virtual levels, and their degrees of fidelity. Third, we address their use in the field of mobility design. Fourth, we discuss previous approaches that use a hybridization of immersive and physical prototypes for the industrial design process and present the research gap regarding the specific application to the field of mobility design. We follow up with the methodology (section 3) used to develop a multi-level prototype experience that allows mobility designers to showcase their vehicle solutions integrated to the urban context, enabling a seamless discussion with urbanists. We also present a case study of the final showcase of a Future Mobility Design undergraduate studio about micro mobility and its integrations with the urban environment, including the testimony of stakeholders in the AR/VR and urban development industries who experienced the multi-level prototype in the showcase. (Section 4) outlines the impact and limitations of our work and future research opportunities.

2 BACKGROUND

2.1 The changing urban fabric and new vehicle paradigms

For the past century, cities have been designed with a car-centric approach, producing barely unchanging street layouts with a stable vehicle ecosystem (e.g., cars, trucks, motorcycles, bicycles) [3], permitting mobility designers and urbanists to work separately. However, as trends in city design transition from car-centricity into multi-modality [4], mobility designers are producing new category-defying vehicle designs which are at a risk of not being considered when creating the streets of the future. One example is the emergence of micromobiles, [5], which are slower and lighter than cars but need different considerations to bicycles (e.g., e-scooters and hoverboards). Such vehicles have and continue to emerge in such a variety that makes it difficult to define what a 'micromobile' is [5], presenting challenges in the creation of street design parameters [6]. Thus, it is important to create tools for urbanists and mobility designers to work together.

2.2 Prototypes at different degrees of fidelity, and at the physical and virtual levels

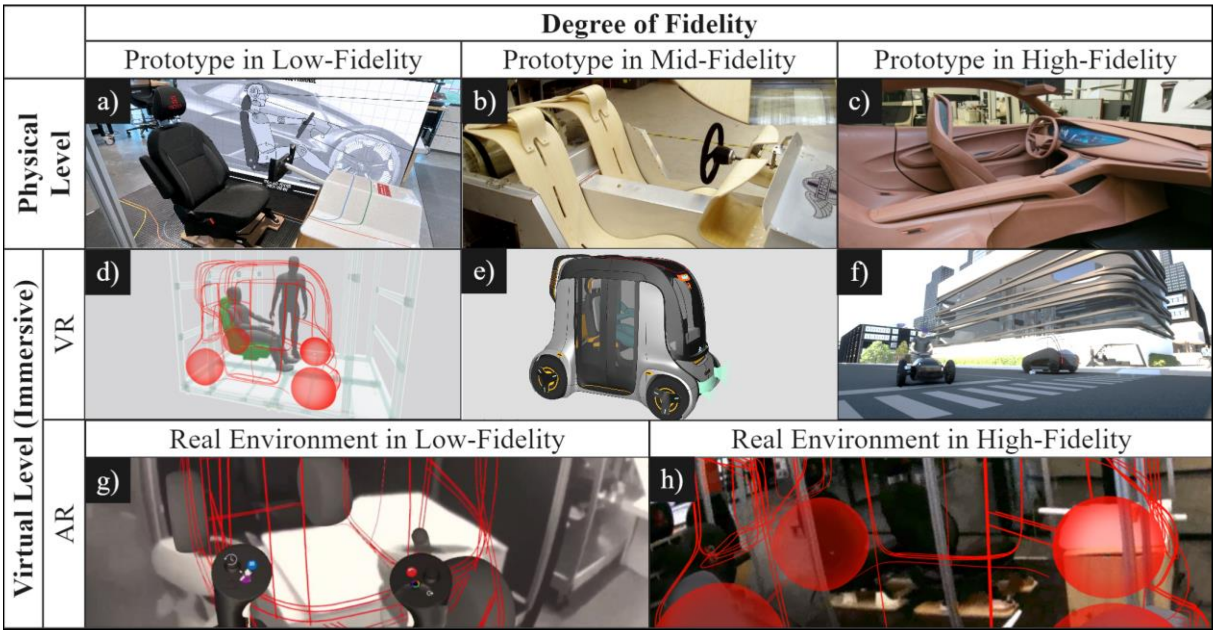
Together with 2D representations (e.g., sketches, renderings, 3D CAD geometry displayed on 2D screens, etc.), 3D representations (e.g., physical mock-ups, CAD models experienced immersively) are part of the representational ecosystem used throughout the design process [7]. We refer to these 3D representations as prototypes, which are preliminary versions of a design that can display its aesthetics and/or function [8] as well as its user interaction and experience. Diverse types of prototypes aid the designer in decision-making at different points of the design process [9]. Of the existing roles of prototypes in literature, two stand out as pertinent for this work: 1) Learning prototypes, used to advance design concepts in development, and 2) Communication prototypes, which represent more developed designs, [8], such as those in final showcases. Thus, the degree of fidelity of the represented design progressively increases as the final design is achieved. Prototypes also have varying degrees of fidelity due to the dimensions of the design object, using small-scale models when fully sized ones become too resource-consuming to construct in high fidelity. While small-scale physical models provide a collective viewpoint for showcase viewers, they do not provide a first-person experience of the design concept.

Virtual geometry in any degree of fidelity has no digital scale limitations but it does not provide a first-person experience while seen behind a 2D screen or image. Thus, virtual reality (immersion) becomes necessary. This can be achieved with projection display systems (e.g., CAVE [10] and Hyve 3D [7]) or with head-mounted displays (e.g., Meta Quest 2, HTC Vive). While projection systems are highly effective for co-located multi-user experiences such as final design showcases, they require specialized equipment installed on-site. Head-mounted displays require little to no extra equipment. However, by being worn on the face, they produce interaction challenges for co-located viewers. Using them for final showcases requires preparation, as untrained individuals will need time to dominate actions such as changing viewing angles, scales, or rotating a virtual object. For showcase attendees to master these basic actions, a training session of about 30 minutes is recommended, although this extra time will not always be available. Moreover, full immersion means the virtual and the physical world do not correspond, and multiple co-located users cannot see each other which can be disorienting. Nonetheless, the recent introduction of in-app passthrough viewing to the Meta Quest 2 turns the headsets into AR tools, bridging the virtual and physical experience by overlaying virtual geometry on a black and white low-fidelity camera-generated reproduction of the real environment.

2.3 Use of prototypes in mobility design showcases

In academia, traditional final mobility design showcases involve a verbal presentation while audiences (usually other designer members of the community of practice) [11] play a spectator role who provide vehicle-centric feedback at the end of the presentation. These academic showcase events include 2D materials such as posters and/or images/animations projected on screens, and physical communication prototypes. Creating high-fidelity (high-fi) full-scale models is reserved for industry practice and not viable in academia. Adding the urban context would make full-scale even more impractical. Thus, final showcases in academia traditionally use high-fi small-scale physical prototypes, with full-scale low-fidelity (low-fi) prototypes appearing less frequently.

High-fi and full-scale virtual representations have been used in industry for decades. In the 2000s, large retro-projected 2D displays representing vehicles in 1:1 scale were introduced (e.g., Powerwalls) [12]. However, the vehicles could only be seen at a distance (a limited first-person experience). Today, the emerging use of VR/AR prototypes provides the required upgrade. Figure 1 shows the use of learning and communication prototypes for vehicle design. They allow audiences to transition from spectators to active participants, capable of experiencing aspects of the concept such as materiality, user-interactions, and the urban context. However, 2D material and physical prototypes, even if small in scale or fidelity are often preferred by showcase participants over VR [13], even when its benefits are lost. As stated in section 2.2, using AR bridges low-fi full-scale physical prototypes with higher fidelity virtual geometry, allowing for mobility designers to display vehicle solutions in the urban environment in a more seamless transition between both disciplines.



Prototyping methods and degrees of fidelity		
a) Low-fi physical learning prototype (from academia): A rough mock-up blocking out essential design elements.	**b) Mid-fi physical communication prototype (from industry):** A more developed mock-up, partially showcasing the design concept.	**c) High-fi communication prototype (from industry):** The design concept's function and aesthetics are fully represented.
d) Low-fi VR communication prototype (from academia): A rough line drawing model showing essential design elements.	**e) Mid-fi VR communication prototype (from academia): A** more detailed model showing touch points and surfaces.	**f) High-fi VR communication prototype (from academia): A** finished model and context environment shown in high quality.
g) Low-fi Real Environment: Black and White cameras from VR headset used to overlay VR content on real environment.	**h) High-fi Real Environment: Full** HD color cameras from VR headset used to overlay VR content on real environment.	

Figure 1. Prototyping levels and degrees of fidelity used in academic final mobility design showcases.

2.4 Prior work integrating immersive and physical prototyping

Prior integrations of physical and virtual prototyping levels including AR and VR have been proposed for both the development and final showcases of design concepts. One uses the term "virtuality continuum" to explain the different degrees of integration between the real and virtual environments [14]. Another is the hybrid representational ecosystem [7], which intends to facilitate multi-user co-creation between the project stakeholders. Also, tangible virtual reality (TVR) is proposed as a 1:1 scale combination of VR/AR furniture models with key physical touch points to provide a first-person virtual and haptic experience [13]. However, none of them combine the attributes of multi-level prototyping using head-mounted displays for viewing VR-generated geometry while integrating AR capabilities alongside 1:1 scale physical prototypes, to meet the specific constraints of mobility design in academia which include: **1)** shorter timelines (academic semesters) than those of industry, **2)** the required degrees of fidelity at the physical and immersive levels (AR /VR), **3)** a first-person experience of the vehicle concept and its urban context, for final showcase participants to give feedback.

3 USING MULTI-LEVEL PROTOTYPING TO SHOWCASE STUDENT MOBILITY DESIGN CONCEPTS IN URBAN CONTEXTS

3.1 Research context

The multi-level prototyping method we propose was developed at the University of Cincinnati between 2016-2023 and the University of Montréal between 2021-2023. The methodology was refined in 23, 15 week-long undergraduate level projects ranging from 8 to 24 students. Each project is divided into three phases of 5 weeks each: 1) research and VR proficiency development, 2) ideation and selection of design direction, and 3) execution and showcase of final design. Every project was done with industry partners, either in full collaboration or with their feedback (e.g., General Motors, Stellantis, BRP), as well as urban planning organizations such as Uptown Consortium, and consultants in the city of Cincinnati. From a mobility design studio project, we have selected one key student's final design showcase to illustrate the outcomes pertaining to the proposed multi-level prototyping methodology. Conclusions are based on the testimony of AR/VR experts and urban planning stakeholders who attended the event.

3.2 Multi-level prototyping proposal

With the main goal to allow participants to experience the functional and aesthetic elements of the mobility design concept in its urban context, Figure 2 shows the proposed multi-level prototyping methodology consisting of **1)** 1:1 scale Low-fi physical communication prototype made of easily modifiable materials such as cardboard, tape, and foam core, to provide tangible touch points, haptics, and ergonomics, **2)** Low-fi black and white AR from the VR headset to create a seamless bridge between the physical and VR prototype without disorientation while keeping other showcase attendees visible, and **3)** Mid-fi VR scene of the final vehicle and surrounding urban environment shown in 1:1 scale (simple materials and environment lighting) correlated with the touchpoints of the physical prototype, while virtual geometry shows the aesthetics, materiality, and interactivity of the vehicle. Participants are situated on or around the vehicle's physical prototype while having a VR overlay that matches the physical footprint and seamlessly walking or moving around the scene using AR. They can also take a spectator role and watch a traditional screen which shows the content from within VR.

Physical Level: Low-Fidelity **AR Level:** Low-Fidelity (Real Environment) **VR Level:** Mid-Fidelity

Figure 2. Multi-Level Prototyping in academic final mobility design showcases

3.3 Multi-level prototyping Case Study approach for final design mobility showcases

The following is a case study from an undergraduate micromobility design studio in the Summer of 2022, consisting of 4 groups of 5 third-year Industrial Design students. Groups proposed concepts for micromobility hubs with each student designing one of the following: micromobiles, stations, hubs, urban context, kiosks, UX/UI, or CMF. The final showcase was held in an open lobby space where each group had large posters with their research, ideation, and final designs. They also had large screens displaying the final VR experience of their urban hub. Chosen students included a multi-level prototype consisting of **a)** low-fi physical vehicle prototypes, **b)** VR Gravity Sketch models of the vehicle's exterior, interior, and surrounding urban environment, **c)** AR enabled features through the VR headsets, and a laptop projecting the VR experience for audience members not wearing headsets (Figure 3).

The following testimonies were documented after the event took place and offer experts' opinions on the relevance and impact of multi-level prototyping in mobility design showcases related to the urban planning context and AR/VR industries. From the urban planning context, the interviewed expert comments that the methods used to showcase the experience were highly persuasive and efficient. VR can be intimidating for non-expert users but using the headset cameras made it more intuitive to sit down on the physical prototype to experience the vehicle concept and surroundings. These methods can help in the communication process between different audiences. Additionally, they highlighted not just seeing the vehicle and its experience (representing the human scale) but understanding the relationship to the urban environment (macro scale). Urban planners also said that these technologies will be crucial to validate the design process of future streets and their components (vehicles, pedestrians, cyclists, public transit, stations, among others), especially since city planning must change as new types of vehicles arise. The interviewed AR/VR expert mentioned that the combination of low-fi physical, low-fi AR, and mid-fi VR created a compelling experience for audience members, allowing full immersion to the design without any disconnection to the physical environment. The AR/VR expert reported that the multi-level prototyping approach felt appropriate, since it considered the scope of the student projects while maximising their impact to a wide variety of guests invited to the final showcase.

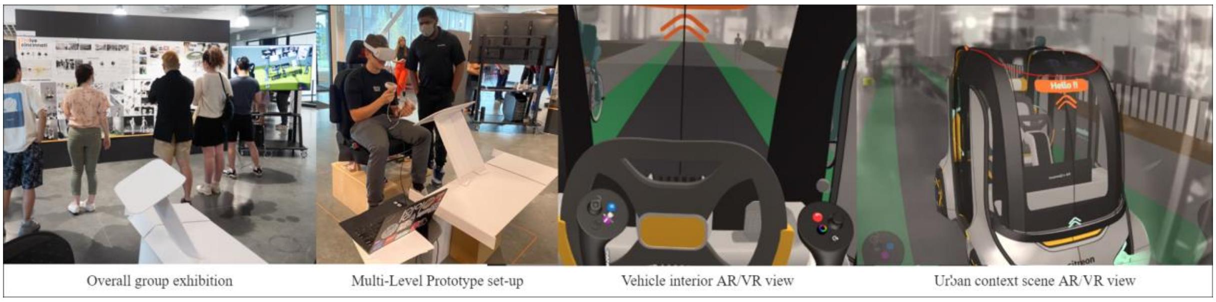


Figure 3. Chosen student's micromobility concept shown in the final showcase.

4 DISCUSSION AND CONCLUSION

Emerging vehicle types and changes in street layouts validate the need for creating compelling methods to connect mobility designers and urbanists. The case study presented in this paper shows how the emergence of immersive prototyping can bridge both disciplines by adding the representation of the vehicle in the urban context at full-scale to final mobility design showcases. The two key contributions proposed in this paper are: **1)** A brief account and evolution of prototyping methods for design, focusing mostly on emerging AR/VR/TVR and the representational ecosystem. **2)** The proposal of a replicable VR headset-based multi-level prototype approach for final showcases of student mobility design projects. This approach contextualizes showcase participants on both the human scale of mobility design and the macro scale of urbanism, which permits the immersive representations of both the urban context and the designed vehicle (mid-fi geometry), its ergonomic and functional touchpoints (low-fi physical mock-up), while maintaining the visibility of the real environment through AR (low-fi visualization). The use of multi-level prototypes as presented in this paper enables multidisciplinary audiences (like urbanists) to provide more comprehensive feedback than with traditional methods (posters, slideshow displays, and animations), which should continue as complimentary elements in the showcase.

Three kinds of limitations arise: **1)** The virtual geometry as proposed is static (not interactive). VR simulations using video game engines are required for more complex interactions. **2)** The democratized use of AR/VR in the field of mobility design is in its infancy, which brings two problems: there are still alignment issues when matching the virtual and physical environments, and the AR feature is in low-fi (black/white, low-res). However, newer generations of VR headsets such as the Oculus Quest Pro present a higher-fi AR representation of the physical environment and applications such as Gravity Sketch have recently begun offering tools to anchor it to the virtual one. **3)** The use of VR headsets presents some inconveniences. Among them, the learning curve for final showcase guests to use the technology smoothly, which could be reduced by having a short training session before the event whenever possible. Another inconvenience is the lack of VR headset availability for all audience members, or attendees who decline to use them. Projecting the VR/AR experience on a screen can be an alternative that provides access for these participants.

Given the proposed methodology and comments from interviewed experts, future work could focus on three areas: **1)** The development of multi-located (in-person and remote) showcase experiences. First, by having remote attendees join the VR portion of the environment while the in-person showcase happens, and second, by recreating the physical mock-up in a different location and synchronously have all attendees join the same multi-level prototype experience. **2)** The constant emergence of new VR features and applications to the field of mobility design in academia pose two paths to enhance final design showcases. The first is that haptic technologies offer a closer link between the physical prototype and virtual geometry. The second is that the learning curve for video game engines is being reduced, making it more viable to add interactions to the showcase during the time constraints of academic terms. **3)** More importantly, future work can focus on further bridging mobility designers and urbanists by including these last ones during a multi-disciplinary design process rather than only at the final showcase.

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