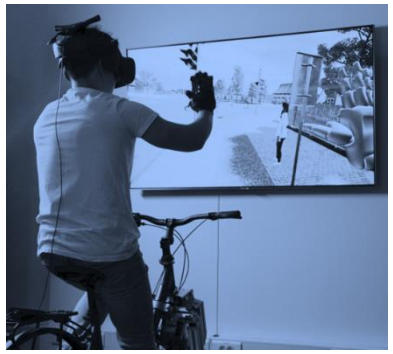
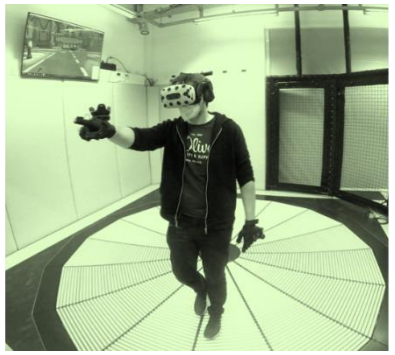


Human-in-the-Loop simulator studies as a tool to design and validate interactive communication between automated vehicles and vulnerable road users



Martin Fischer,
Gerald Temme,
Kilian Gröne,
Michaela Rehm,
Donaji Martinez Garcia

Motivation for incorporating **Vulnerable Road Users** (VRUs) in future research

- ~50% of all crashes in urban areas take place at or nearby intersections
- Intersections can be very complex and hard to solve for all road users
- Various interactions take place between pedestrians, cyclists and motorised vehicles
- It is important to understand human behaviour in order to design the future mobility system

Source:: acatech

Motivation for incorporating Vulnerable Road Users (VRUs) in future research

- With **higher levels of vehicle automation** new issues moving into the focus
  - Interaction of automated vehicles with surrounding traffic, including all non-motorised road users
    → Need for better understanding of the behaviour of pedestrians and cyclists
  - Simulation-based validation of automated vehicles
    → Need for validated models of pedestrians and cyclists

- **Passive and active safety measures** in order to protect VRUs gain importance

- **New modes of transport** appear

- General awareness of **VRUs as part of the overall transportation system** increases

⇨ Need for **Human-in-the-Loop Simulation of pedestrians and cyclists** which enables the investigation of
  - general VRU behaviour
  - their interaction with other road users
  - the effect of safety measures

without any real risk and **under repeatable conditions**

Exploring wide virtuale spaces utilizing small areas

Source: wallpaperflare.com


Source: DLR.de
Enable
realistic decisions

Source: Freepik.com

Source: Freepik.com

Design Criteria
Overview

D1) Free, unlimited 360° movement in virtual environment

D2) High immersion and presence

D3) Realistic walking/cycling/driving behavior

D4) Direct and indirect communication between all ego-participants

D2) High Immersion and Presence
Definition

	Slater et al.	*Kalawasky*
Immersion	immersion is an objective description of the technology	immersion essentially refers to the physical extent of the sensory information and is a function of the enabling technology
Presence	presence is a subjective experience and only quantifiable by the user experiencing it	presence is essentially a cognitive or perceptual parameter

Slater, M., Usoh, M., & Steed, A. (1994). Depth of presence in virtual environments. Presence: Teleoperators and Virtual Environments 3:130–144

Kalawsky, R.S. (2000). The validity of presence as a reliable human performance metric in immersive environments. Presented at Presence 2000: International Workshop on Presence, Delft, Netherla

D2) High Immersion and Presence
Visualization

TRIAN 3D BUILDER
Database Generation System

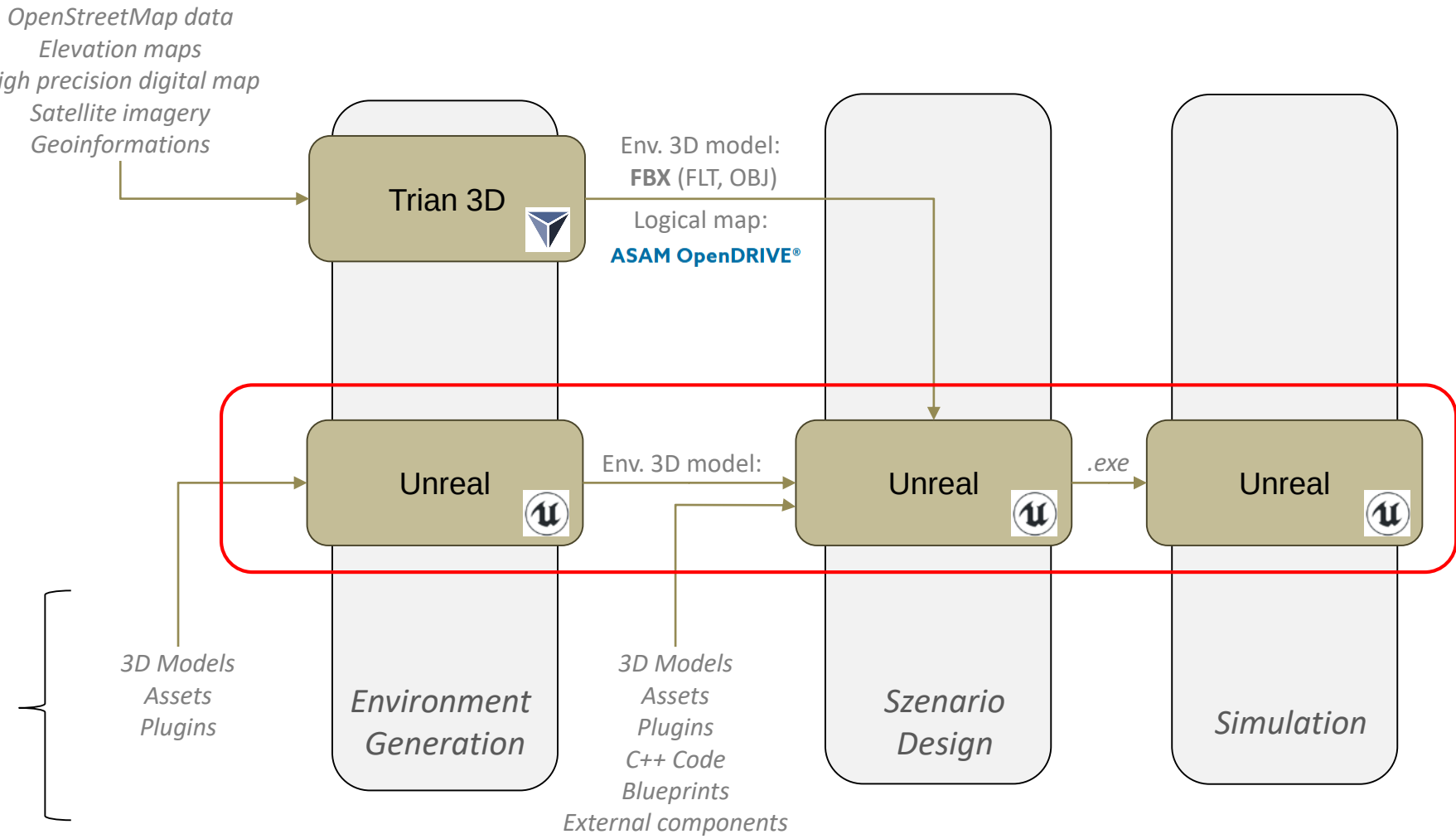
- 3D terrain generation software

UNREAL ENGINE 4 soon 5

- Open source game engine

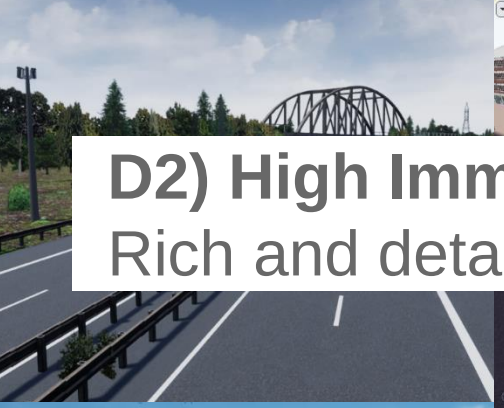
GitLab

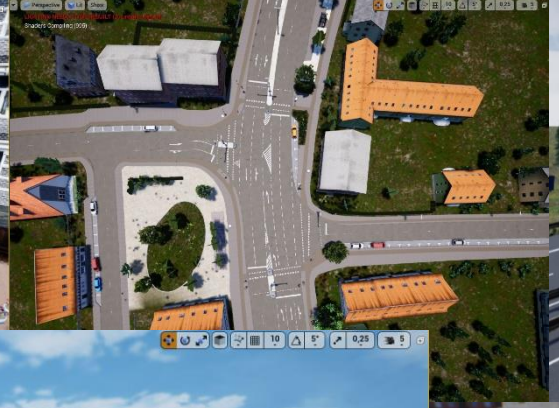
- Version management
- Persistent data storage
- Remote access

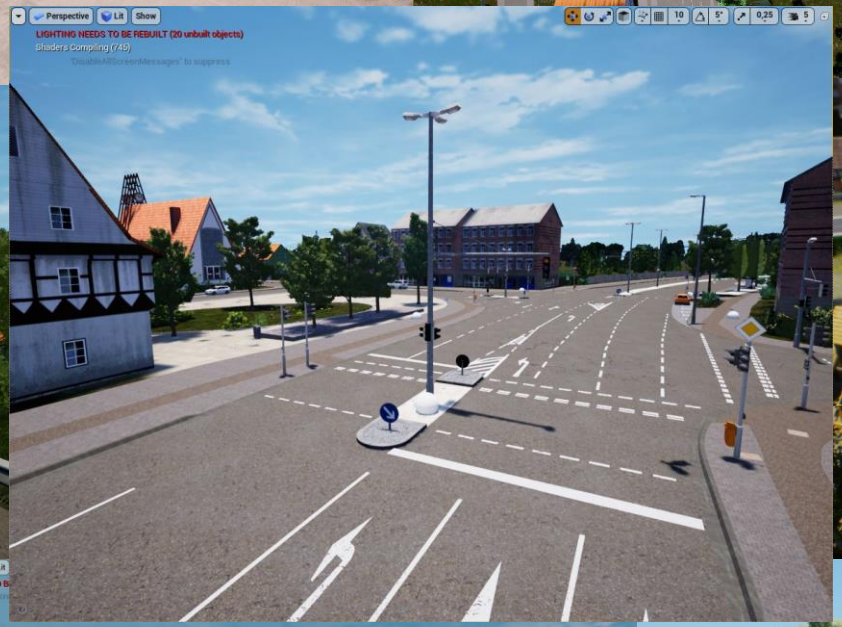


D2) High Immersion and Presence

Rich and detailed Environments










D4) Direct and indirect communication between all ego-participants

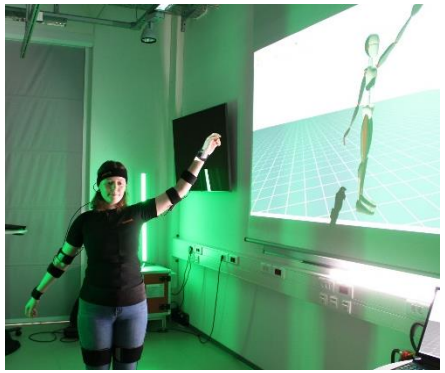
- Motion capturing and self-representation

VR Controller

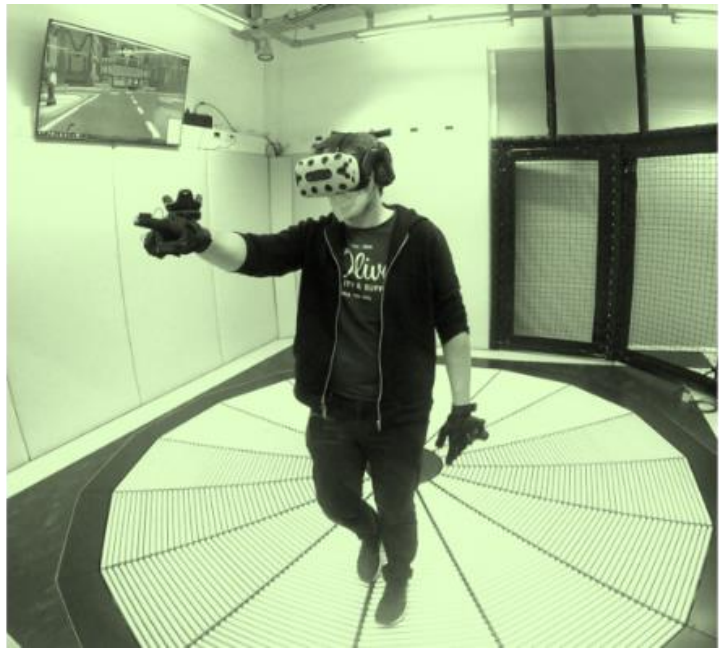
VR Tracker

Xsens body suit

Manus VR glove



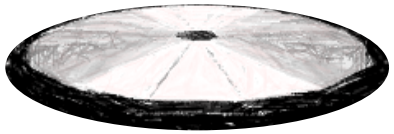
Pedestrian Simulator



Pedestrian Simulator – Central Design Aspects

- Free, unlimited 360 movement in virtual environment (D1/D3)
  - with realistic walking behavior
  - by limited available laboratory space

OmniDeck



Alternative Cyber Shoes

- High immersion and presence (D2)
  - Enables realistic decisions

VR HMD

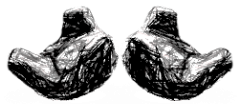
- Rich and detailed environments (D2)
  - Pedestrians are close to surfaces
  - Pedestrians pass objects with low speed
  - Pedestrians have direct interaction with environment

Unreal Engine

- Full body motion capturing (head, hands, fingers, torso, feet's) (D4)
  - For communication (direct, indirect)
  - For interaction with the virtual environment

VR Gloves &

VR Tracker or body suit



Pedestrian Simulator – Omnifinity treadmill

- 4.2 m wide 360° motorized treadmill
- 16 individually driven sections
- 48 rolls per section

- Requires VR gaming PC hardware
- Support of various tracking systems, e.g. lighthouse tracking

- Unreal Engine API available
- Supports SteamVR API and OpenVR Device Driver

- Various, parametrizable deck speed calculation algorithms
- Offers almost normal walk movement in virtual environments

Bike Simulator

Bike Simulator – Central Design Aspects

- Leaning possibility (D2/D3)
  - Enables realistic curve driving
- Perception of Road irregularities and slope (D2)
  - Enables Sensation of the road

2 DoF Motion system

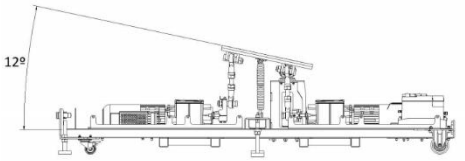


Figure 1: Pitch inclination

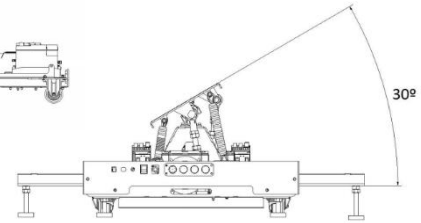
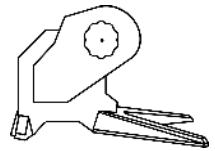


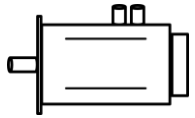
Figure 2: Roll inclination

- Realistic Force feedback (D1/D2/D3)
  - Enables realistic bike driving ability

Wheel resistance through bike trainer



Steering resistance through motor



- High immersion and presence (D2)
  - Enables realistic decisions
- Realistic speed perception (D2/D3)
  - Enables realistic bike driving ability

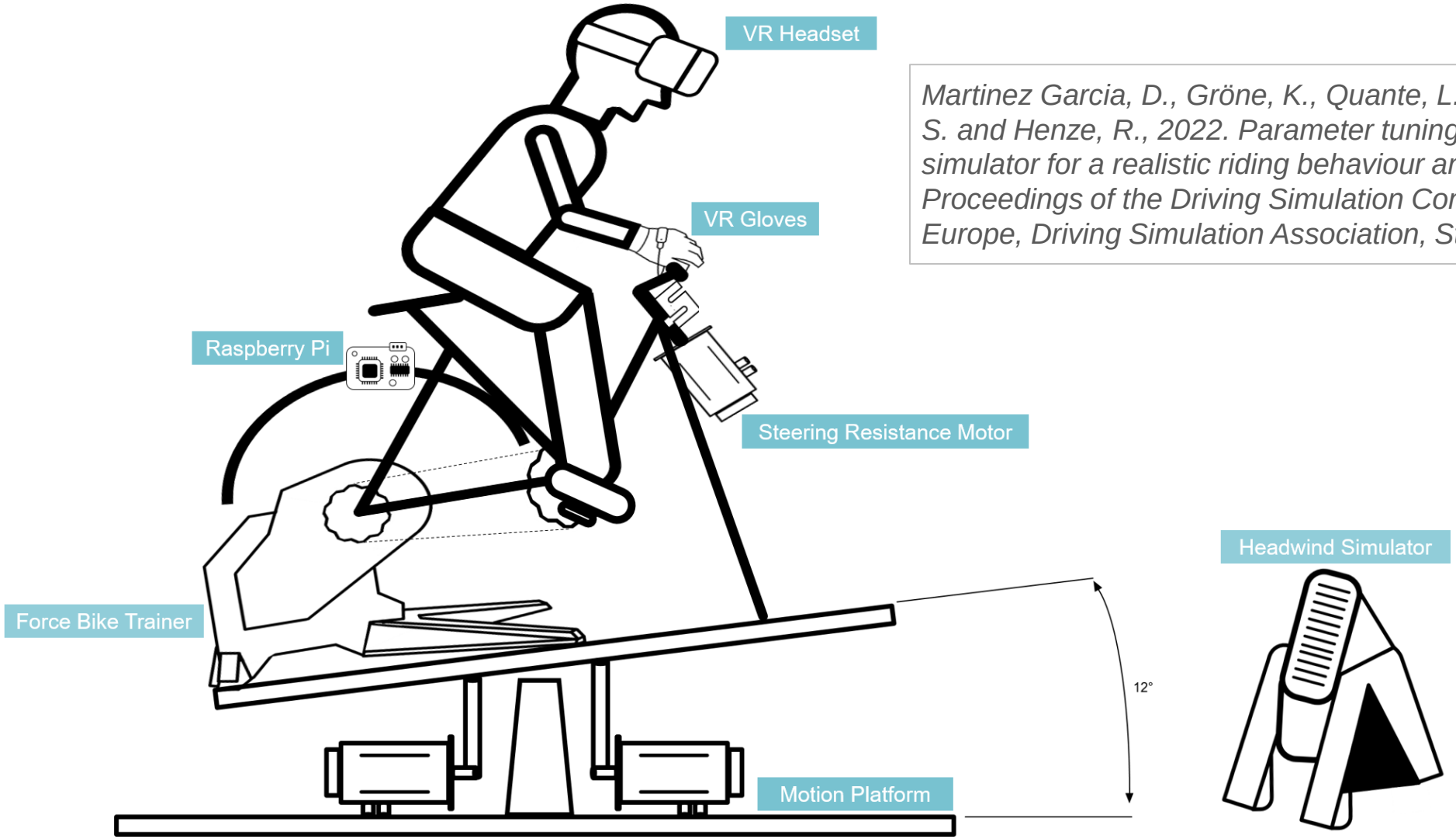
VR HMD

UNREAL ENGINE

Animation of own body for a good sense of self

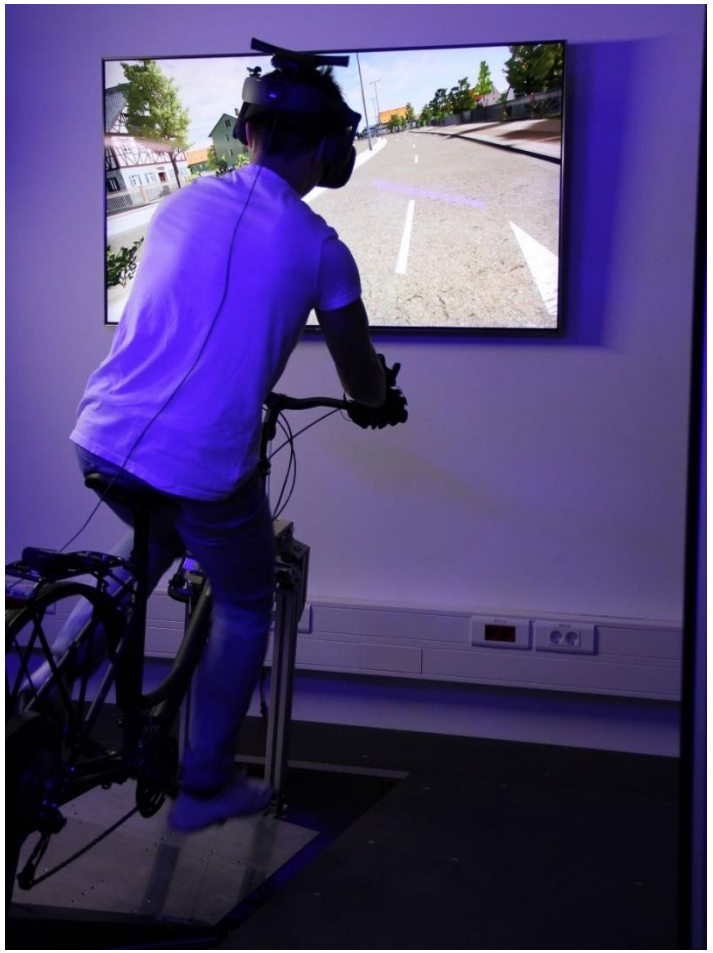
Speed dependant wind simulation

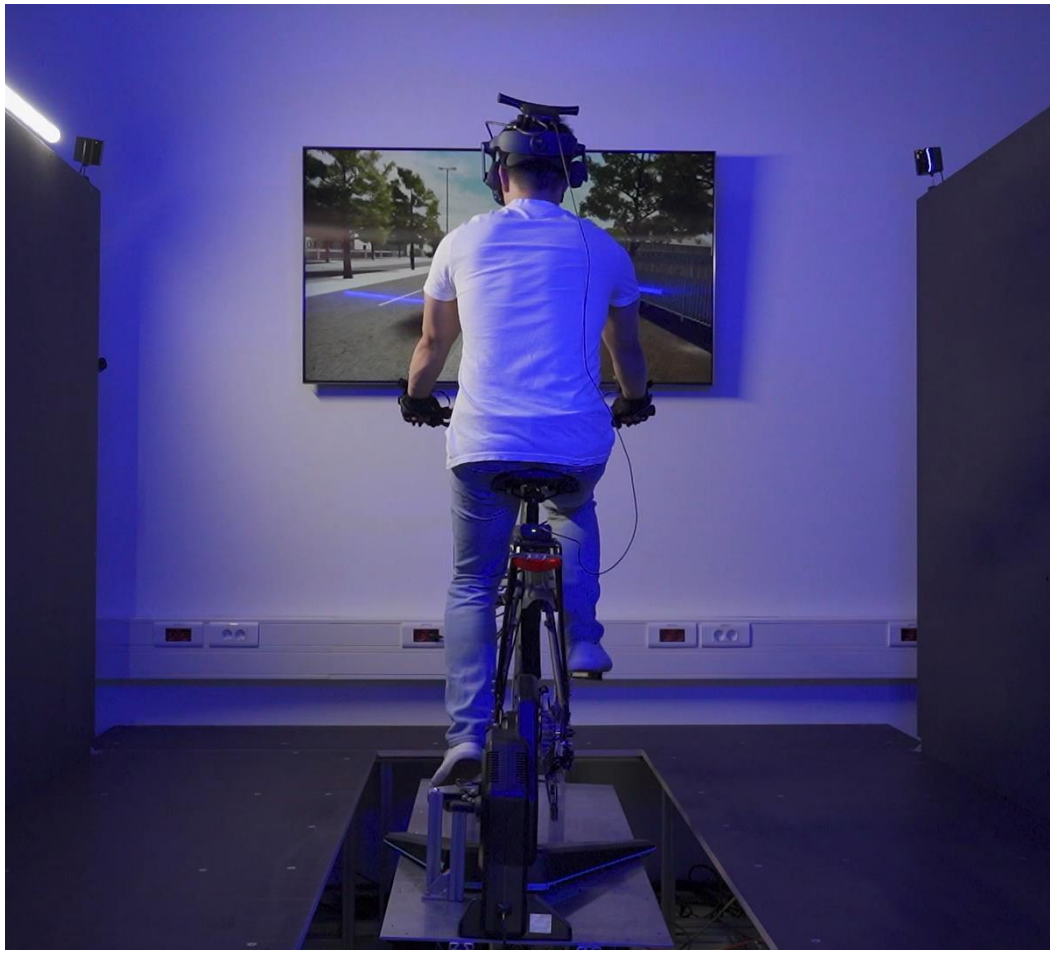
Bike Simulator – Scheme

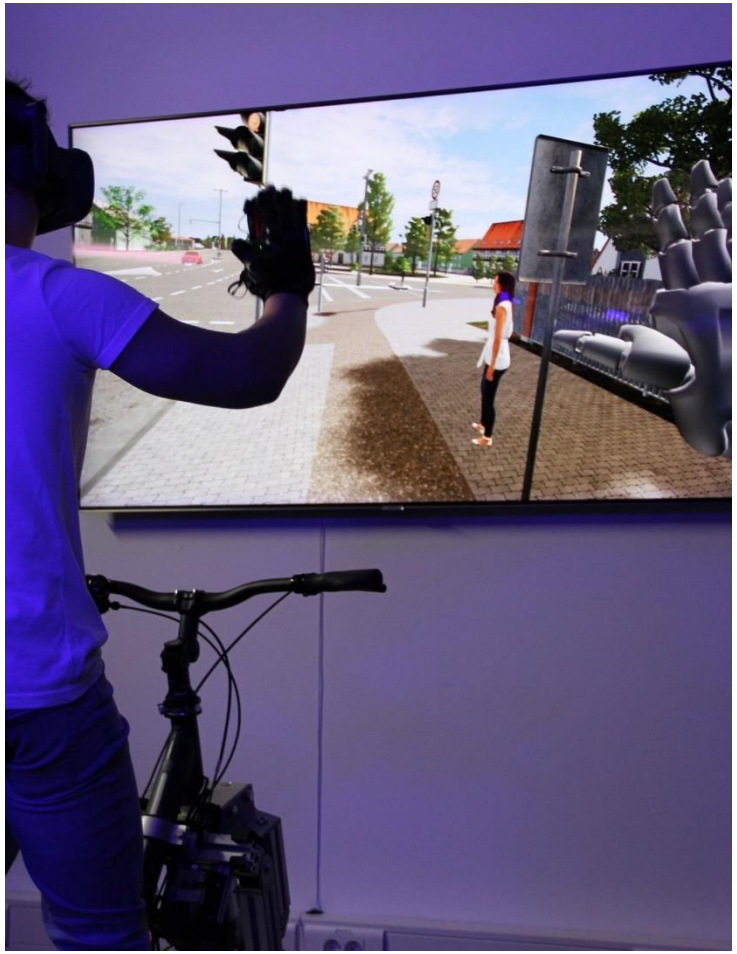


Martinez Garcia, D., Gröne, K., Quante, L., Fischer, M., Thal, S. and Henze, R., 2022. Parameter tuning of a bicycle simulator for a realistic riding behaviour and motion perception, Proceedings of the Driving Simulation Conference 2022 Europe, Driving Simulation Association, Strasbourg, France

Bike Simulator in action



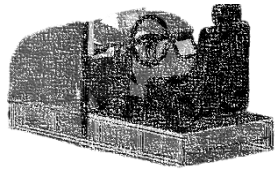




Car Simulator

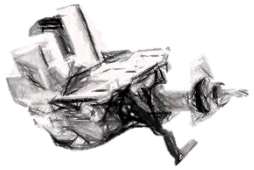
Car Simulator – Central Design Aspects

- Minimum usage of laboratory space (D1)



Fix Base Simulator

- Realistic steering and pedal force feedback (D2/D3)
  - Enables realistic car driving ability



Steering resistance through automotive Steering Wheel system
Pedal resistance through motors

- High immersion and presence (D2)
  - Enables realistic decisions

Vehicle Model, Vehicle Cockpit visualization

UNREAL ENGINE

- Support of monitor and VR-HMD visualization (D2)
  - High flexibility for research questions

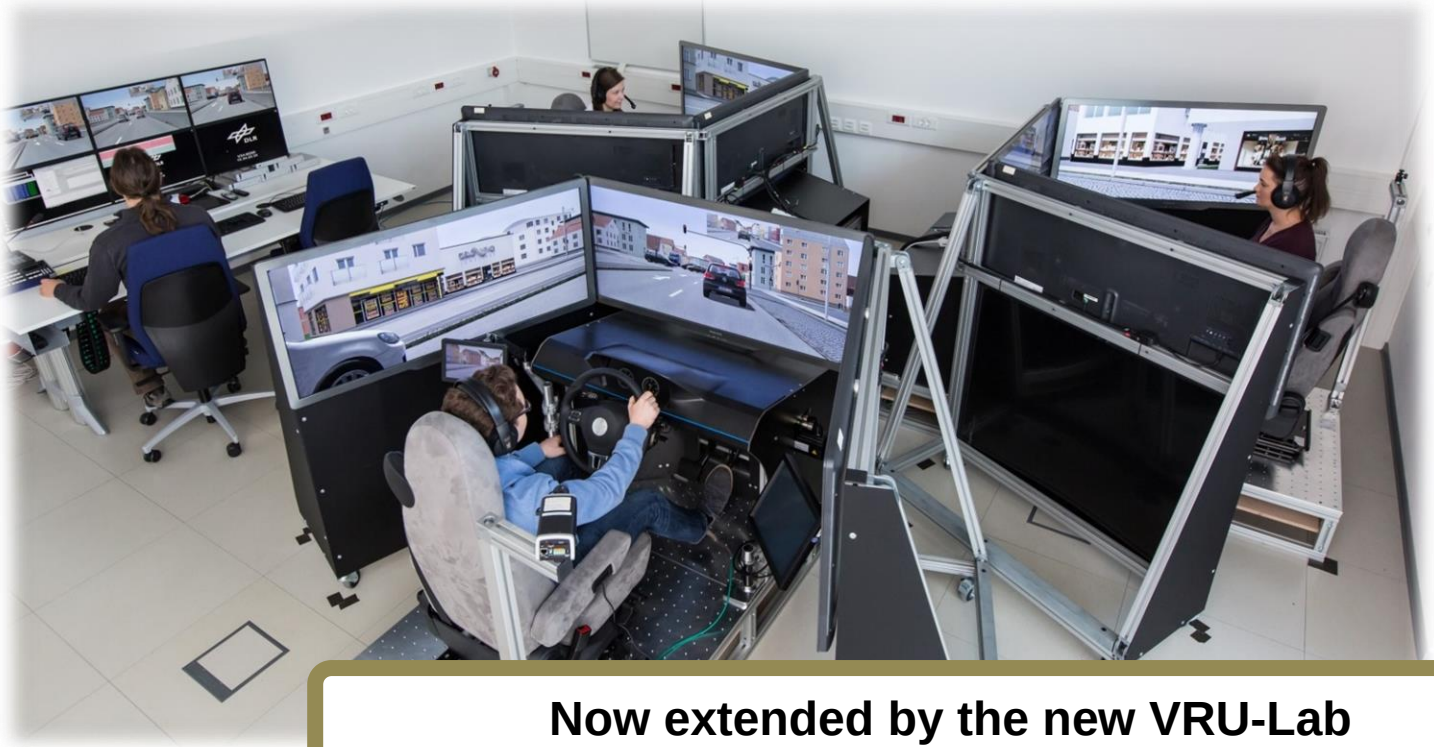
VR HMD  or Multi Monitors

- Support of body tracking (head, hands, fingers) (D4)
  - For communication (direct)

Animation of driver body for a good sense of self

MoSAIC – since 2014

- **MoSAIC** –**Mo**dular and **S**calable **A**pplication platform for **I**TS **C**omponents
  - Supports development of cooperative driver assistance & automation systems
  - So far consisted of three fixed-base driving simulators



Now extended by the new VRU-Lab

Car Simulator – Field-of-View

~210° horizontal by three UHD 4k monitors

Multi Monitor Setup

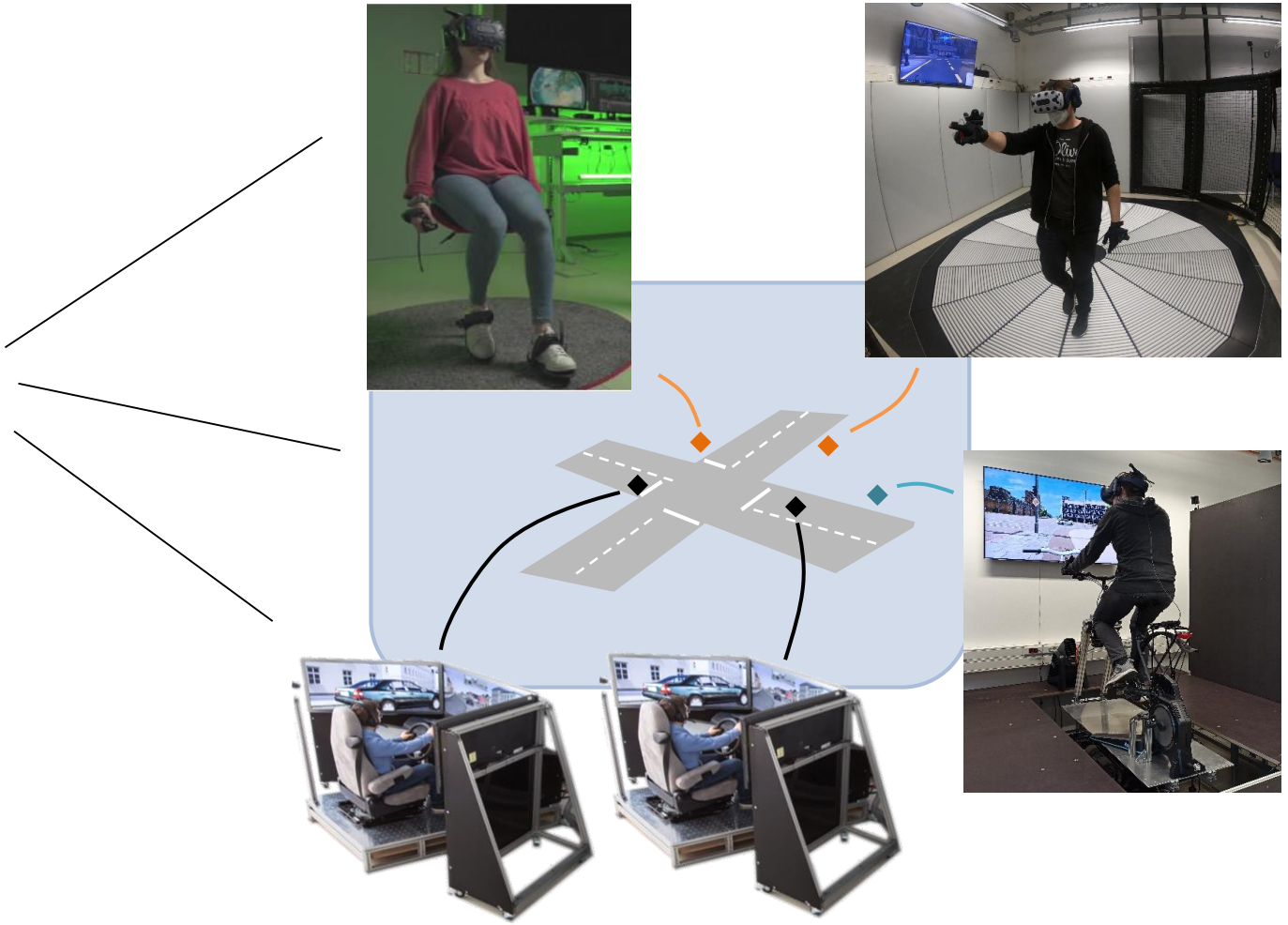
110° to 170° horizontal by equipped VR- HMD
360° with additional head rotation

VR HMD Setup

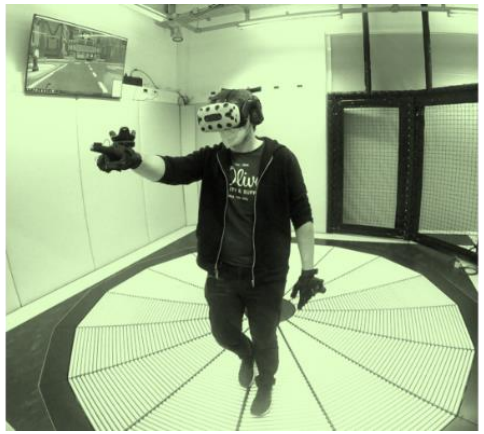
D4) Direct and indirect communication between all ego-participants

Connected Simulators

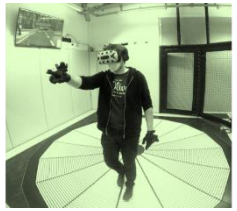
MoSAIC VRU Lab control station



Simulator Studies



VRU studies



drone acceptance

iUSIM 2021

LoD visualization & simulation metrics

VALKyRie 2022

walking behaviour & simulation evaluation

Coala 2023

VR evaluation & effect of display type

VALHaLa 2023

202x N.N.

N.N. 202x

Interaction behaviour

@City-AF 2022

202x STADT:up

Interaction behaviour

Bike Eval 2021

Bike Eval 2 2022

simulator evaluation & simulation metrics

@CITY – Overview

Goal

- **Evaluation of** internal and external **HMI**
- **Description of interactions** in between traffic participants
- Evaluation of using **Multi-User-Simulation as a method** for evaluating interaction behavior

Research Intersection in Brunswick

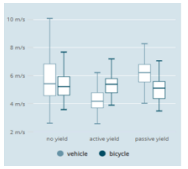
Car

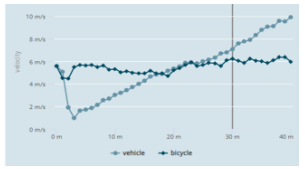
Bicycle

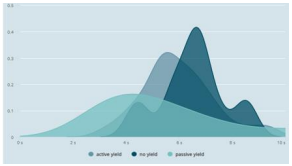
Internal HMI

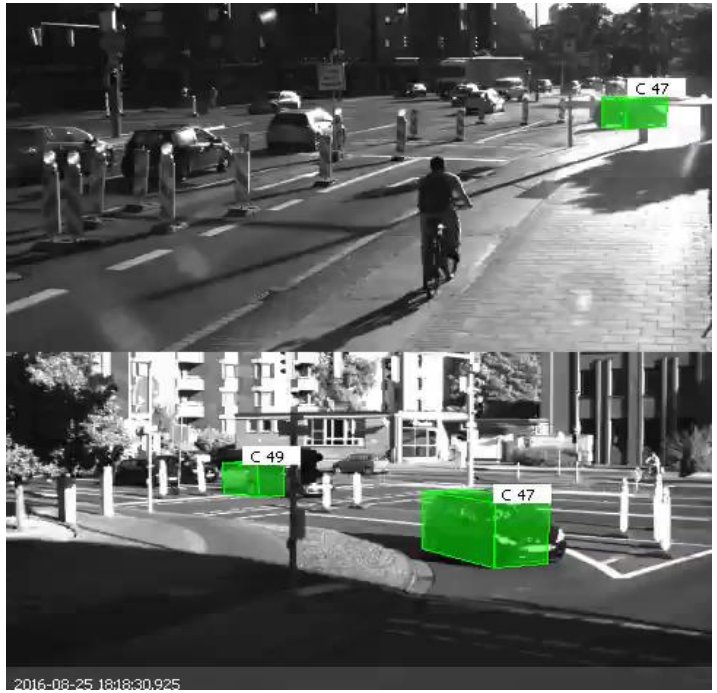
External HMI

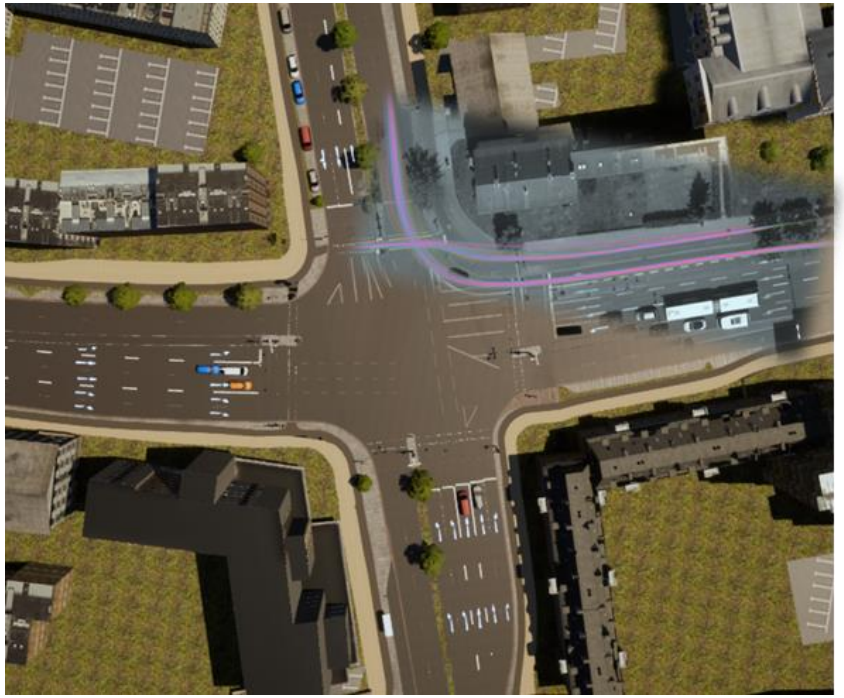
@CITY – Real world interaction behavior







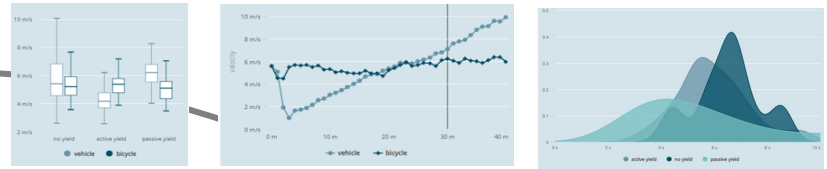


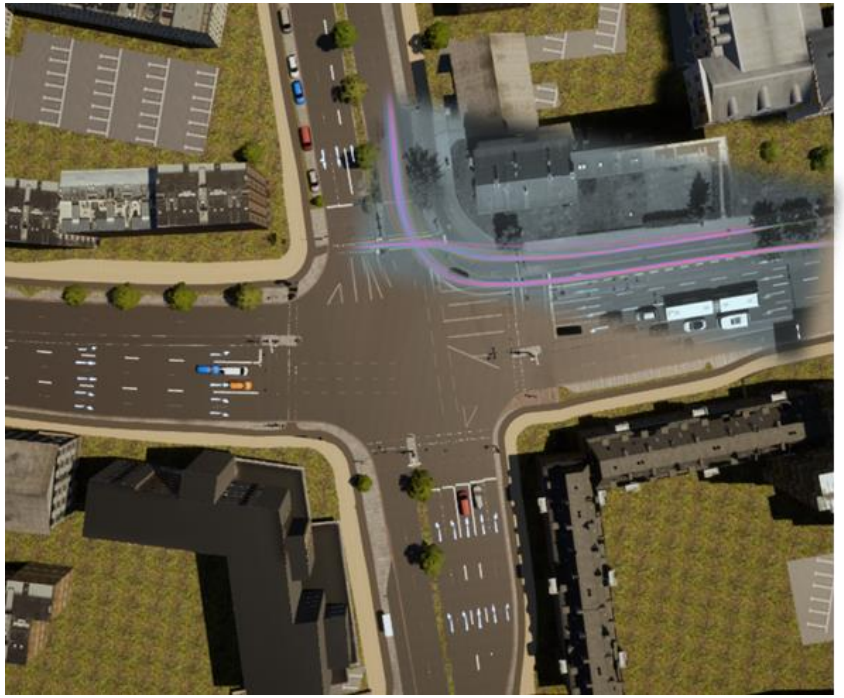


Observation of driver cyclist interaction

@CITY – Virtual interaction behavior study

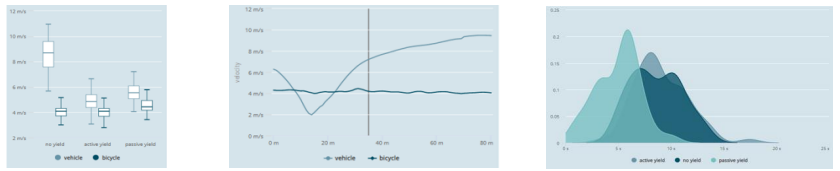
Virtual replication of interaction scenario



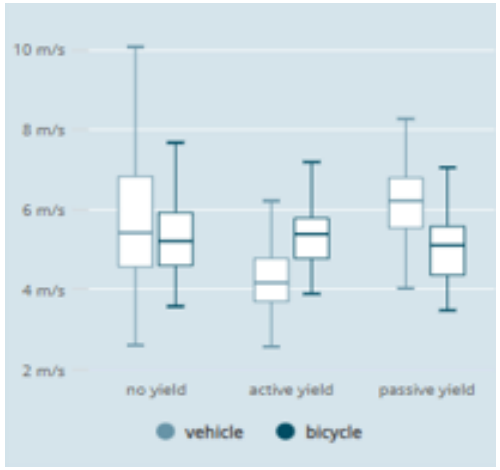


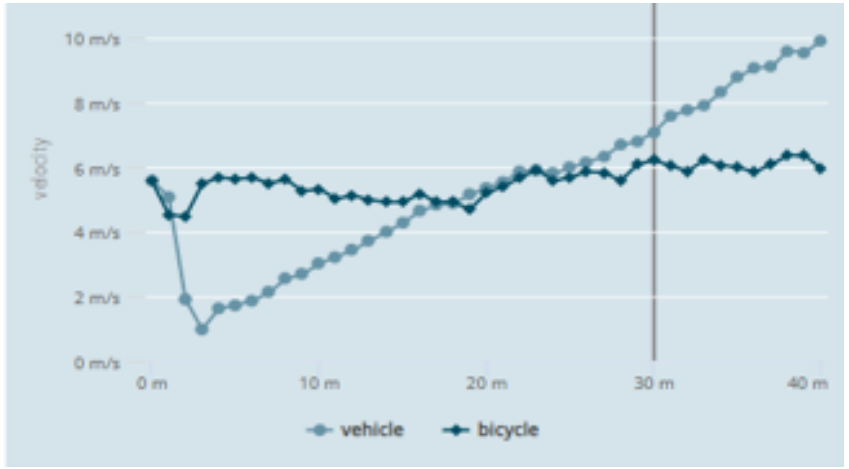
External HMI

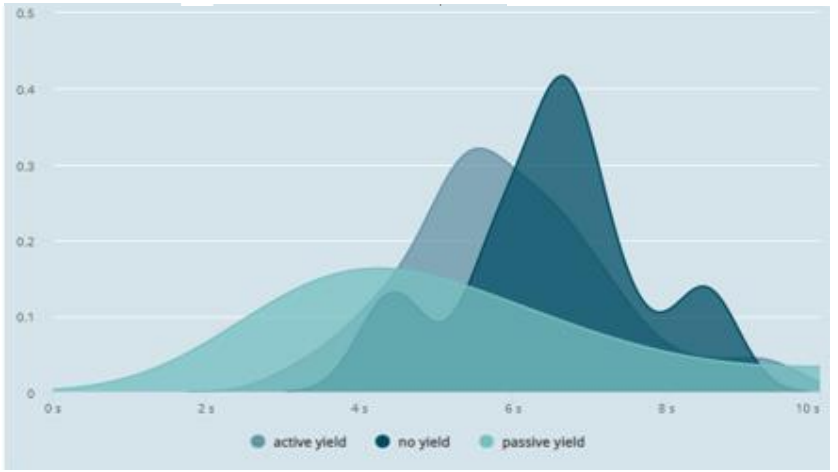
Internal HMI

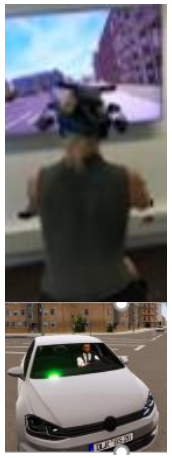


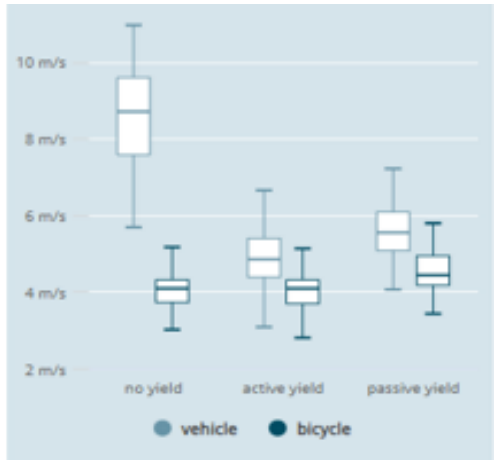
@CITY – Virtual interaction behavior study results

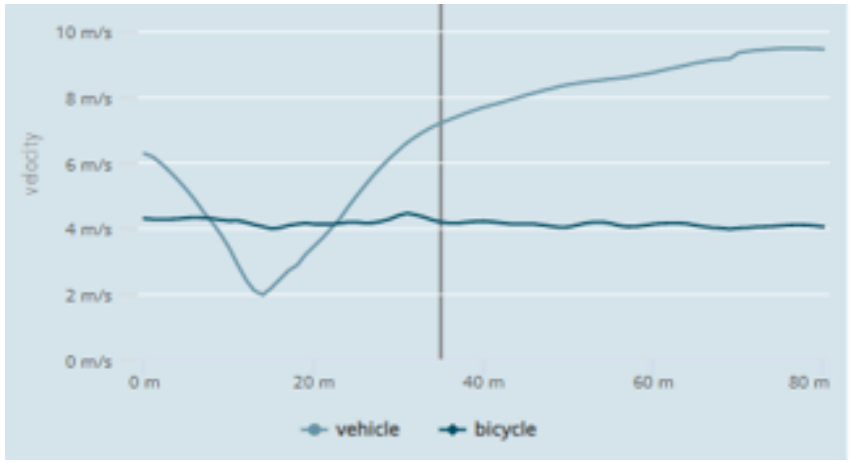


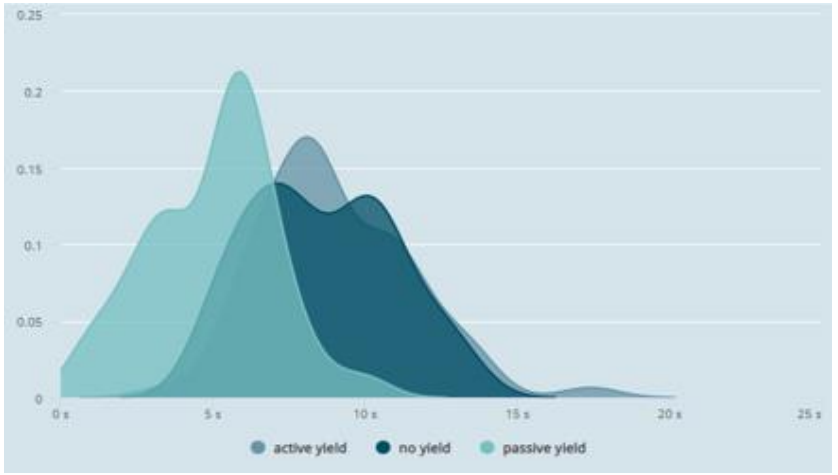




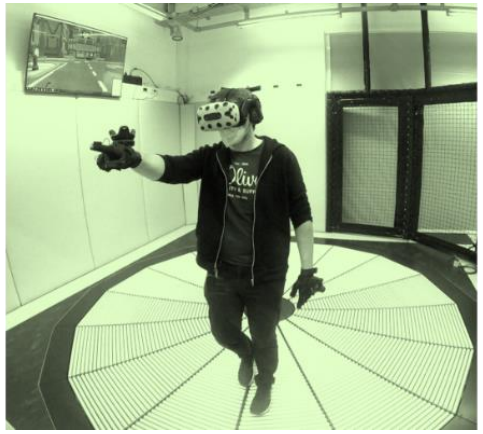






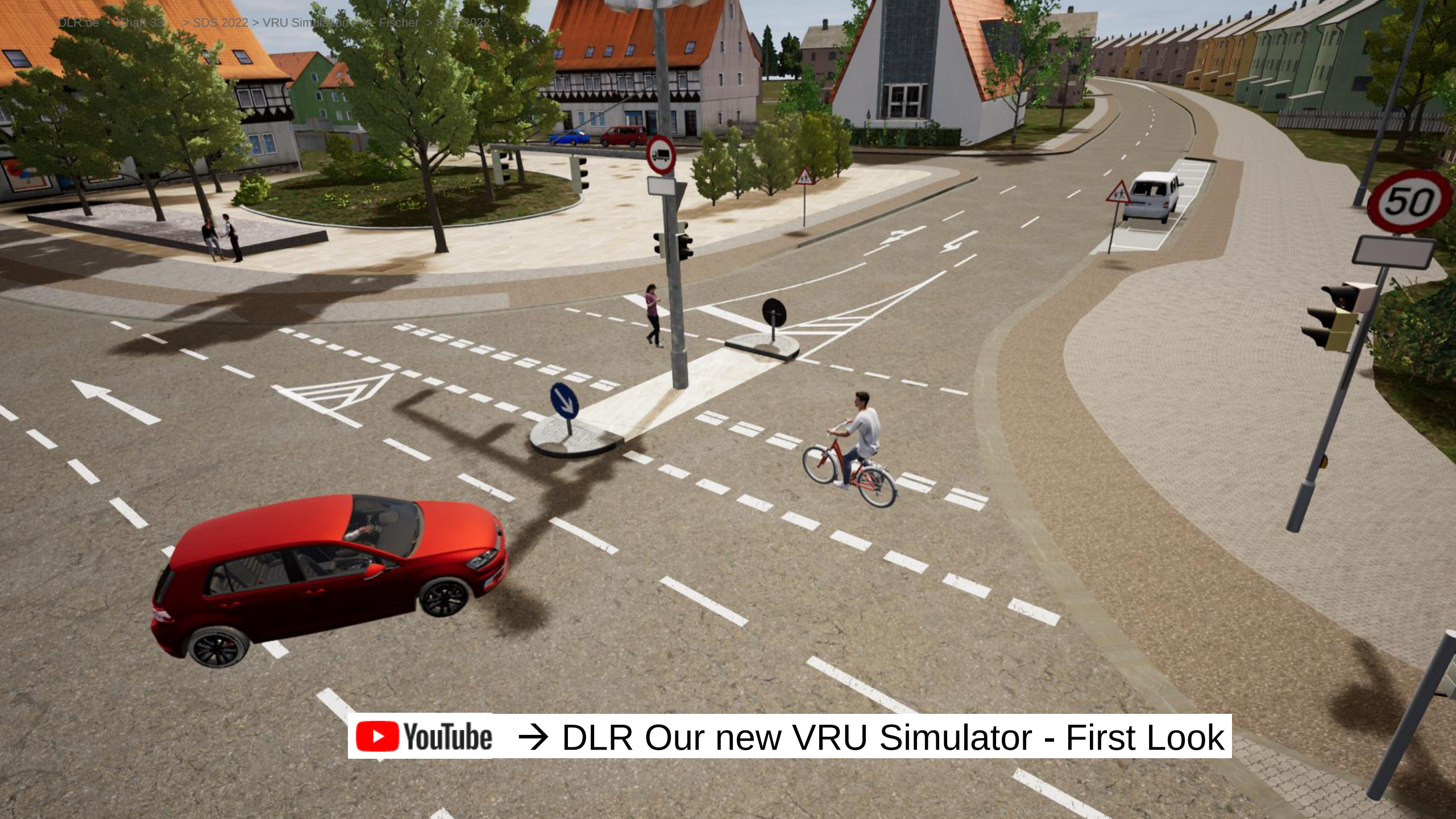


Summary & Outlook

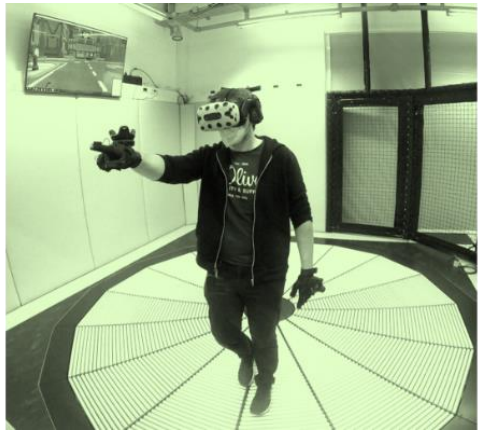


Summary & Outlook

- Need for better understanding of the **behaviour of pedestrians and cyclists**
- Need for **Human-in-the-Loop Simulation of pedestrians and cyclists** which enables the investigation of their interaction with other road users
- In order to get **valid simulation results**, **simulator design** should enhance **presence** and minimize **simulator sickness** effects
- **Future challenges of interaction research** will be
  - … the design of multi-user scenarios
  - … the appropriate representation of gestures to allow for direct communication
  - … the appropriate representation of postures & body movements to allow for indirect communication
  - … the validation of pedestrian and bicycle simulators


50
YouTube
→ DLR Our new VRU Simulator - First Look

Thank You For Your Attention!



Dr. Martin Fischer | Team Leader „Human-Centered Simulation“
+49 531 295 3476 | ma.fischer@dlr.de
www.DLR.de | Institute of Transportation Systems