

BEYOND REALITY: USING AR FOR VRU-AV COMMUNICATION AND INTERACTION

RESEARCH UPDATE AND FUTURE DIRECTION: 04/X/2022

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Communication between AVs and VRUs

EXPLICIT

hand gestures,
vocal
communication,
and eye contact

Loss of driver cues may decrease pedestrian confidence and trust.

External Human-Machine Interfaces

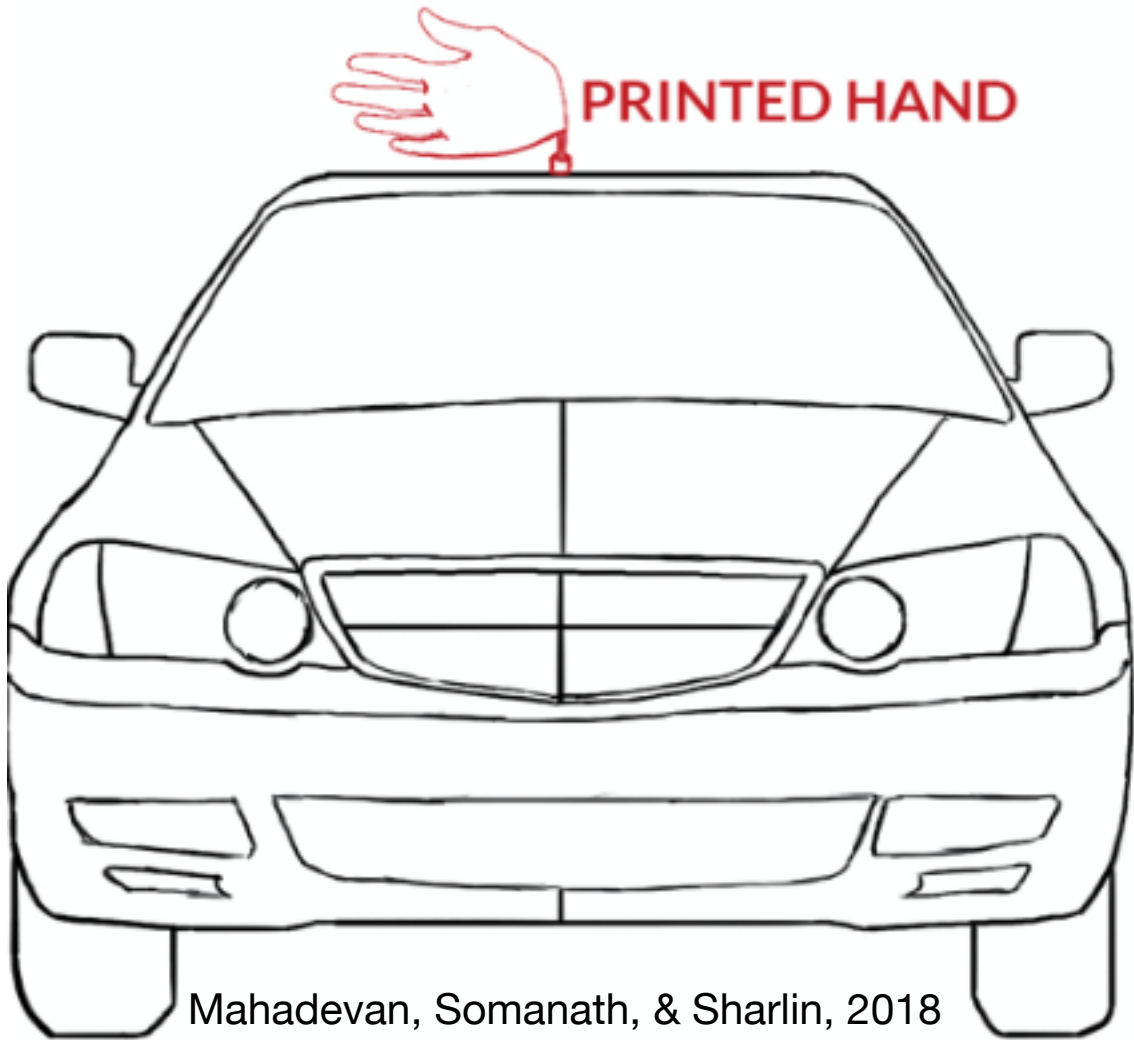
eHMIs



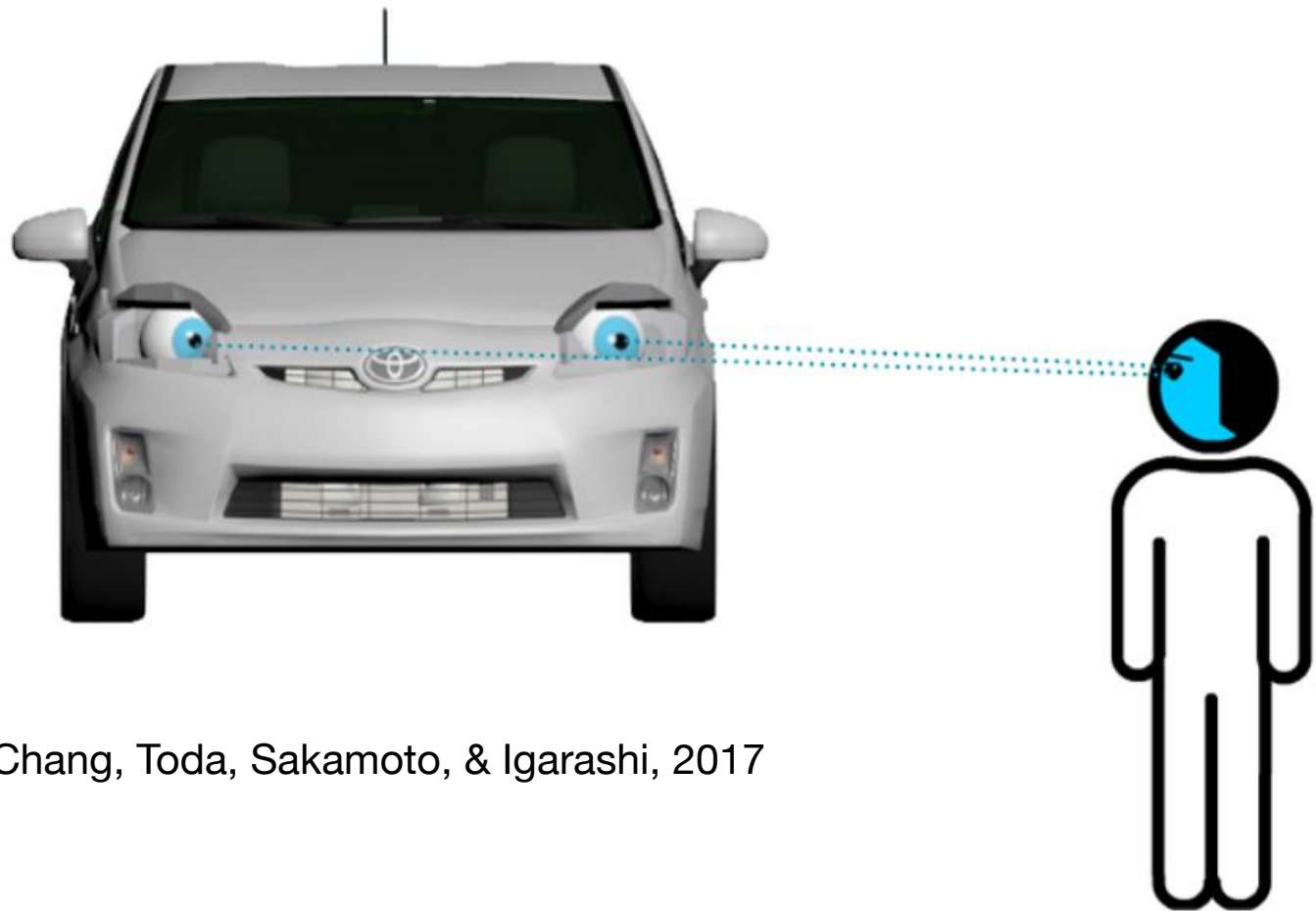
Daimler, 2017



Dietrich, Willrodt, Wagner, & Bengler, 2018



Mahadevan, Somanath, & Sharlin, 2018



Chang, Toda, Sakamoto, & Igarashi, 2017



Semcon, 2016

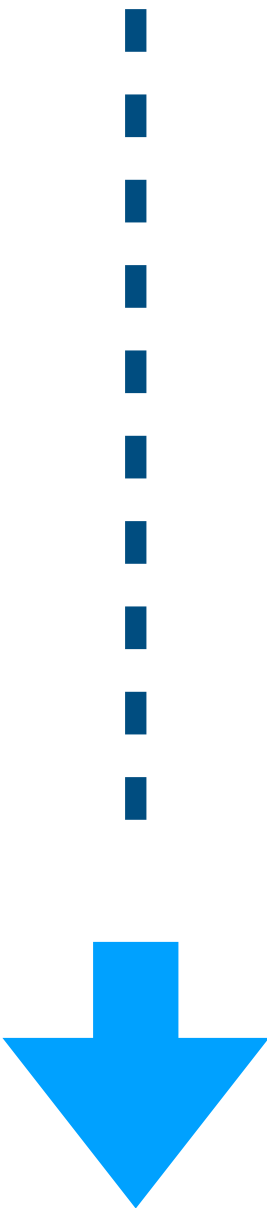


Bazilinskyy, Dodou, & de Winter, 2019

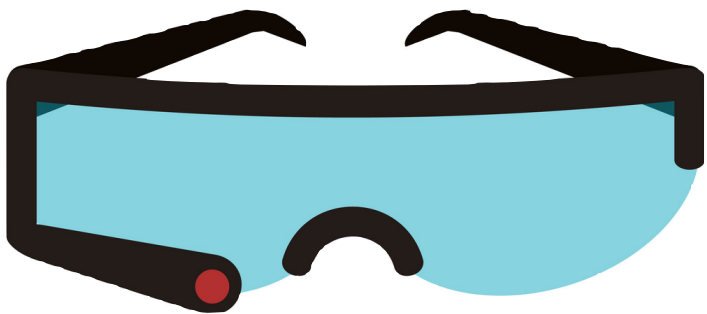
Problem Space



Person



Person



eHMI



Automated Vehicle



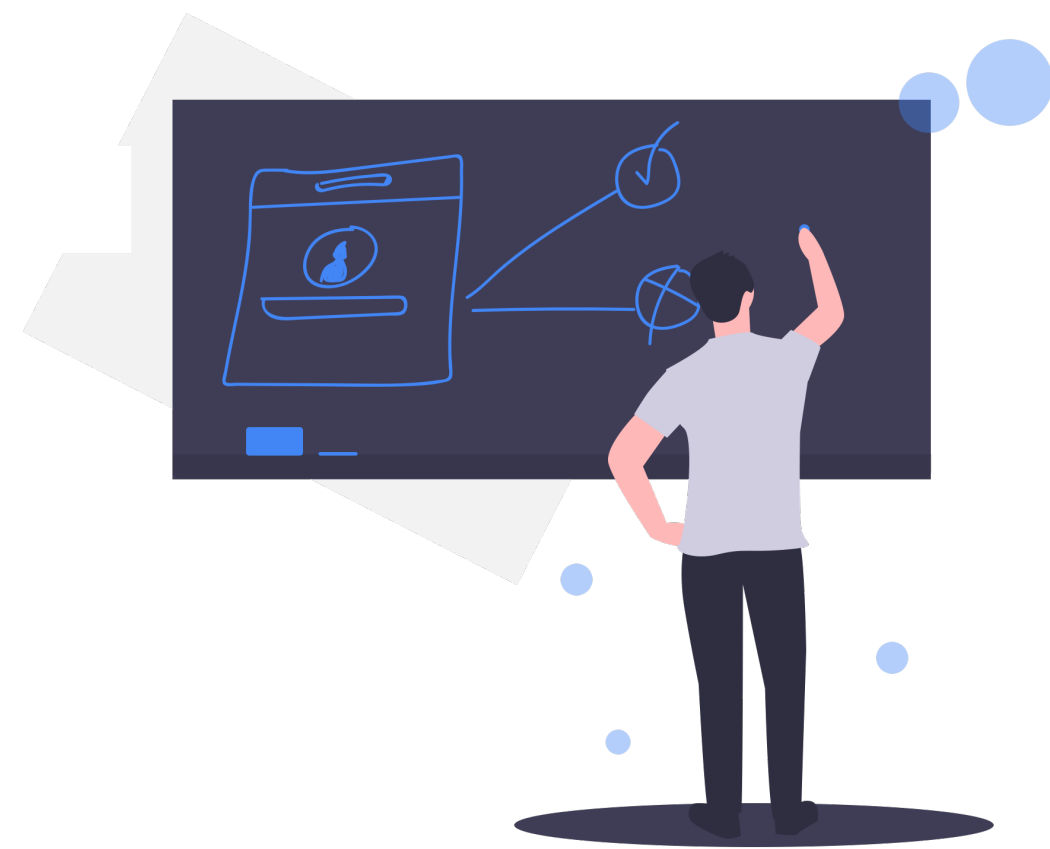
Automated Vehicle

Main Themes and Objectives

- 1** Assess whether humans trust indirect communication from an Automated Vehicle.
- 2** Assess whether augmented reality is a suitable technology for the development of interfaces which facilitate AV-VRU communication.
- 3** Identify user-preferred design elements for AR interfaces which facilitate AV-VRU communication.
- 4** Develop virtual/augmented reality simulation methods to investigate the interaction between AVs and VRUs.

Approach

Design and implement theoretically informed prototypes, and assess their validity and effectiveness empirically.



Brainstorming Design Exercise



Implement and test in VR and AR



Evaluate with users

Work so far

Vulnerable Road Users and The Coming Wave of Automated Vehicles: Expert Perspectives

Towards future pedestrian-vehicle interactions: Introducing theoretically-supported AR prototypes

Augmented reality interfaces for pedestrian-vehicle interactions: An online study



Vulnerable road users and the coming wave of automated vehicles: Expert perspectives

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ABSTRACT

Automated driving research is increasingly focusing on the interaction between automated vehicles (AVs) and vulnerable road users (VRUs). This paper presents the results of a survey of experts in the field of AV-VRU interaction. The survey was conducted with 16 experts from 10 different countries. The results show that experts agree that AV-VRU interaction is a complex issue that requires a multidisciplinary approach. The most common challenges identified were the lack of communication between AVs and VRUs, the lack of information about the intentions of VRUs, and the lack of space for VRUs to manoeuvre. The most common solutions proposed were the use of communication technologies, the use of predictive models, and the use of dedicated infrastructure.

ARTICLE INFO

Keywords:
Automated vehicles
External human-machine interfaces
Smart infrastructure
Augmented reality
Virtual reality
Position paper

Glossary

• **Anthropomorphism**: The tendency to attribute human characteristics to non-human entities.
• **AV**: Automated vehicle.
• **VRU**: Vulnerable road user.

Augmented reality interfaces for pedestrian-vehicle interactions: An online study

23rd August 2022

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Augmented Reality (AR) technology could help pedestrians to navigate safely through traffic. However, whether potential benefits such as AR solutions is currently unknown. Nine novel AR interfaces were developed using an experience-based questionnaire study presented to 100 participants from Sweden, Norway, and the United Kingdom. The results indicated that the interfaces were perceived as convincing, aesthetically pleasing, and easy to use. The study also showed that there were no significant differences in the perceived effectiveness of the interfaces across the different countries. The results of this study can be used to inform the design of future AR interfaces for pedestrian-vehicle interactions.



Figure 3. Virtual environment used in the study. Each participant was shown a video of the virtual environment from the perspective of a pedestrian. The video started with the camera pointing towards the other end of the crossing (Figure 4, at time 0 s). The camera then slowly rotated (panned) to the right as the vehicle approached from point A (at an elapsed time of 2 s, the camera would have rotated to point B, at an elapsed time of 4 s, the camera would have rotated to point C, at an elapsed time of 6 s, the camera would have rotated to point D, at an elapsed time of 8 s, the camera would have rotated to point E, at an elapsed time of 10 s). The video ended with the camera pointing towards the other end of the crossing (Figure 4, at time 10 s). The video was shown to participants in a virtual reality environment. The participant's position in the virtual environment was also marked with a camera icon.

Keywords

Augmented reality
Pedestrian-vehicle interactions
Virtual reality

Towards future pedestrian-vehicle interactions: Introducing theoretically-supported AR prototypes

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ABSTRACT

The future urban environment may consist of mixed traffic in which pedestrians interact with automated vehicles (AVs). However, it is still unclear how AVs should interact with pedestrians. Augmented reality (AR) could be used to support pedestrians in the future of interactions between AVs and pedestrians. This paper presents the results of a survey of experts in the field of AV-VRU interaction. The survey was conducted with 16 experts from 10 different countries. The results show that experts agree that AV-VRU interaction is a complex issue that requires a multidisciplinary approach. The most common challenges identified were the lack of communication between AVs and VRUs, the lack of information about the intentions of VRUs, and the lack of space for VRUs to manoeuvre. The most common solutions proposed were the use of communication technologies, the use of predictive models, and the use of dedicated infrastructure.

1 INTRODUCTION

Future automated vehicles (AVs) have to be able to drive in complex environments containing many interaction partners, including vulnerable road users (VRUs). In recent years, the control loop, in which the automated vehicle locates itself, perceives its surroundings, and decides upon the best trajectory, has changed into an 'interaction loop', where multiple road users cooperate through the wireless exchange of information [57]. To close the interaction loop, the AV may need to communicate its intentions to VRUs, who traditionally received such information explicitly from the driver and implicitly through vehicle kinematics [31]. Current solutions are smart infrastructure and vehicle-mounted external human-machine interfaces (eHIMs) [7, 10, 36, 51], and see [8] for a review of 70 eHIM concepts. However, these interfaces may be hard to read from a distance and potentially ambiguous, especially when encountering multiple pedestrians, as it could be unclear to whom the AV is communicating [46].

AR has already been used to support operators in many domains, including the military [32, 55], museums [52], industry [35], and aviation [24]. As AR technology becomes more context-aware, it could be used to remove the display from the vehicle and place it in the environment. Since each pedestrian would receive a different AR display, AR could solve the one-to-many problem of eHIMs [53]. Additionally, AR may prove to be more effective than physical counterparts such as traffic lights, for example, in the form of augmented reality (AR) glasses [28, 54] and AR glasses [28, 54]. AR glasses could be used to augment the visual information available to the driver, for example, by highlighting the location of VRUs in the environment. This could help the driver to make better decisions about how to drive in the presence of VRUs.

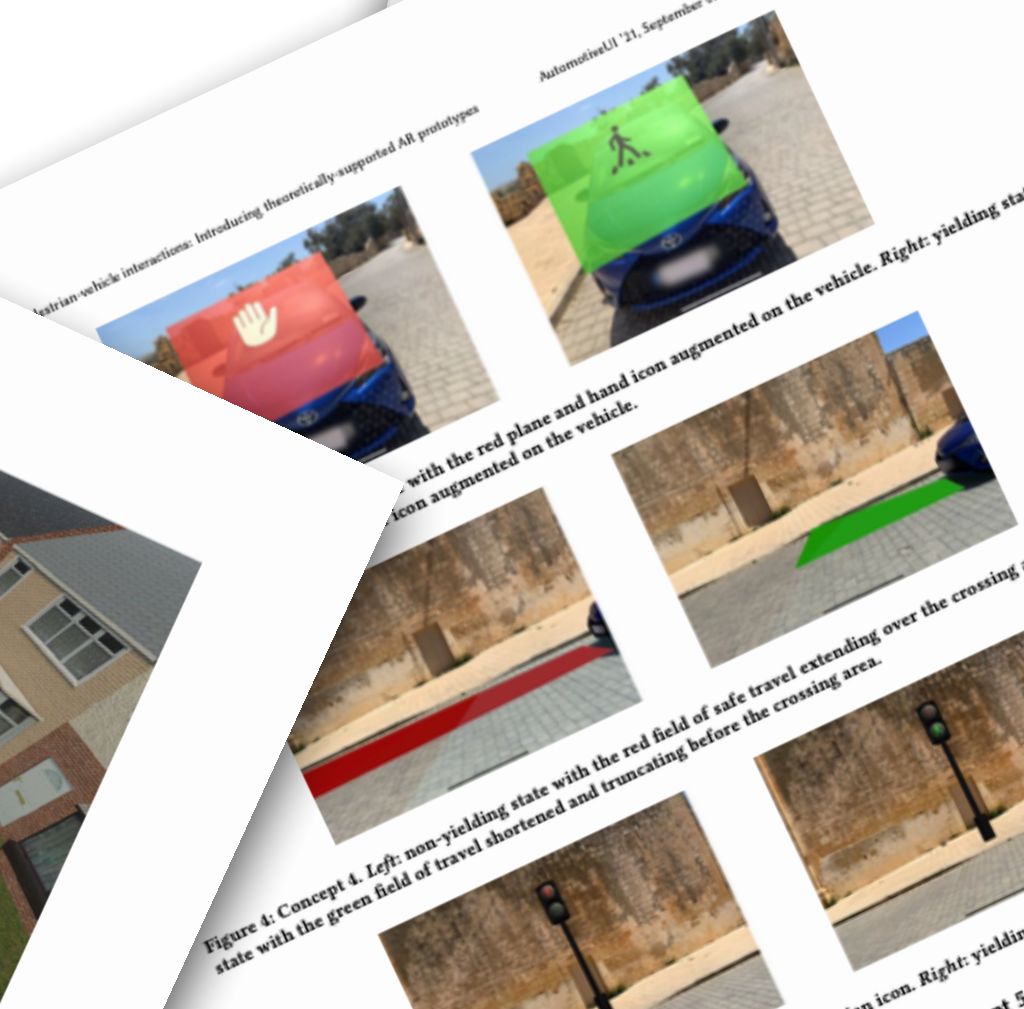


Figure 4. Concept 4: Left: non-yielding state with the red plane and hand icon augmented on the vehicle. Right: yielding state with the green field of travel shortened and truncating before the crossing area.

3.5 Concept 5: Fixed pedestrian traffic lights

For this AR concept (Figure 5), based on the fourth quote in Phase 1, the familiar concept of binary pedestrian traffic lights was chosen. These lights would pop up on the other side of the crossing area and alert the pedestrian whether a vehicle is approaching and intending to cross. As an additional cue to the red and green traffic light, a yellow light could be used to indicate a 'caution' state. The model of the human figure are superimposed on the ground to comply with the model of the light was set as a yellow light. Once the iPad was used to interact with the AR interface, the light would change from red to green, indicating that the vehicle has stopped and the pedestrian can cross.

Interview Study

Vulnerable Road Users and The Coming Wave of Automated Vehicles: Expert Perspectives

Expert position paper.

Invited **16 researchers** to give their **perspectives of automated vehicles (AVs)** and the **interaction with vulnerable road users (VRUs)** in the **future urban environment**.

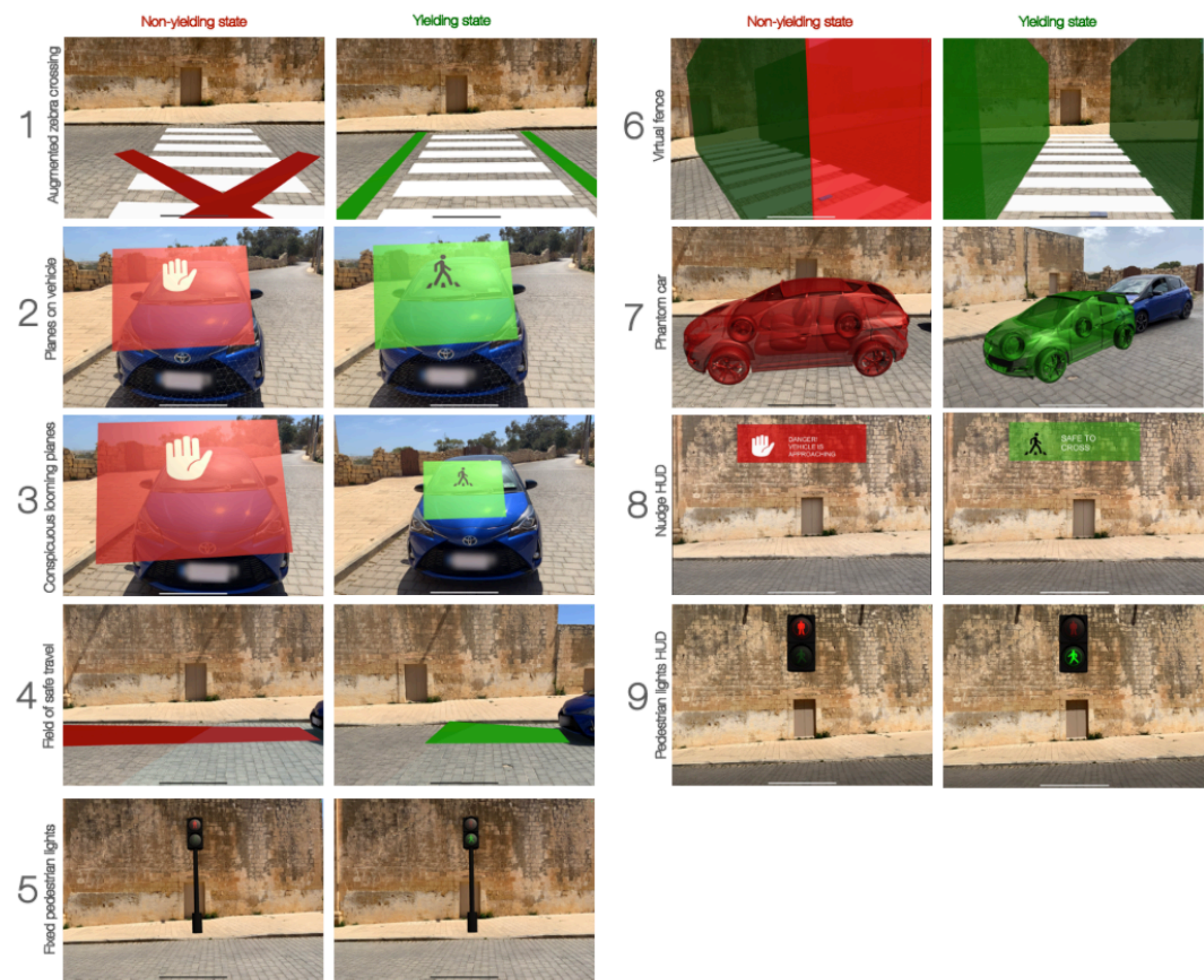
Aspects such as **smart infrastructure**, external human-machine interfaces (**eHMI**s) and the **potential of augmented reality** were addressed during the interviews.

(Tabone et al., 2021)



Design Study

Towards Future pedestrian-vehicle interactions: Introducing theoretically-supported AR prototypes



(Tabone et al., 2021b)



Evaluation of Augmented Reality Interfaces

Online Questionnaire Study

Simulator Study

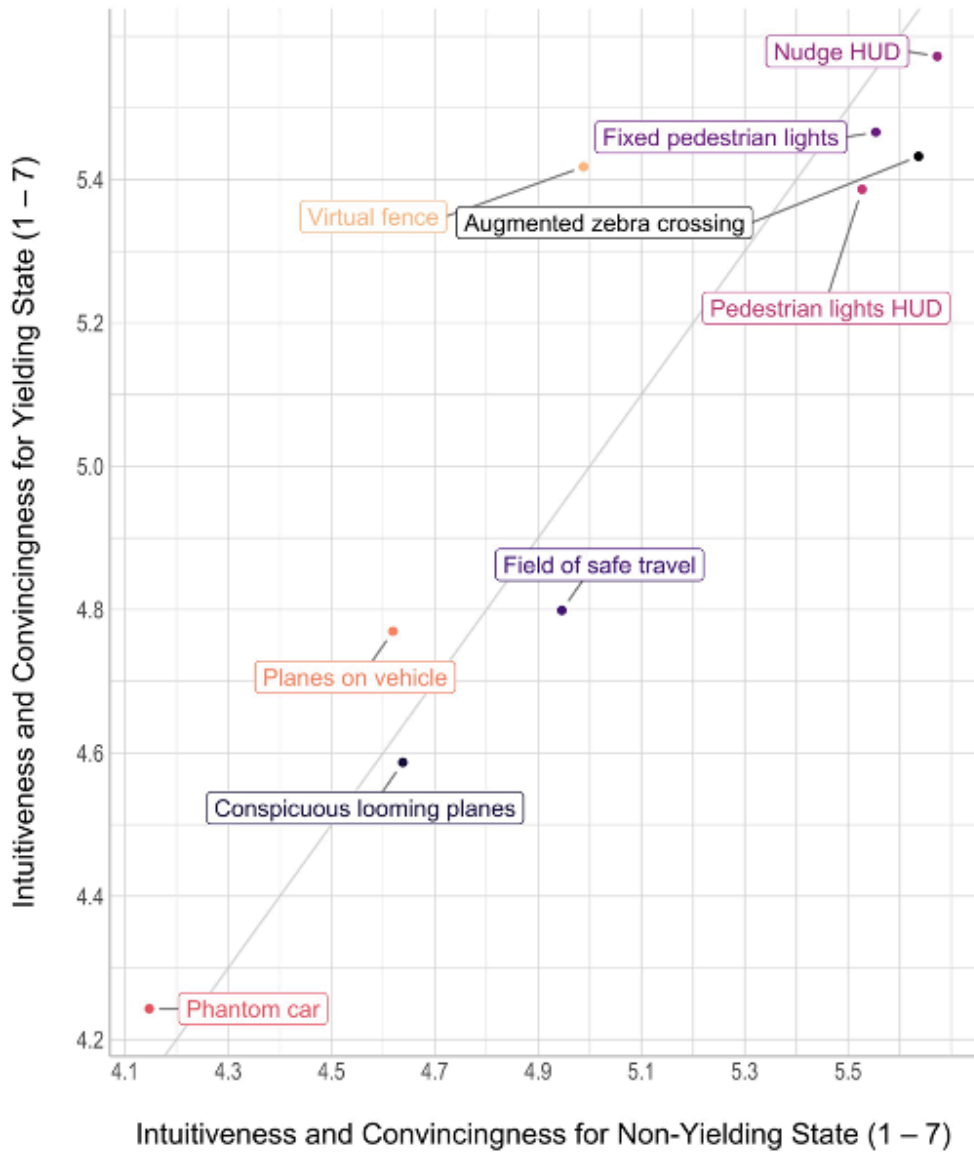
Naturalistic Study

Increase Ecological Validity

Online User Evaluation Study

Augmented reality interfaces for pedestrian-vehicle interactions: An online study

Interface	Composite Score M (SD)
8. Nudge HUD	0.36 (0.85)
1. Augmented zebra crossing	0.32 (0.89)
5. Fixed pedestrian lights	0.28 (0.88)
9. Pedestrian lights HUD	0.24 (0.86)
6. Virtual fence	0.03 (1.00)
4. Field of safe travel	-0.13 (1.00)
2. Planes on vehicle	-0.22 (0.98)
3. Conspicuous looming planes	-0.36 (1.00)
7. Phantom car	-0.53 (1.05)



(Tabone et al., 2022)

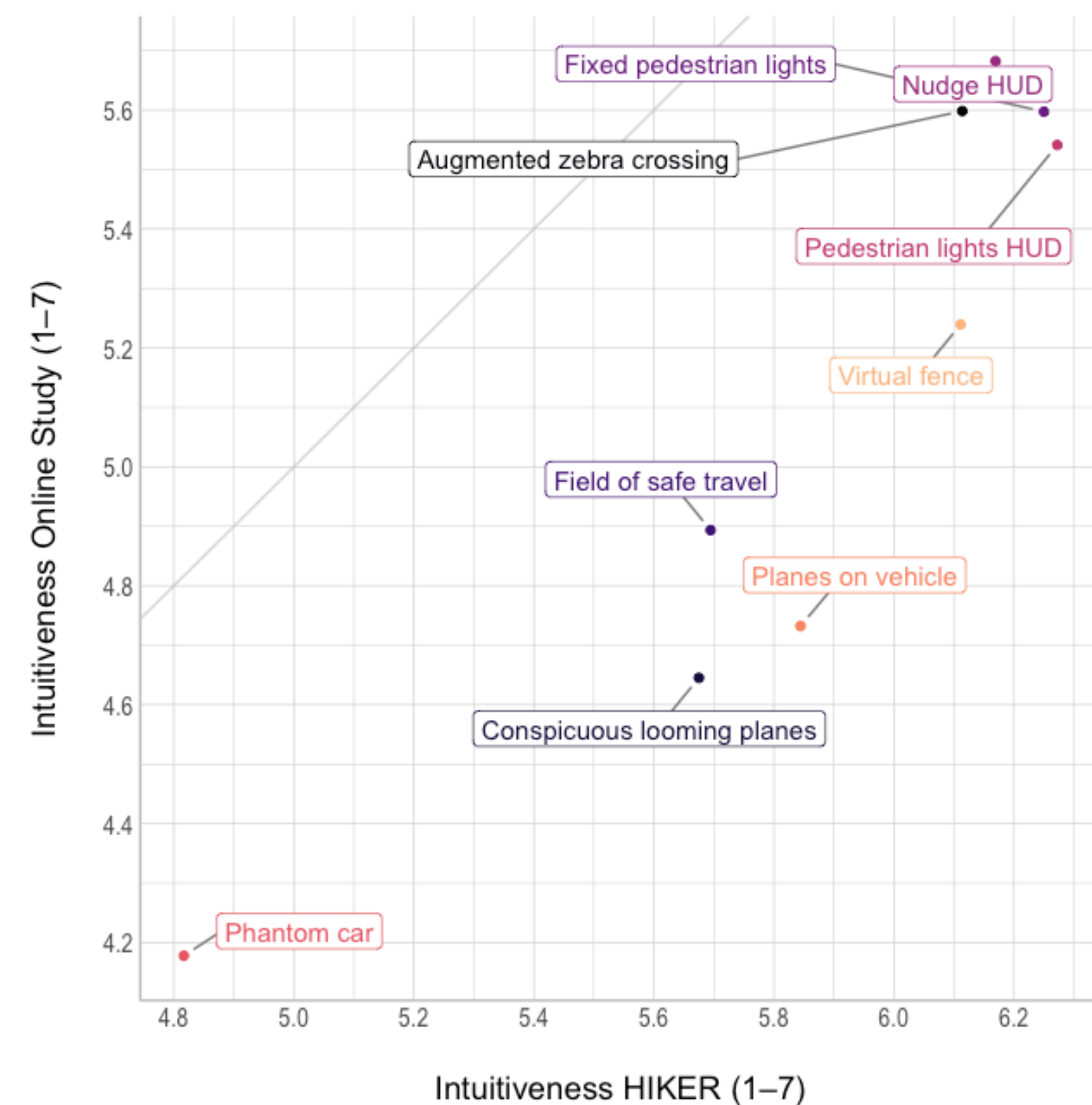
Simulator User Evaluation Study

Augmented reality interfaces for pedestrian-vehicle interactions: An simulator study



Simulator User Evaluation Study

Augmented reality interfaces for pedestrian-vehicle interactions: An simulator study

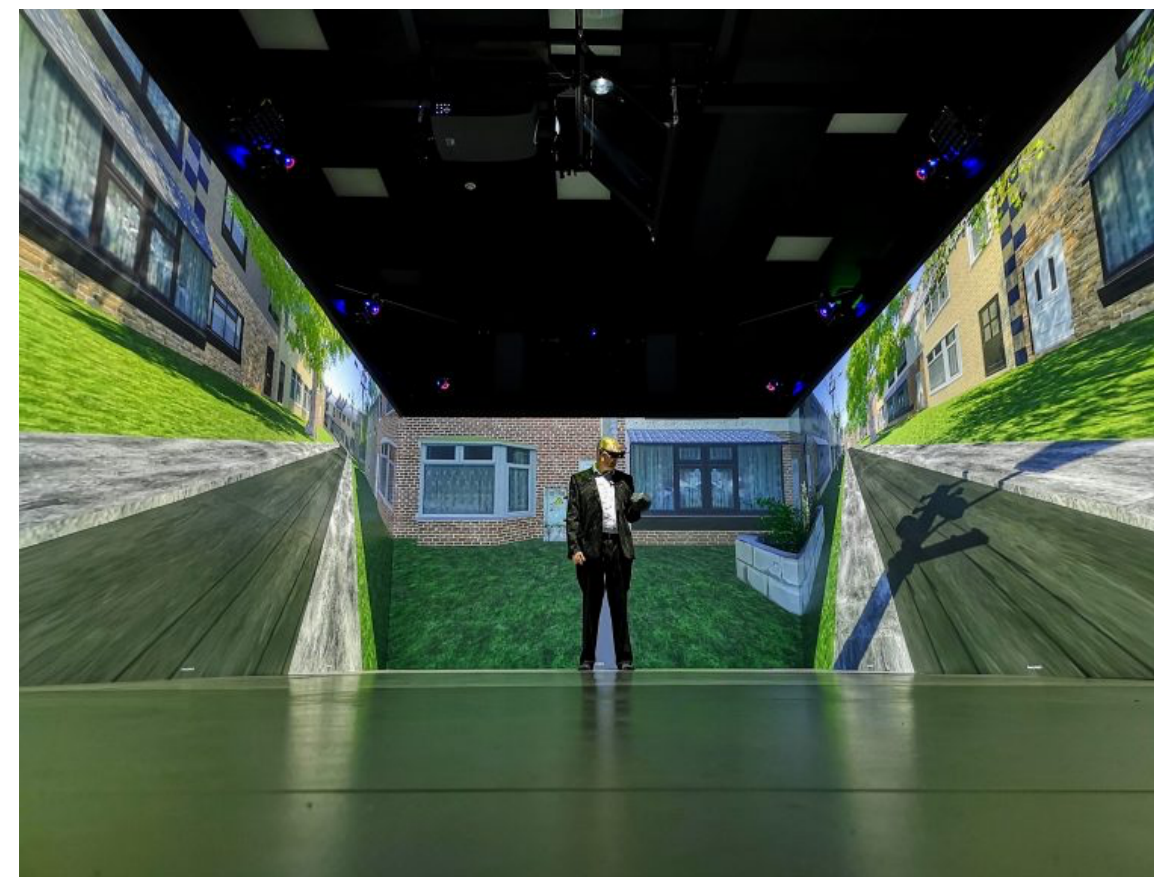


Moving forward

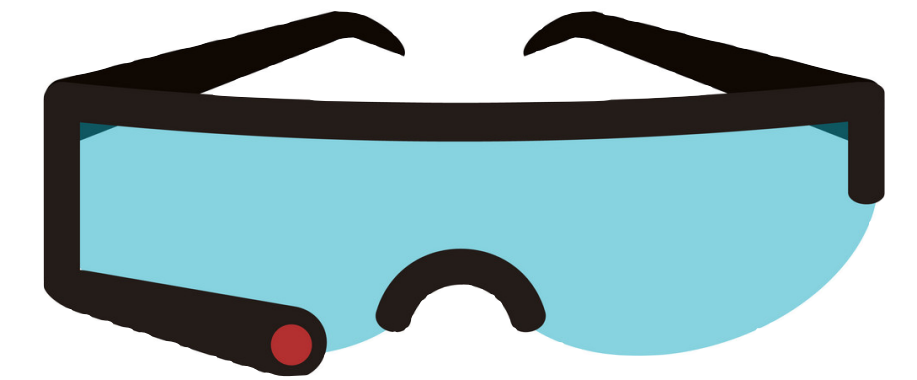
Select the most promising AR interfaces, re-implement them in AR, and assess their validity and effectiveness empirically.



Evaluate with users



Implement and test in VR



Test in AR

Validation study

Implement the AR interfaces on actual AR HMDs (eg. Varjo XR3).

Test on Wizard of Oz vehicles, virtual vehicles, or actual AVs.

Investigate whether there are any correlations between the simulator study and the real-world study.



Challenges and Open Issues

- 1. Best approach for real-world validation (measures)**
- 2. Arguments towards the adoption of this technology**



References

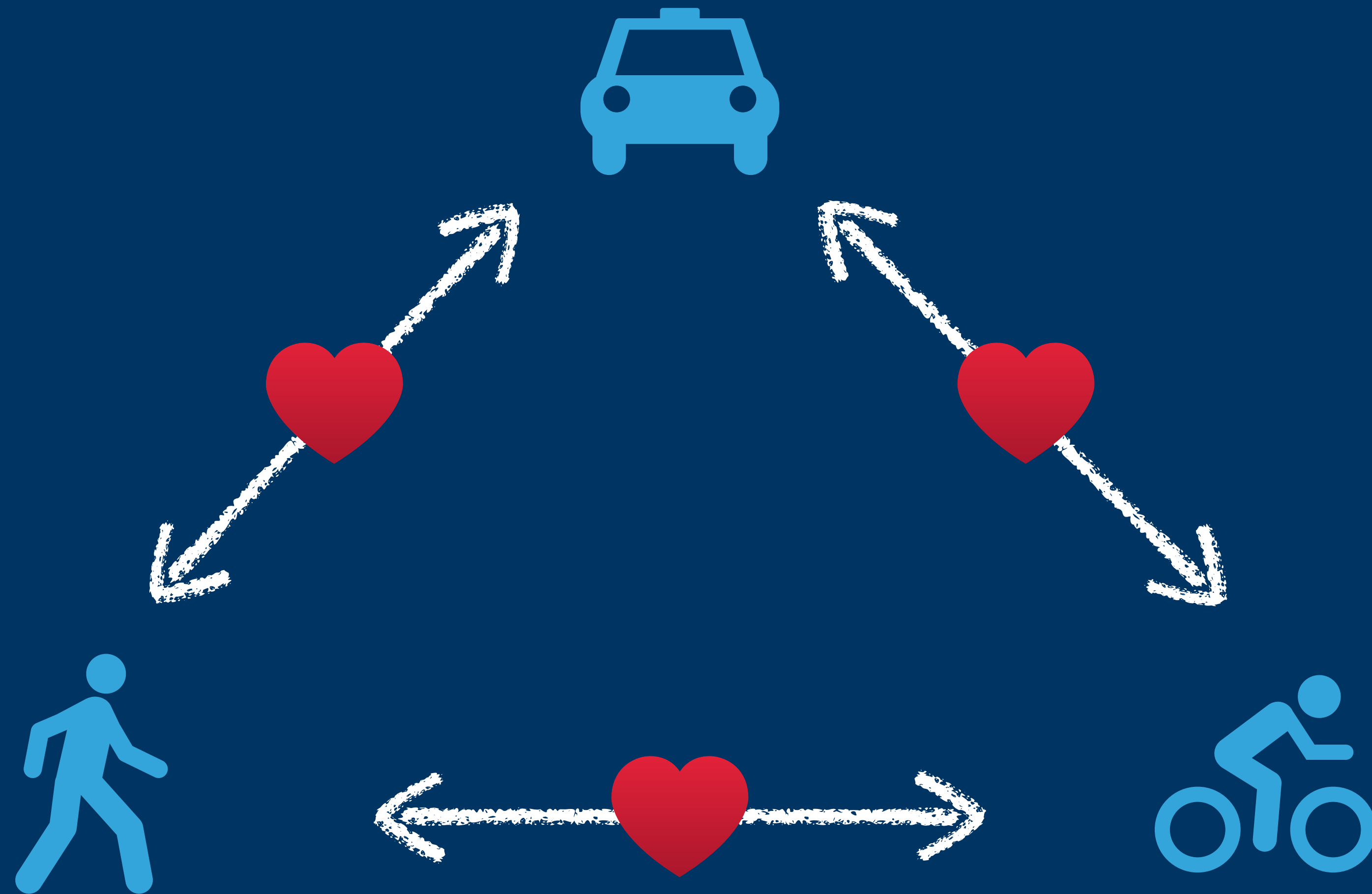
Tabone, W., De Winter, J. C. F., Ackermann, C., Bärghman, J., Baumann, M., Deb, S., Emmenegger, C., Habibovic, A., Hagenzieker, M., Hancock, P. A., Happee, R., Krems, J., Lee, J. D., Martens, M., Merat, N., Norman, D. A., Sheridan, T. B., & Stanton, N. A. (2021). Vulnerable road users and the coming wave of automated vehicles: *Expert perspectives. Transportation Research Interdisciplinary Perspectives*, 9, 100293.

<https://doi.org/10.1016/j.trip.2020.100293>

Tabone, W., Lee, Y.M., Merat, N., Happee, R., & De Winter J.C.F. (2021b). Towards future pedestrian-vehicle interactions: Introducing theoretically-supported AR prototypes. *Proceedings of the 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 209–218). Leeds, United Kingdom.

<https://doi.org/10.1145/3409118.3475149>

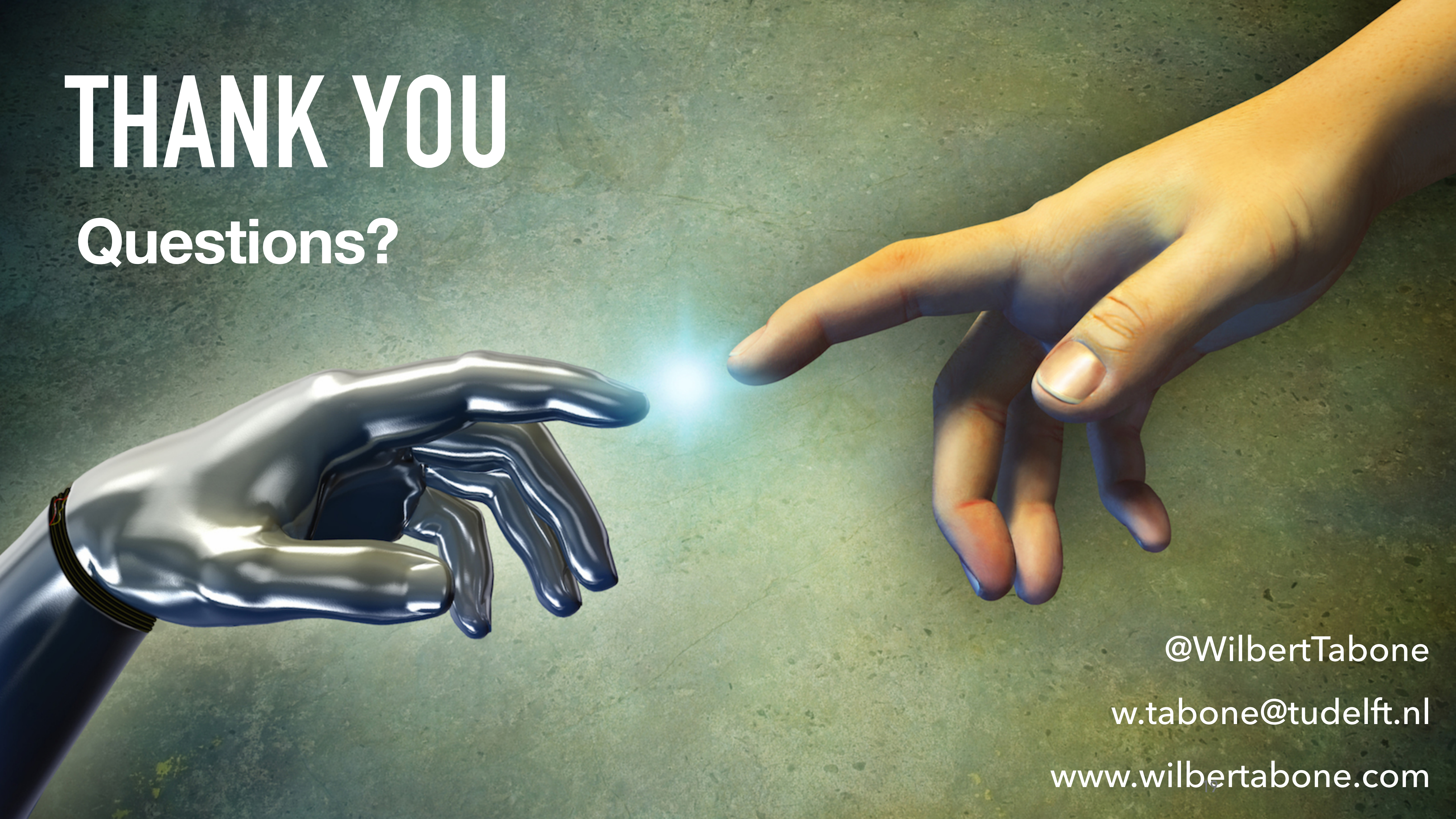
Tabone, W., Happee, R., García, J., Lee, Y. M., Merat, N., Lupetti, L., & De Winter J. C. F. (2022). Augmented reality interfaces for pedestrian-vehicle interactions: An online study. Under review.



#SpreadTheVRU-AV-Love

THANK YOU

Questions?



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