DSC 2022 EUROPE VR

Driving Simulation & Virtual Reality Conference & Exhibition

A VRU-simulator for the evaluation of pedestrian- and cyclist-vehicle interaction

Design criteria and implementation

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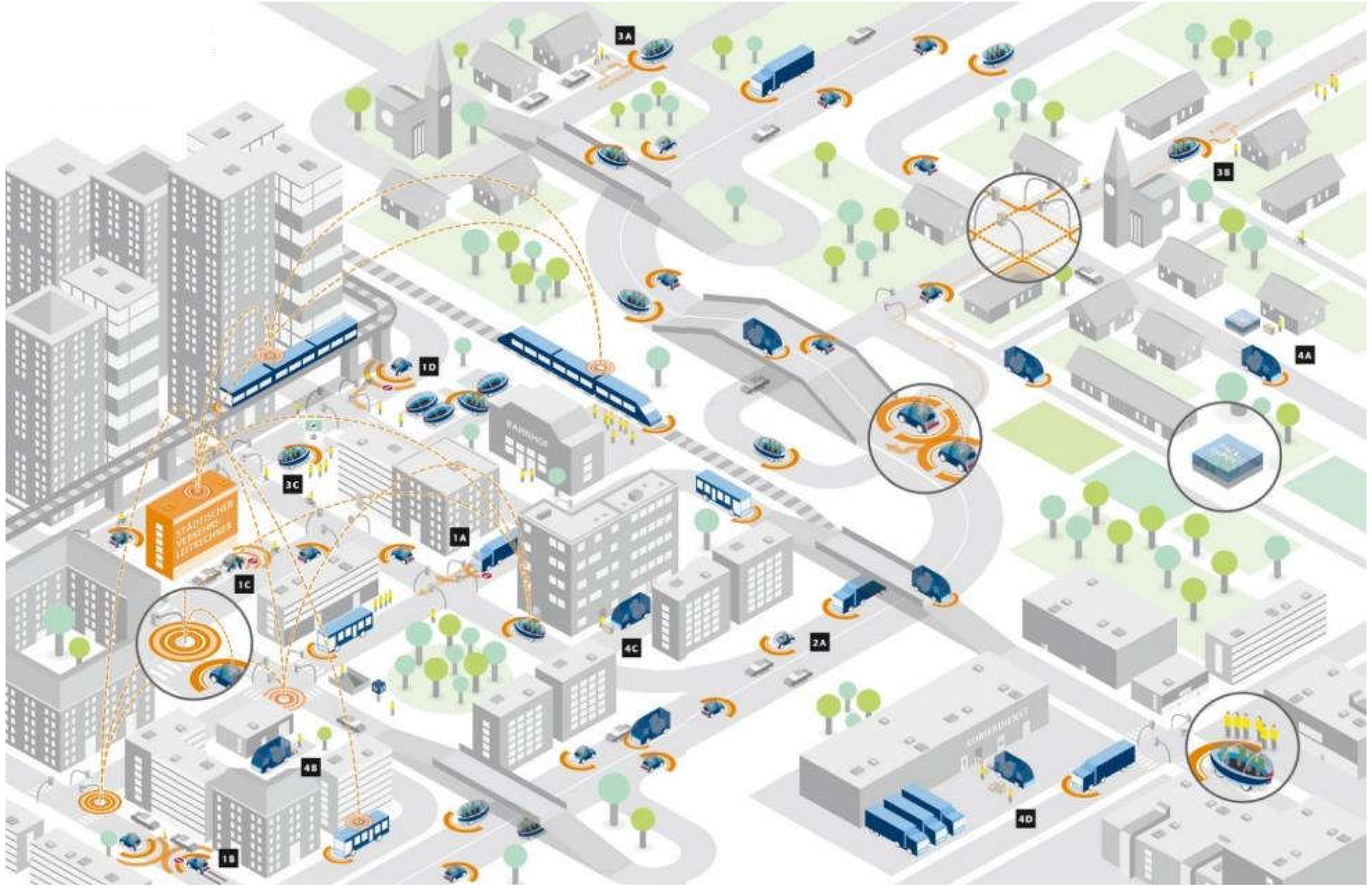
Strasbourg

September 14th – 16th 2022

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

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

D1) Free, unlimited 360° movement in virtual environment

Visualization

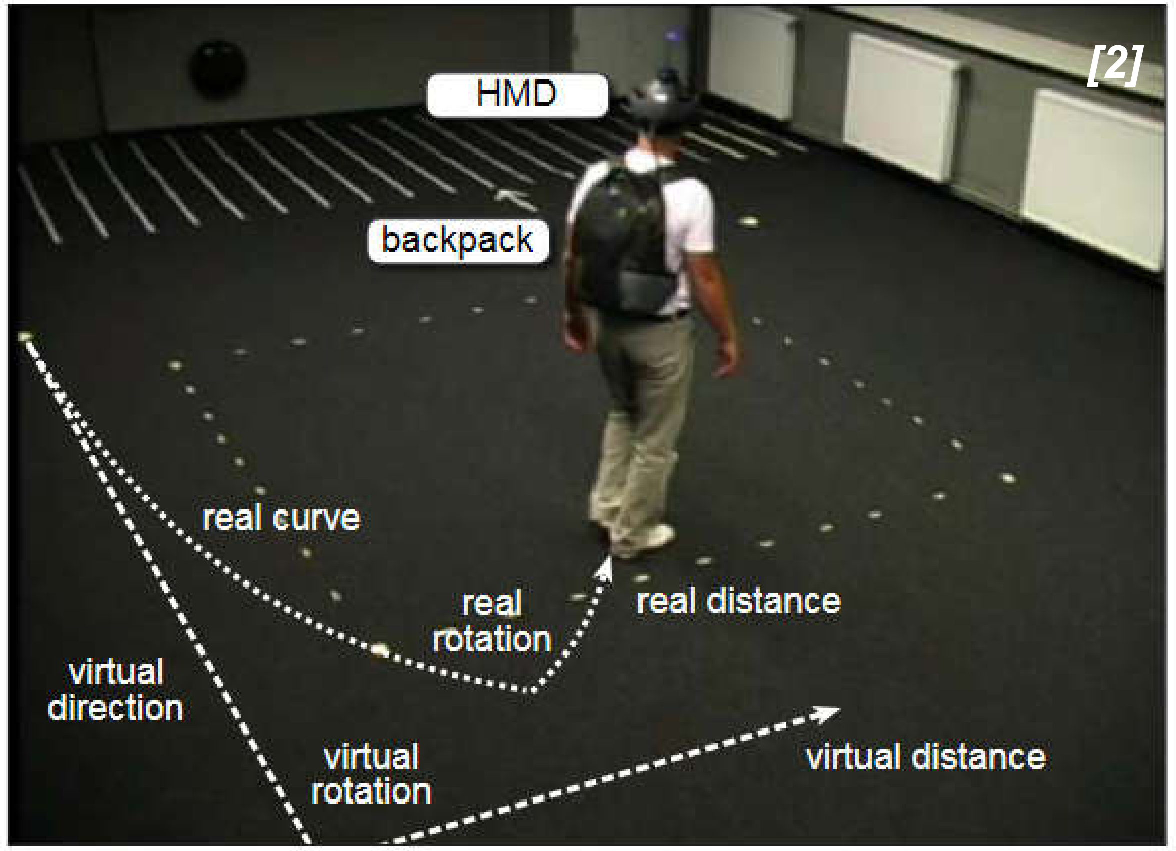
- 360° field-of-view enabled by VR-HMDs

- Important characteristics
    - Direct Field-of-view
    - Resolution
    - Frame rate
    - Weight
    - Visual Robustness

D1) Free, unlimited 360° movement in virtual environment

Moving around in the virtual world (Pedestrian Simulator)

- Free walking
  - High realism
  - Scenario area limited to available space



- Redirected walking, teleporting
  - Manipulated realism
  - Scenario area limited to available space to a certain extent

- Treadmill
  - Unclear realism
  - Scenario areas not limited

[1] https://www.ifsttar.fr/en/exceptional-facilities/simulators/equipement/simulateurs_de_conduite_pour_lanalyse_des_comportements_de_conduite_induits_par_des_facteurs_inte/

[2]: F. Steinicke, G. Bruder, J. Jerald, H. Frenz, and M. Lappe, 2010. Estimation of Detection Thresholds for Redirected Walking Techniques, IEEE Trans Vis Comput Graph. 16 (1): 17–27, doi:10.1109/TVCG.2009.62.

[3]: pictures are taken from the respective manufacturer's homepage

D1) Free, unlimited 360° movement in virtual environment

Moving around in the virtual world (Bicycle Simulator)

- Different Solutions which allow for unlimited cycling
  - Commercial
  - Research Developments
  - Combined

[1] https://www.kurtkinetic.com/trainers

[3] www.garmin.com

[2] https://psychology.uiowa.edu/hank-virtual-environments-lab/bicycling-pedestrian-simulator-research

[4] https://wivw.de/en/news/silab/379-wivw-invests-in-progressing-the-bicycle-simulato

[6] http://bicycle.tudelft.nl/schwab/Bicycle/

[5] https://www.simutech.de/produkte/verkehrserziehung/e-bike-pedelec-simulator/

[7] https://simusafe.eu/deliverables/

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

TRIAN3DBUILDER
Database Generation System

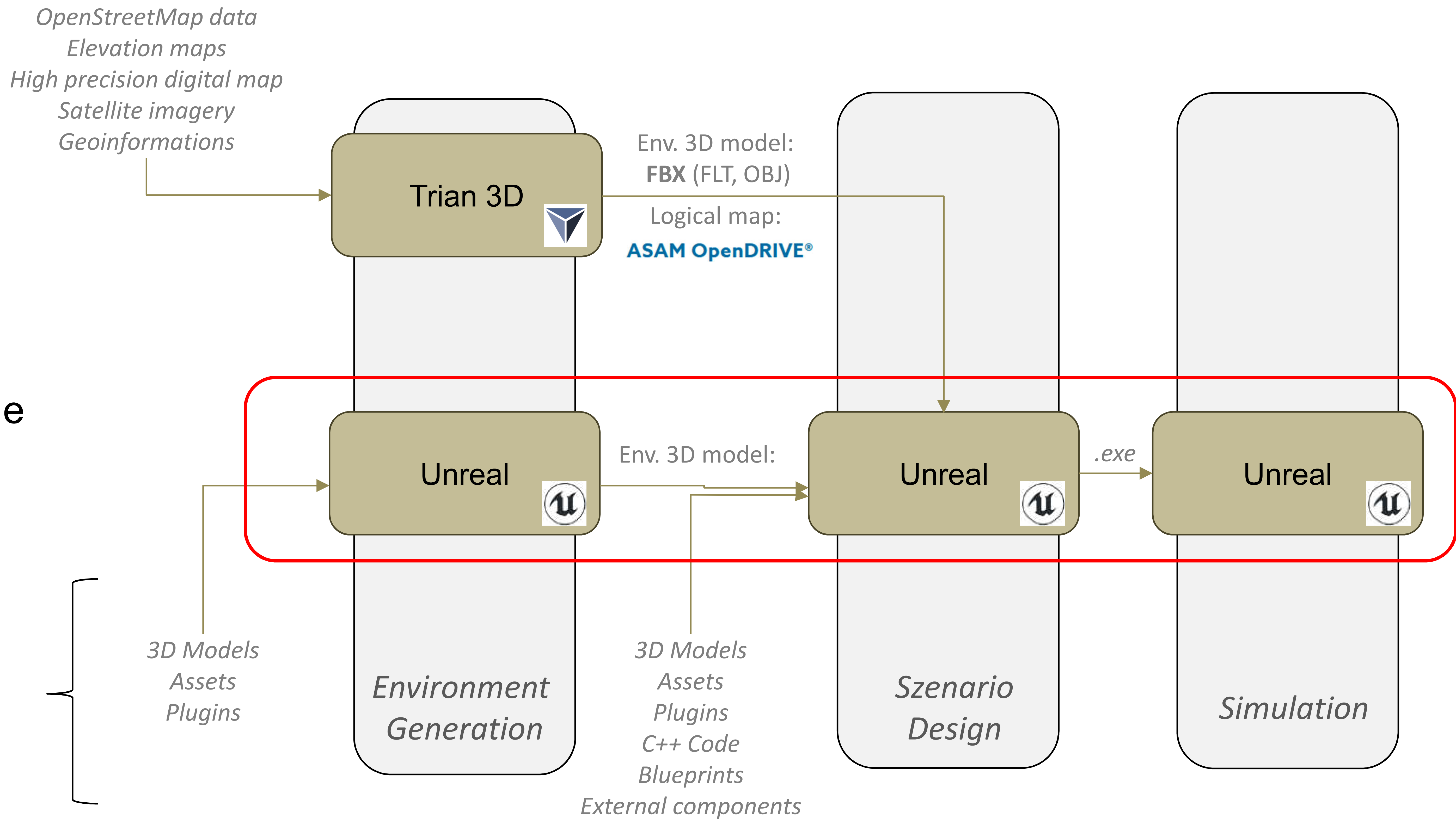
- 3D terrain generation software

4
UNREAL ENGINE

- Open source game engine

GitLab

- Version management
- Persistent data storage
- Remote access



D2) High Immersion and Presence
Rich and detailed Environments

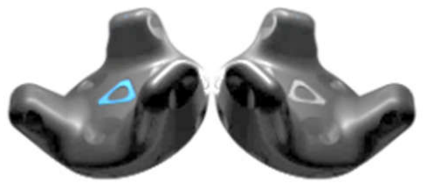
D2) High Immersion and Presence

- Supported by D1) Free, unlimited 360° movement in virtual environment
    - VR glasses
    - Treadmill/moving base
- Motion capturing and self-representation
- Realistic force feedback
- Headwind (Bicycle Simulator)
- Environmental sounds
- Simulation and Scenario Design

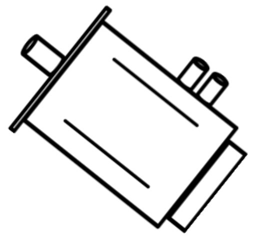
VR glasses

VR Controller

Xsens body suit



VR Tracker



Force feedback motor

Headwind generator

Manus VR glove

D3) Realistic cycling

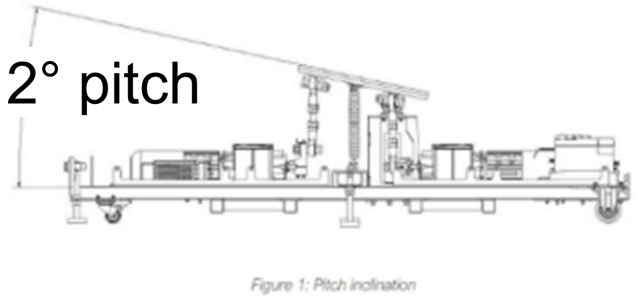
Moving around in the virtual world (Bicycle Simulator)

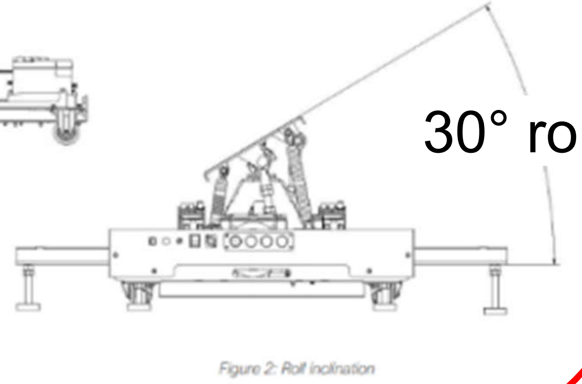
- Supported by D1) Free, unlimited 360° movement in virtual environment
- Supported by D2) High Immersion and Presence

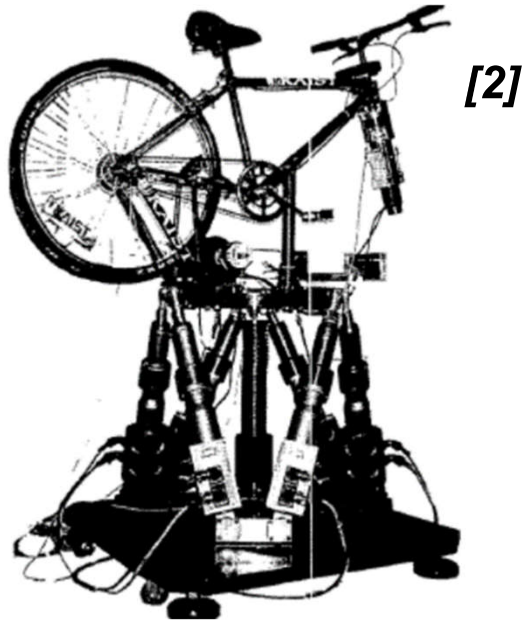
Criteria for motion base

- Enable leaning possibility for realistic curve driving
- Enable Sensation of the road
  - Elevation
  - Road surface
- Limited lab space

2 DOF







6 DOF

8 DOF

[1] simumak.com/en/motorcycle-simulator/

[2] Dong-Soo Kwon et al., "KAIST interactive bicycle simulator," Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No.01CH37164), 2001, pp. 2313-2318 vol.3, doi: 10.1109/ROBOT.2001.932967

[3] https://www.vinnova.se/en/p/bikesim---development-and-demonstration-of-an-anvanced-bicycle-simulator/

D3) Realistic walking behavior

Moving around in the virtual world (Pedestrian Simulator)

Product	Technology	Physiology	Picture*
Omnideck (S) *www.omnifinity.se*	Active electromagnetic treadmill with numerous small roll segments	Normal upright position. Normal foot movement.	
Infinadeck (US) *www.infinadeck.com*	Active electromagnetic x/y-treadmill	Normal upright position. Normal foot movement.	
Virtualizer (D) *www.cyberith.com*	Passive body support.	Forward leaning. Backward foot movement	
KatVR (CN) *www.kat-vr.com*	Bowl to guide foot movements backwards. Hip and thigh fixtures.	Upright position. Parabolic transmission of feet.	
Cyber Shoes (US) *www.cybershoes.com*	360° spinning chair	Sitting position. Backward foot movement	

** pictures are taken from the respective manufacturer's homepage*

D4) Direct and indirect communication between all ego-participants

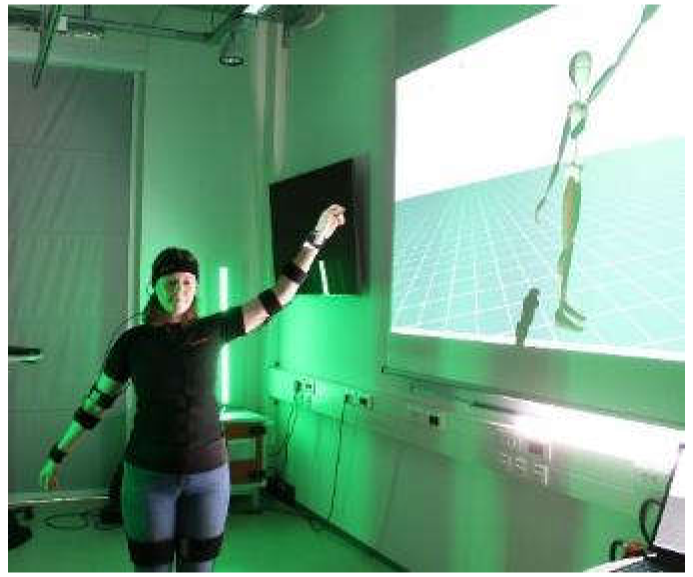
- Motion capturing and self-representation

VR Controller

VR Tracker

Xsens body suit

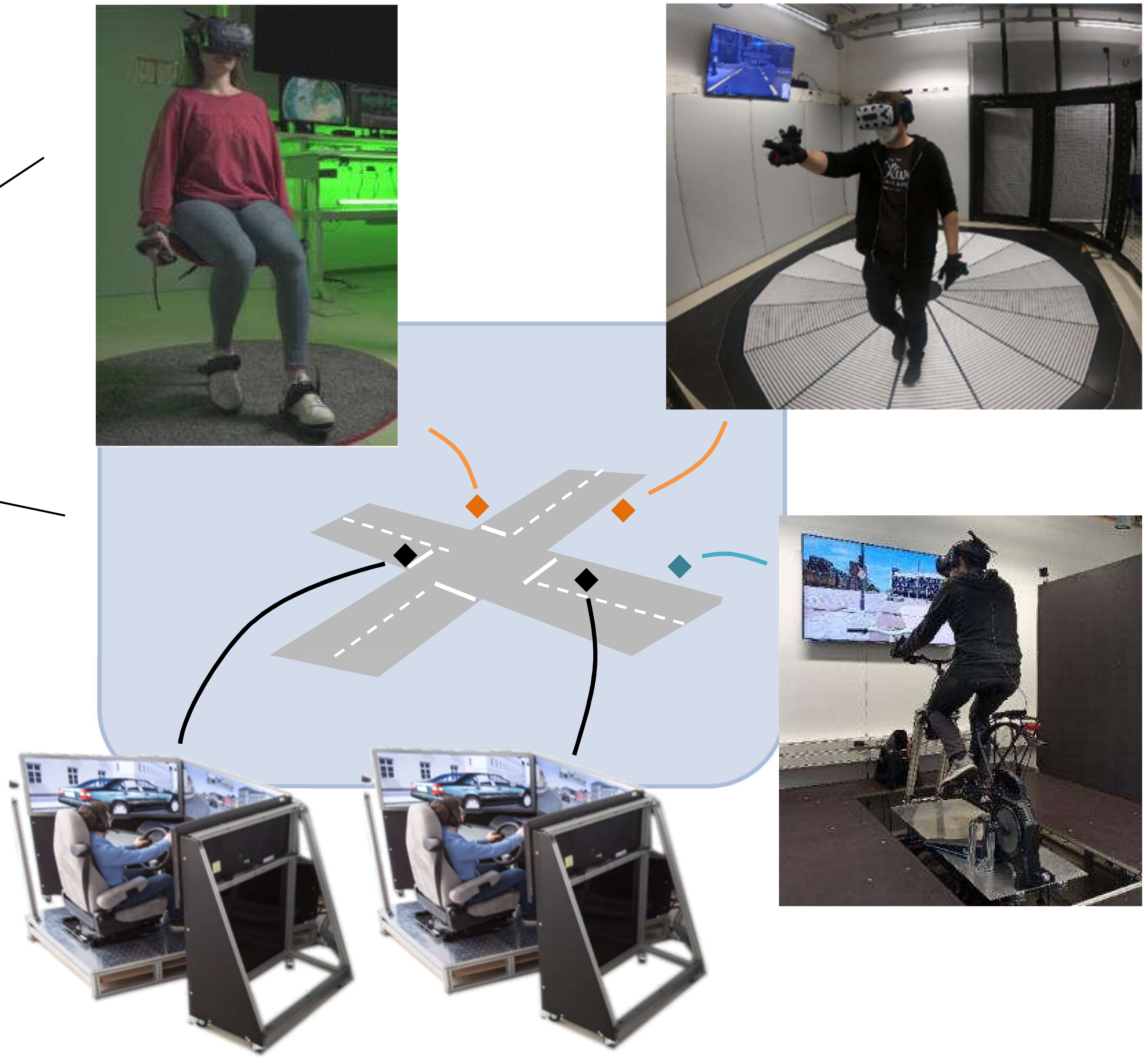
Manus VR glove

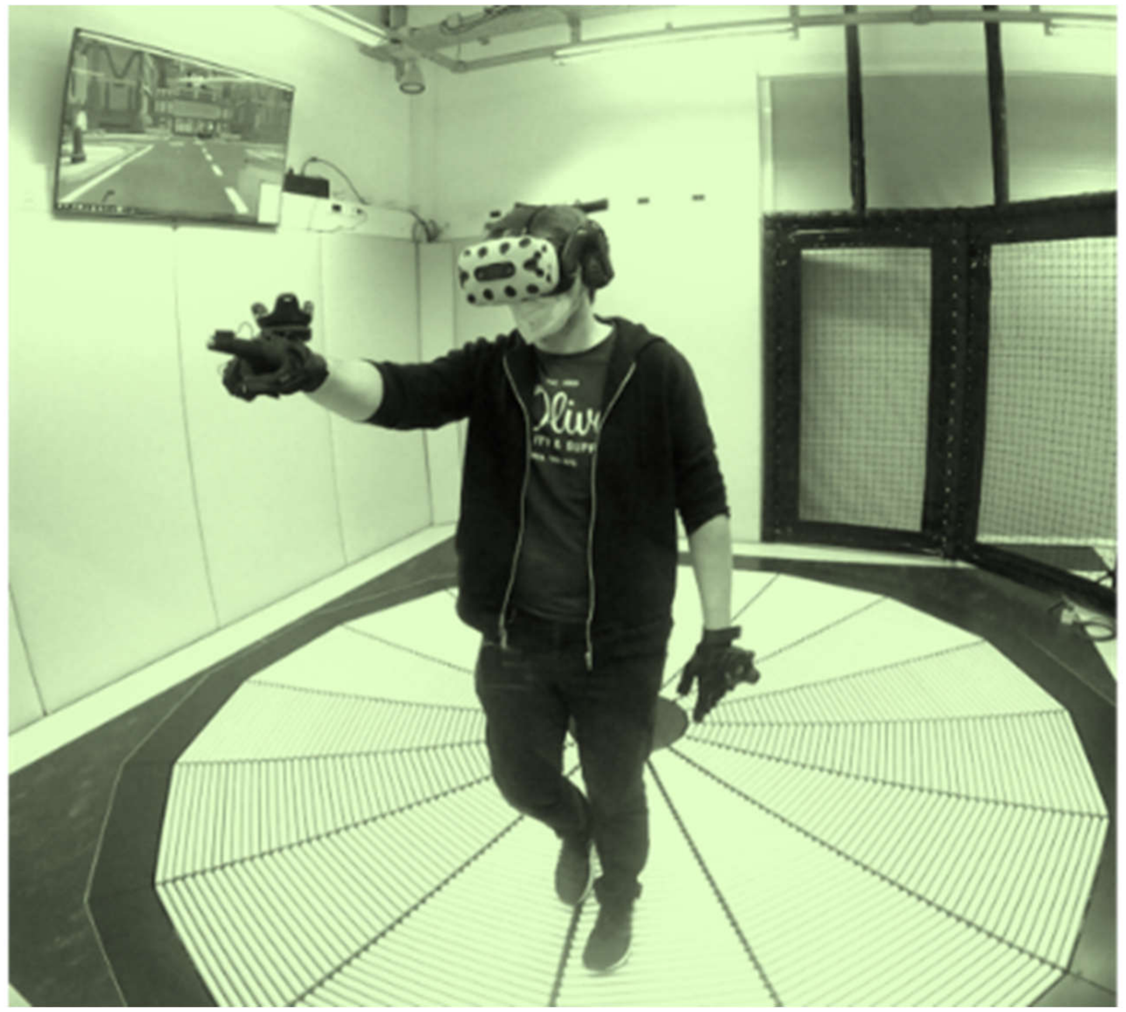


D4) Direct and indirect communication between all ego-participants

Connected Simulators

MoSAIC VRU Lab control station



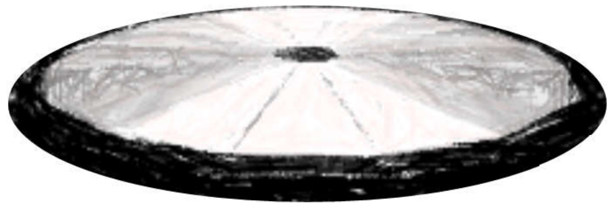


Pedestrian Simulator

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

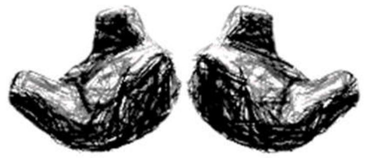
VR HMD

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

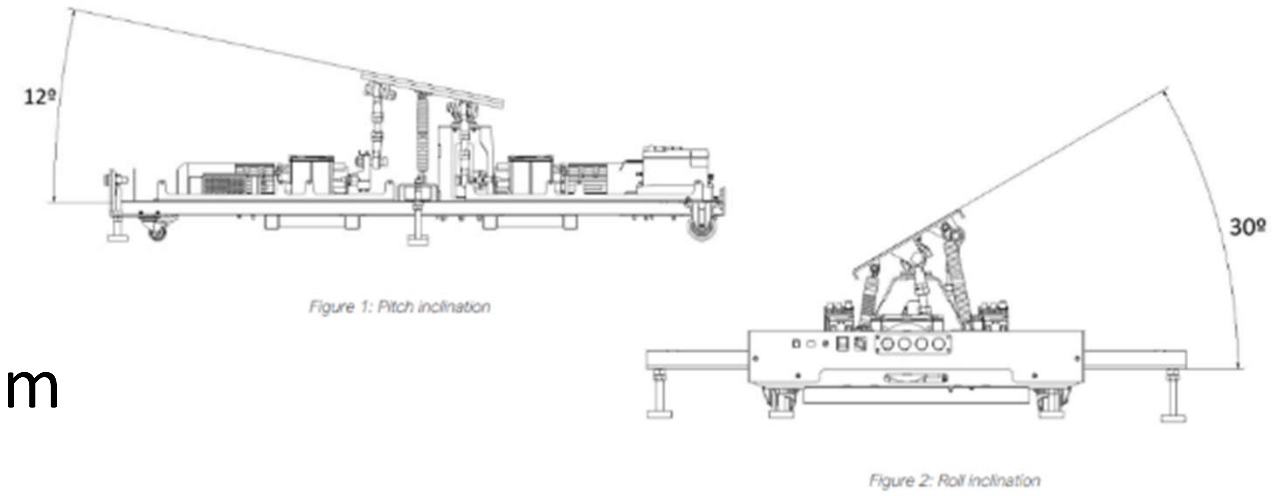
- Various, parametrizable deck speed calculation algorithms
- Offers almost normal walk movement in virtual environments

Bike Simulator

Bike Simulator – Central Design Aspects

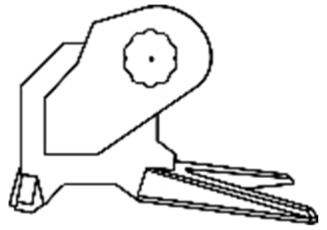
- Leaning possibility (D2/D3)
  - Enables realistic curve driving
- Perception of Road irregularities and slope (D2)
  - Enables Sensation of the road

2 DoF Motion system

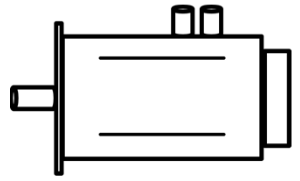


- Realistic Force feedback (D1/D2/D3)
  - Enables realistic bike driving ability

Wheel resistance through bike trainer



Steering resistance through motor



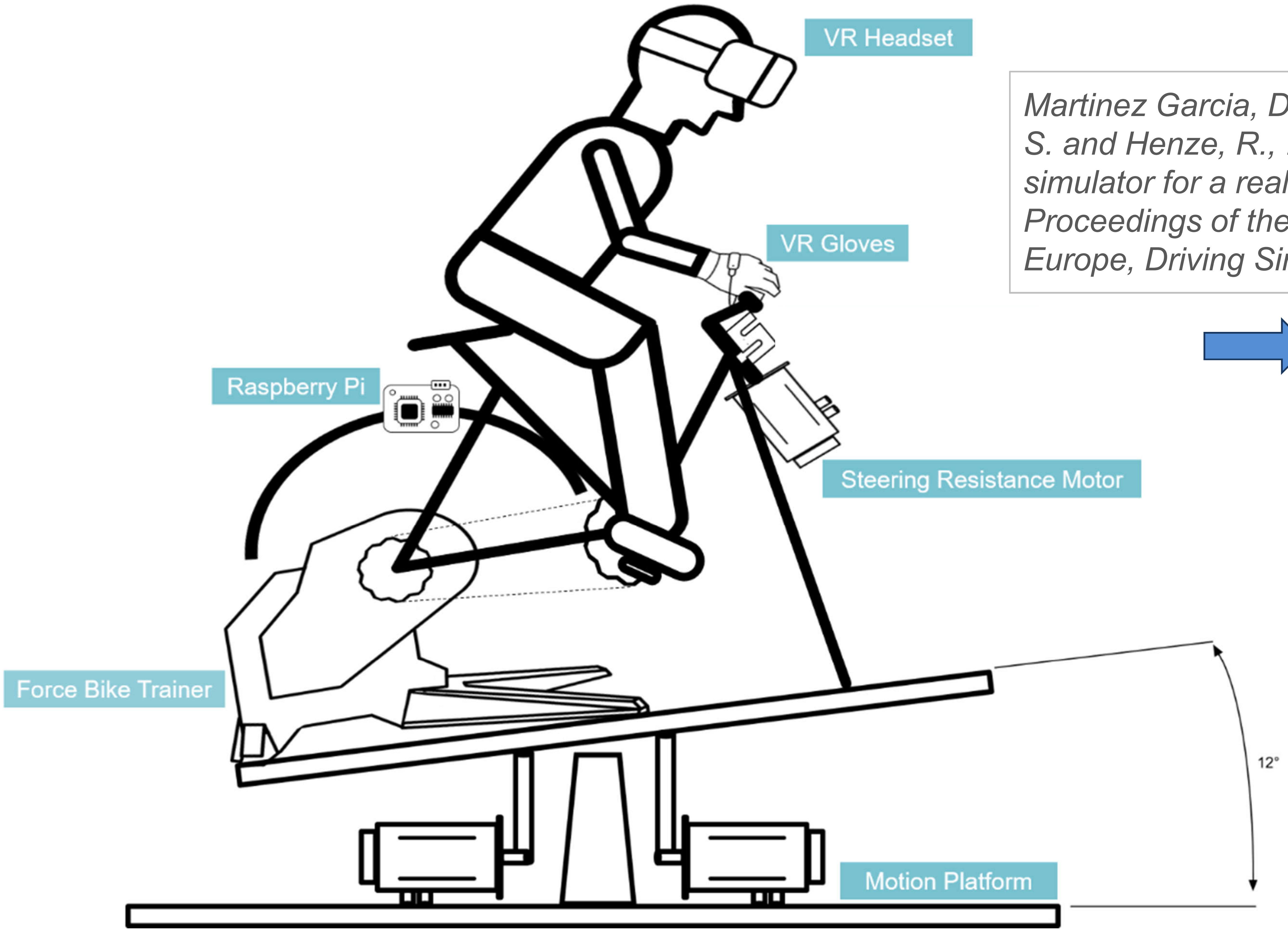
- High immersion and presence (D2)
  - Enables realistic decisions
- Realistic speed perception (D2/D3)
  - Enables realistic bike driving ability

VR HMD

Animation of own body for a good sense of self

Speed dependant wind simulation

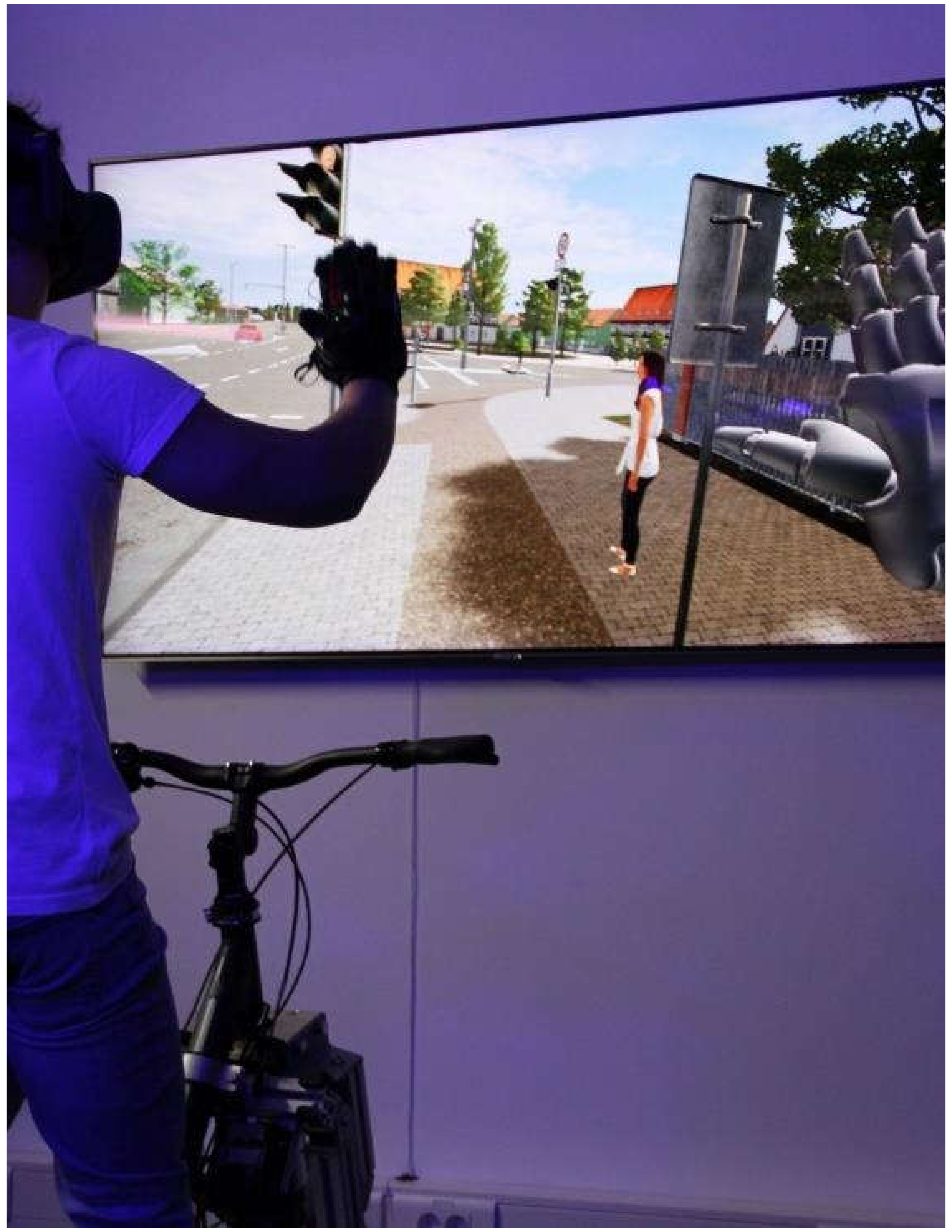
Bike Simulator – Scheme



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

➡ **See Poster @ DSC exhibition**

Bike Simulator in action

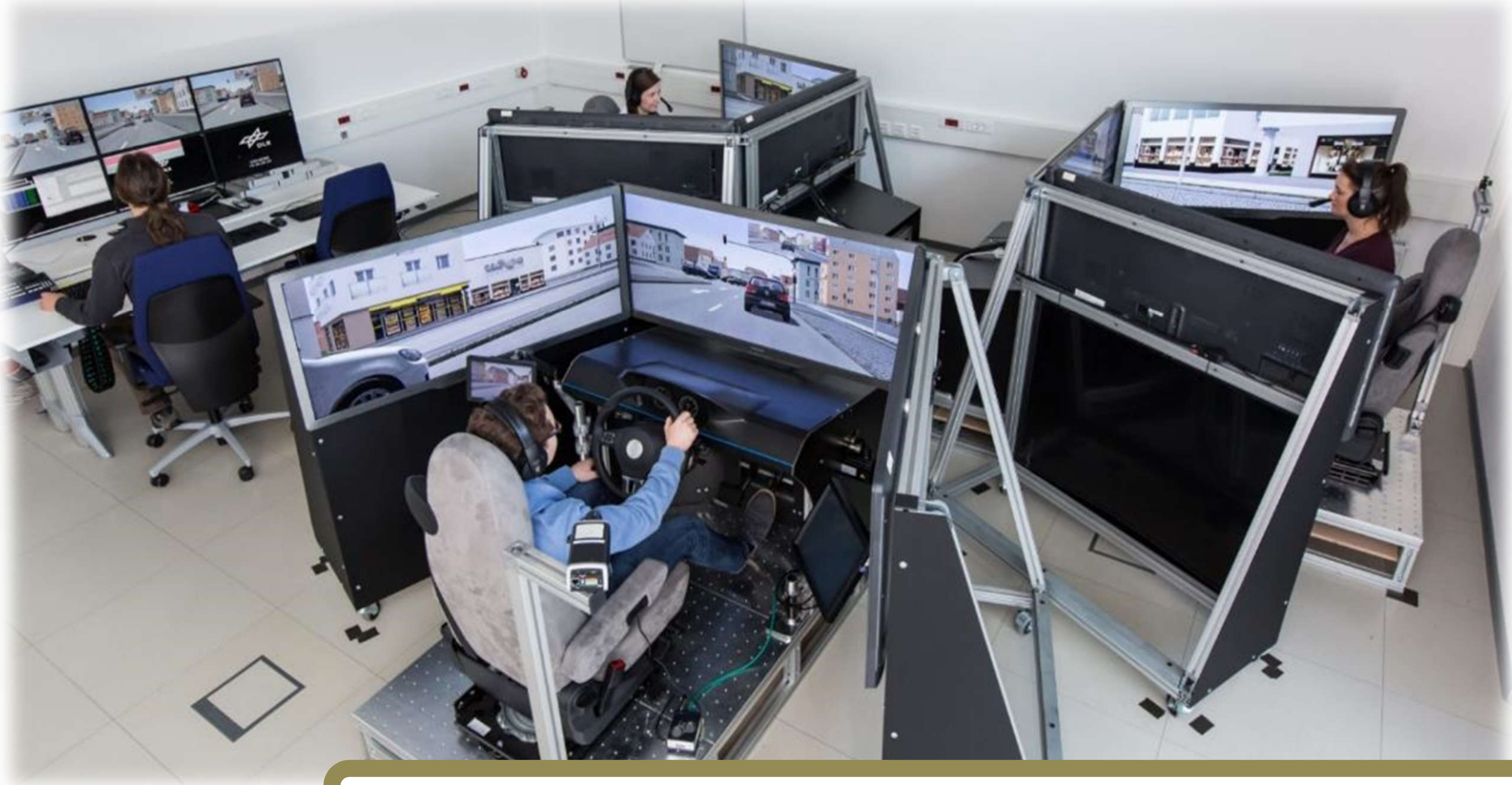


Car Simulator

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

MoSAIC



Now extended by the new VRU-Lab

Car Simulator – Central Design Aspects

- Minimum usage of laboratory space (D1)
- Realistic steering and pedal force feedback (D2/D3)
  - Enables realistic car driving ability

Fix Base Simulator

Steering resistance through automotive Steering Wheel system
Pedal resistance through motors

- High immersion and presence (D2)
  - Enables realistic decisions
- Support of monitor and VR-HMD visualization (D2)
  - High flexibility for research questions
- Support of body tracking (head, hands, fingers) (D4)
  - For communication (direct)

Vehicle Model, Vehicle Cockpit visualization

UNREAL ENGINE

VR HMD  or Multi Monitors

Animation of driver body for a good sense of self

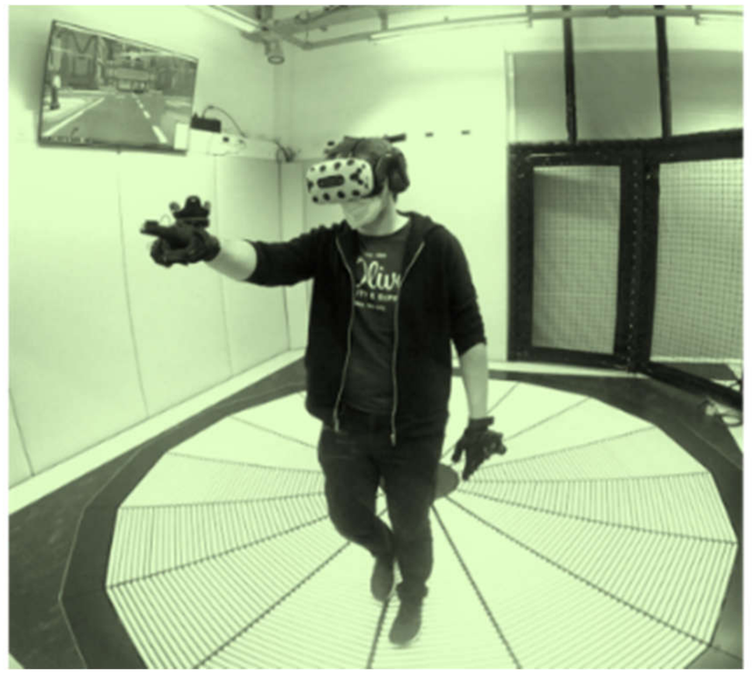
Car Simulator – Field-of-View

~210° horizontal by three UHD 4k monitors

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

Multi Monitor Setup

VR HMD Setup



Simulator Studies

Bike Simulator – KoFIF Evalution Study

**Study carried out in July 2021.
Results published**

Research questions

RQ 1: Are the differences between the driving profiles perceived?

RQ 2: Which driving profile provides a better driving sensation?

RQ 3: How high is the acceptance of the simulator?

RQ 4: Does the simulation set-up correspond to the behavior of a real bike?

Scenario design

Scenario	Description	Graphical representation
1-A	Driving straight ahead and stopping at the traffic light with crossing vehicle	
1-B	Driving straight ahead and stopping at the traffic light with a vehicle driving straight ahead	
1-C	Driving straight ahead and stopping at the traffic light without a vehicle	
2	Turning to the right and avoiding a construction site without a vehicle	

Bicycle
Car

Parameter Variation

Parameter	Description	Profile A	Profile B
Yaw Rate	Factor between the calculated yaw rate, coming from the dynamic model and the applied yaw rate in the virtual reality visualization	0.5	1
Roll	Factor between the measurement of the slope from the motion platform and the virtual reality visualization	2	1.5

Questionnaires

- Acceptance (Acceptance scale - Van der Laan)
- Realism (One-dimensional scale, two open questions)
- Simulator Sickness Questionnaire (SSQ)
- Fast Motion Sickness Scale

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

**See Poster
@ DSC exhibition**

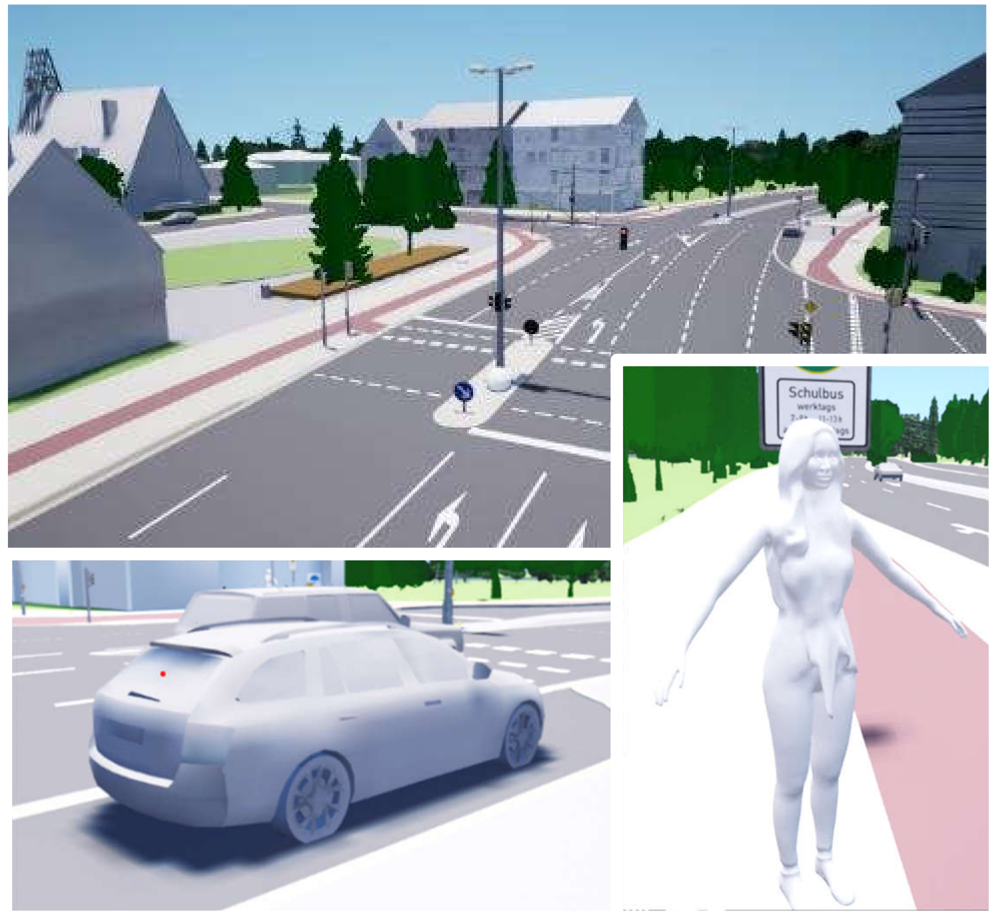
NGC-KoFiF – Simulator Study VALKyRie

Study carried out in Oct/Nov 2021.
Analysis ready. Publication prepared

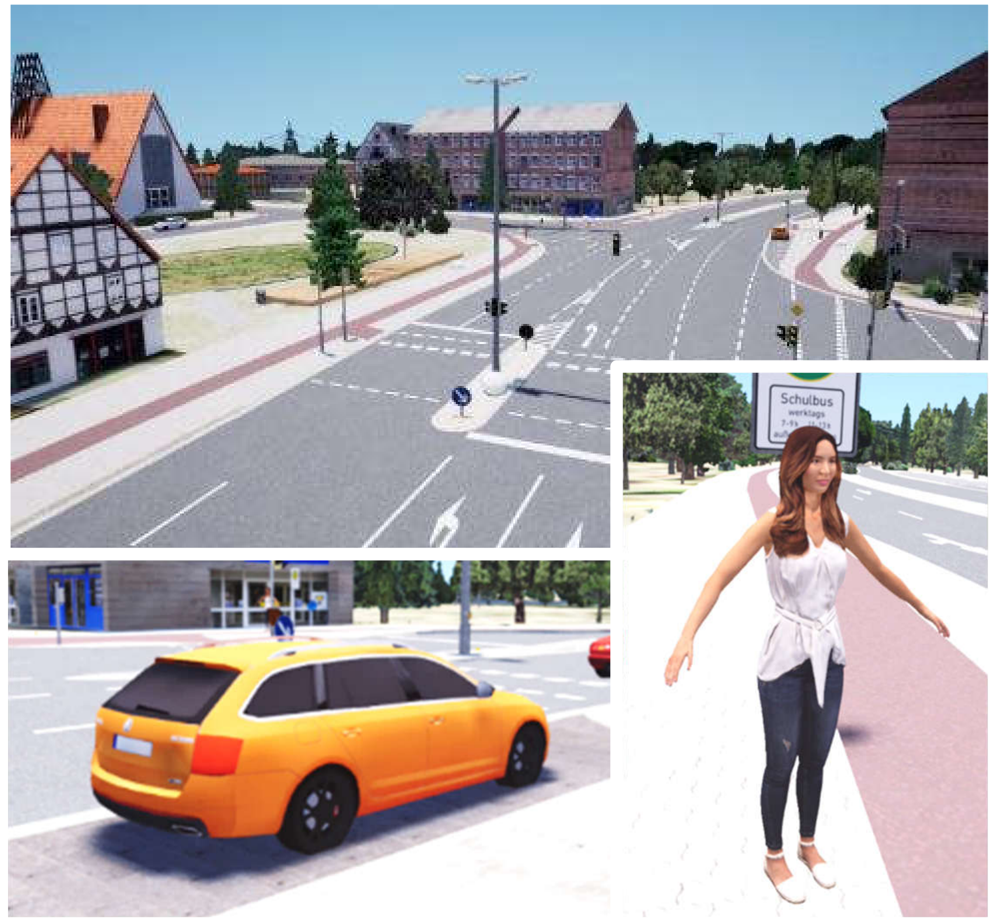
Goals
- Investigation of **abstraction levels in scenario visualization** while maintaining data validity
- Evaluation of **metrics** regarding **simulation sickness**, **presence** and **realism**

Research questions
- How much reality can a simulator study represent?
- How abstract can the visualization be, so that the immersion is preserved or even improved?
- How much reality is required?
- Do we have to create maximum realism or is less enough?

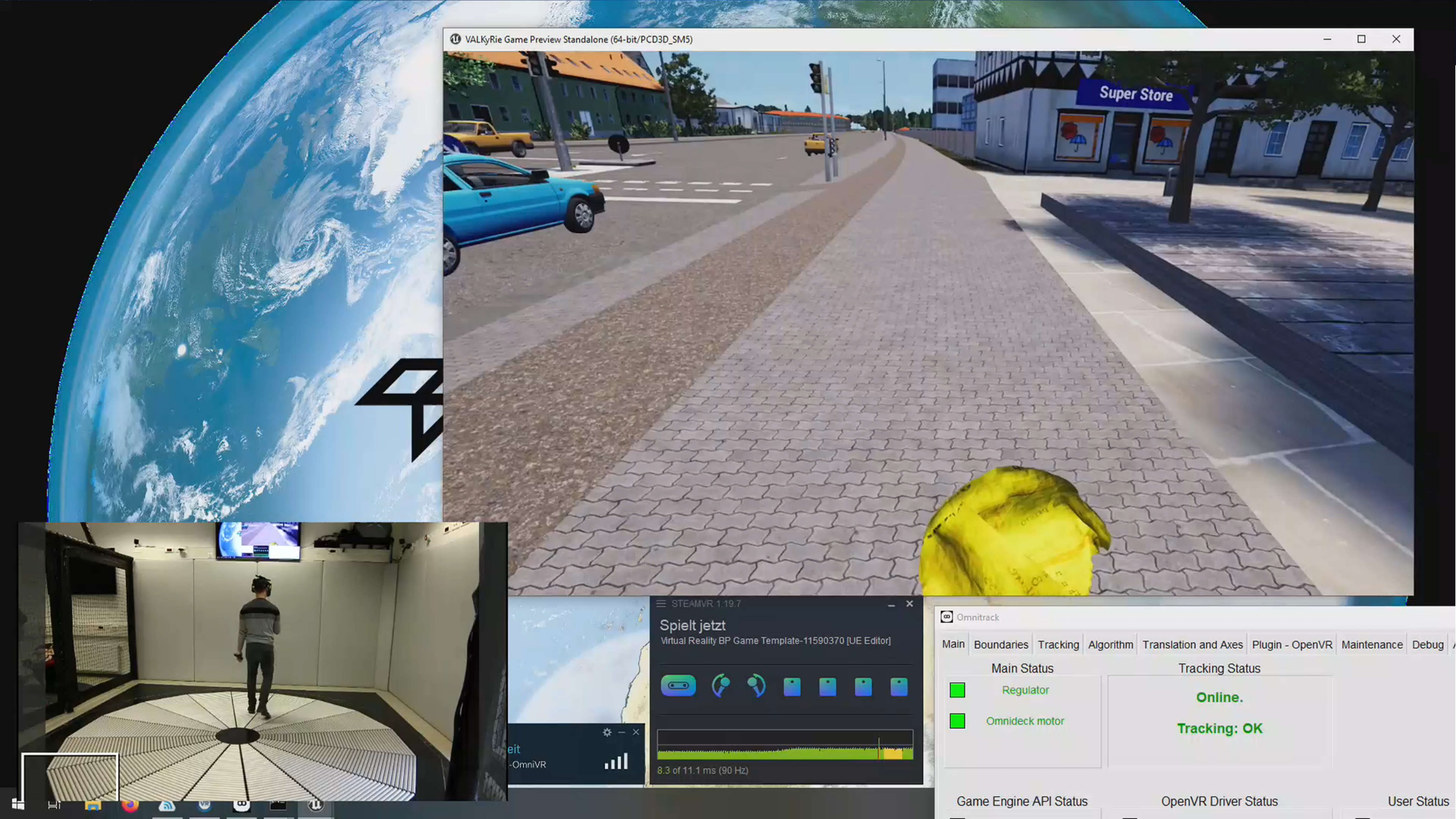
low



medium



high


VALKyRie Game Preview Standalone (64-bit/PCD3D_SM5)
Super Store
STEAMVR 1.19.7
Spielt jetzt
Virtual Reality BP Game Template-11590370 [UE Editor]
8.3 of 11.1 ms (90 Hz)
Omnitrack
Main
Boundaries
Tracking
Algorithm
Translation and Axes
Plugin - OpenVR
Maintenance
Debug
Main Status
Tracking Status
Regulator
Omnideck motor
Online.
Tracking: OK
Game Engine API Status
OpenVR Driver Status
User Status

iUSIM – Simulator Study on drone acceptance

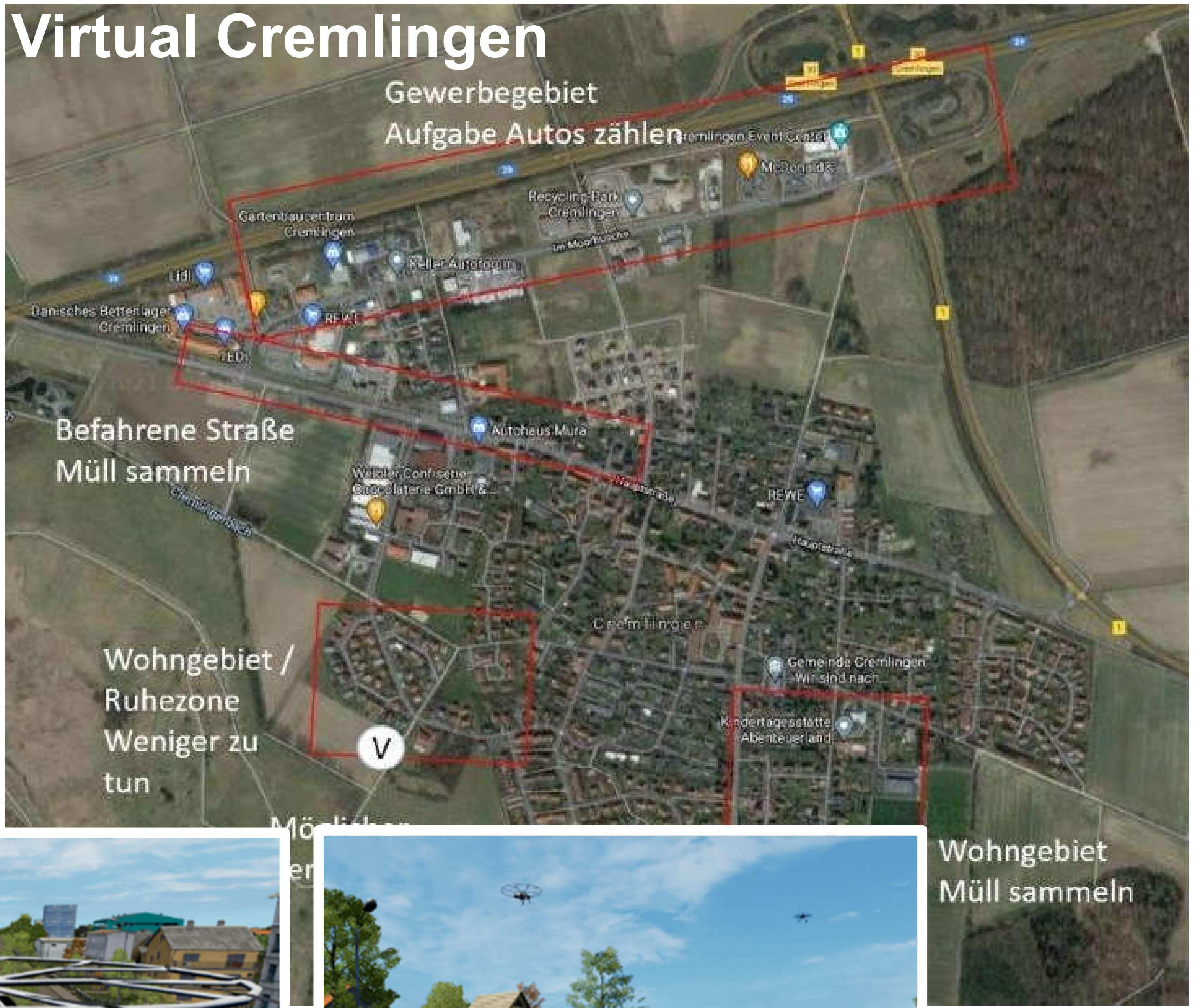
Study carried out in Nov 2021.
Results published @ DUCAM

Goals

- Investigation of general aspects of **drone acceptance in urban environment**

Research questions

- How is pedestrian perception of drones in the city?
- How do factors such as volume, height, number, size, and movement patterns affect acceptance?
- From which limit values does a test person feel unsettled by the presence of drones?



VUV4NGC – Simulator Study VALHaLa

Study planned for October 2022

Goals

- Investigation of **influence of** the **display form** (monitor vs VR glasses) used on driving behavior in the simulator
- In particular, the influence on **simulator sickness, presence and objective driving data** shall be analysed

Research questions

- Is the usage of a certain display type in general favourable or is this dependent of the driving task/situation?
- What is the influence of the display type on presence and simulator sickness?

HTC Vive Pro Eye

XTAL 8K

Triple Display set-up

@City - Overview

Study carried out in Feb 2022

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

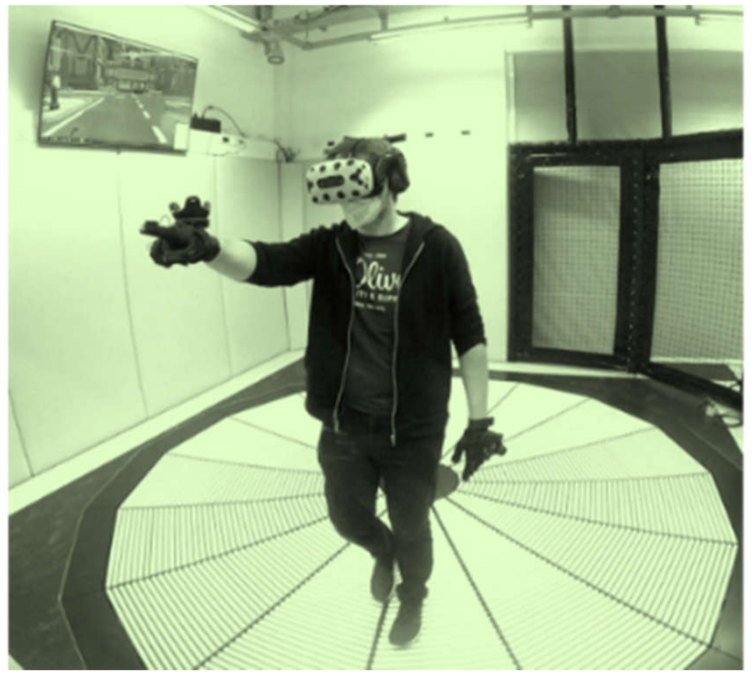
Car

Internal HMI

Bicycle

External HMI

@City - Impressions



First Conclusions & Lessons learned

First Conclusions & Lessons learned

Unreal

- Keep an eye on performance
  - Low framerates tends to increase simulator sickness
- Creation of plug-ins makes new developments and features reusable

Pedestrian Simulator

- In the pedestrian study so far surprisingly low motion sickness issues and not many drop-outs
- The noise of the Omnideck is recognizable when no other sound is present. However, using headphones and adding environmental sound can cover the noise sufficiently, especially with the participants focused on specific tasks (see above).

Training

- Let the study participants ride the bike simulator without a HMD first
- Perform at least 15 min of training
- Start with simple tasks and avoid training situations with simulator sickness trigger

HMDs

- Don’t make sudden changes between different levels/scenarios
  - Tends to provoke motion sickness
  - Instead let participants close their eyes or switch smoothly
- A 360° picture of the lab as the first impression has a very positive effect (you put on the HMD and you see the same as before)
- Gear-up time for the VR-glasses and the simple tracker set-up is reasonable, about 10 minutes. Using the body suit instead will raise the gear-up time up to 20 min.

Miscellaneous

- Simulator handling is well documented and easy to execute
- Prepare dark VR-rooms for the survey breaks between the rides, when the participants have to keep on the HMD
- The design of a specific task (here: collection of paper balls) helps to guide the participants in the desired direction

Outlook – Future tasks

Tool Chain

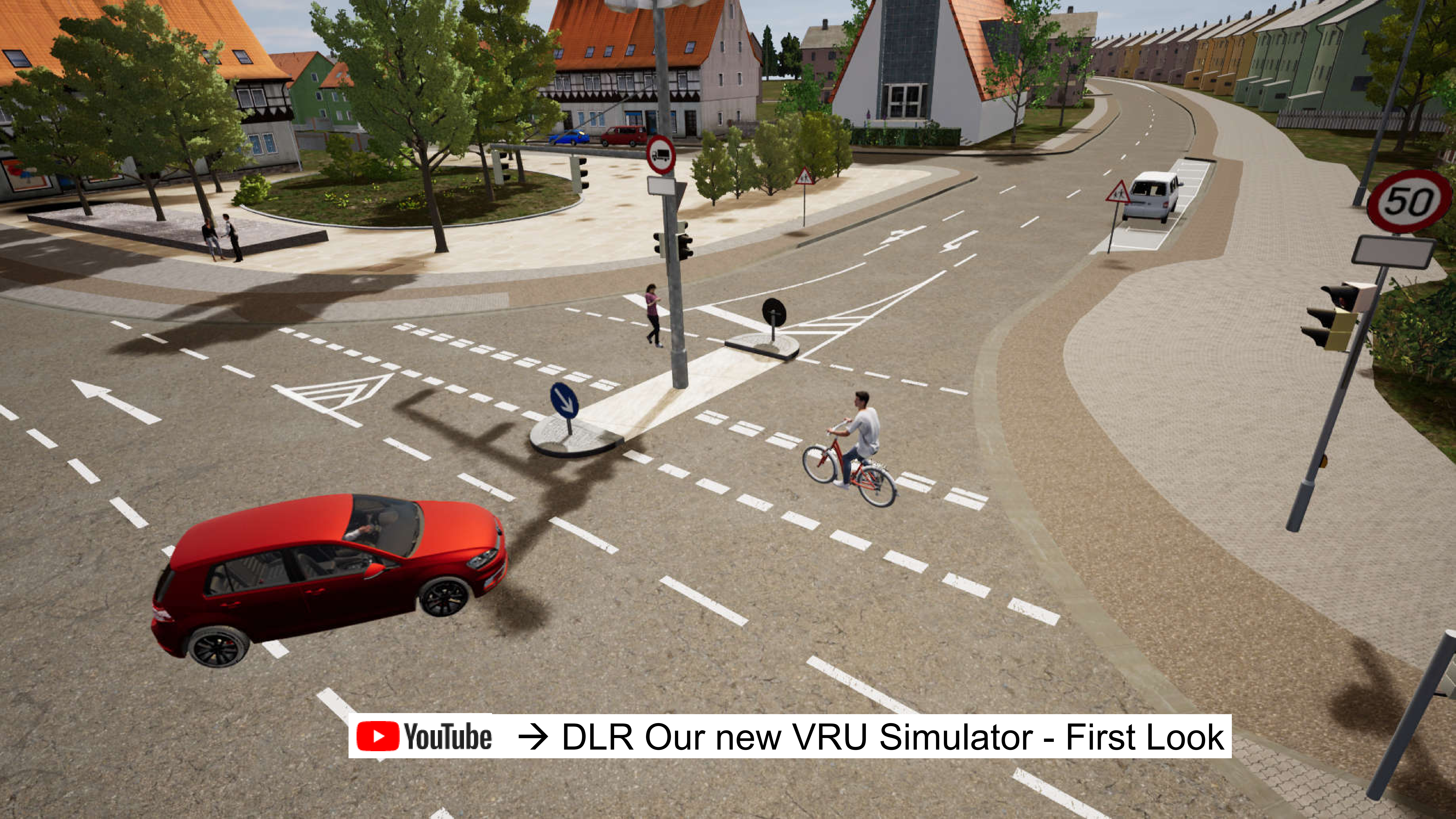
- Representation of own body (in general and in terms of adaption to the current participant)
- Integration of surrounding pedestrians (crowd simulation)

Bike Simulator

- Improvement of speed tracking and resistance control
- Further improvement of the motion cueing
- Implementation of usability features
- Calibration and validation of steering force feedback
- Tracking of legs and pedal position

Pedestrian Simulator

- Further improvement of the motion cueing
- Integration of full body motion capturing
- Validation of relation between step size and walking speed
- Validation study on walking behavior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YouTube → DLR Our new VRU Simulator - First Look

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Thank You For Your Attention

THANK YOU

Strasbourg

September 14th – 16th 2022