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# INTERSECTING URBAN AND TRAFFIC MODELS FOR VIRTUAL REALITY ENVIRONMENTS WITH REALISTIC TRAFFIC BEHAVIOUR

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**Abstract.** A novel framework for modelling urban infrastructure and traffic for Virtual Reality with a focus on data-driven scalability and integration of simulated realistic driving behaviour is presented. Publicly available terrain and building models are automatically fused to recreate a representative traffic intersection of the German city of Erfurt. The generated 3D model is used to incorporate longitudinal road inclines in a microscopic traffic simulation. The simulated vehicle trajectories are visualized on the 3D model in a Virtual Reality environment, resulting in an environment based on a real intersection with realistic traffic behaviour. The developed framework is easy to use and can be adapted to other cities with similar data available. The Virtual Reality environment can be used, among others, for the evaluation of traffic safety, urban planning, and emerging technologies.

**Keywords:** Virtual Reality, BIM, traffic simulation, traffic safety.

**JEL Classification:** C63, C88.

## Introduction

A three-way framework is created with the CAD program Autodesk Revit, which can read in geo data, the multi-modal traffic simulation software PTV VISSIM (Fellendorf & Vortisch, 2010), which can generate vehicle trajectories, and the game engine Unity, in which the Virtual Reality (VR) environment is rendered. The framework is part of the Bauhaus. Mobility Lab research project and is being used to create a digital twin of the Brühl quarter in the city of Erfurt for the transport and logistics sector. As a digital twin, the environment requires a high degree of realism, which is why official geo models are combined to create the 3D urban model. Besides the usage as a digital twin, the framework can be used for visually appealing presentations of simulated vehicle trajectories from PTV VISSIM on a realistic urban model. This can be used to introduce simulations to decision makers and traffic planning projects to residents and potentially allow them to participate in the planning process. The framework also enables the experience of urban places with comparably little effort, as major steps of the development get automated. In research, eye-tracking studies can be conducted under laboratory conditions while being virtually in the field. New architectural plans can be presented embedded in their natural context and furthermore, Virtual Reality applications can benefit from more realistic traffic. Both components, the reality-based environment and the realistic traffic behaviour should improve the immersion in the VR environment jointly and thus increase the overall user experience. The framework is not only useful for Virtual Reality, but also for simpler 3D environments, as the display form is easy to modify.

## 1. Related work

PTV VISSIM has already been successfully used in combination with Virtual Reality on several instances, frequently for VR bike simulators. Maheshwari et al. (2016) developed 360° videos for traffic research that can be experienced using head mounted displays. The environment was based on a 3D model provided by the local authority and displayed in the game engine Unity. Traffic behaviour was pre-simulated in PTV VISSIM and then displayed in the 3D environment. The authors interpolated the simulation with a self-developed script. Interactions with traffic were not possible, as only videos were created. Erath et al. (2017) describe an alternative pipeline for creating the environment of Maheshwari

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et al. (2016). A 3D model was procedurally generated in ESRI City Engine, the traffic was again modelled in PTV VISSIM, and both rendered in Unity. Ullmann et al. (2020) used Unity for the visualization of their VR bike simulator and PTV VISSIM for the traffic simulation. To enable interaction, the PTV VISSIM simulation was run in real-time. The environment was modelled using Google SketchUp and photos were used as textures. For increased realism, the authors implemented sophisticated audio. Hasan et al. (2021) developed a multi-user Virtual Reality driving simulator in Unity that can be used with PTV VISSIM and an alternative tool. The simulations were run in real-time; the authors used their own interpolation and a hypothetical city served as the model. Wahbeh et al. (2021) describe an image-based approach for mapping the real world into a 3D world. The images were captured with a backpack equipped with GNSS, LiDAR and camera-sensors. A post-processing pipeline was then used to combine the images with pre-existing models to assemble the final model. The model was combined with a PTV VISSIM simulation. The simulation used the same road network, but not the 3D model from the previous step. Both were then displayed in Unity. Brenner & Haala (1998) used a digital surface model from airborne laser scanning and ground plans to reconstruct a building model in an automated way. By using photos as textures, the model looked like a LoD3 model, even though it only was LoD2. Yu & Fan (2017) developed an automated calibration of PTV VISSIM with metaheuristic algorithms. Hale et al. (2021) presented a workflow to calibrate PTV VISSIM with individual vehicle trajectories.

As an alternative to PTV VISSIM, the open-source tool SUMO (Alvarez Lopez et al., 2018) can be used for microscopic traffic simulations. This has also already been done in conjunction with Virtual Reality. Keler et al. (2018) built a VR bicycle simulator to study traffic interaction, where the traffic behaviour was simulated in real-time by SUMO. For the visualization of the environment, they used the tools DYNAanimation and DYNA4, both by TESIS. The communication between the animation software and SUMO was orchestrated by MATLAB Simulink. The environment was set-up with data from OpenStreetMap and building models from a public entity. Another publication by the same working group (Busch et al., 2019) goes into more detail about the development of their VR bike simulator. In the second version of the environment, MATLAB Simulink was not needed for the orchestration anymore and DYNA4 by VECTOR was used for the visualization.

Others, such as Yu & Fan (2017), relied on self-developed solutions for microscopic traffic simulation in Virtual Reality.

## 2. Methodology

The development and operation of the virtual environment requires an urban model and a traffic model. In relation to the size and complexity of these models, the environment is built up and calibrated in an automated and extensible process. The designed framework can be divided into three parts, which build upon each other (Figure 1): First, the urban model is built based on several open spatial data sets being fused into one model. Second, the construction and calibration of a microscopic traffic model generates realistic traffic behaviour within the simulation. Finally, the Virtual Reality environment visualizes the traffic behaviour in a visually appealing way on the urban model and enables the interaction with the user. The described framework is reproducible and scalable, enabling the methodology to be applied to other use cases in traffic engineering.

To test the suitability of the framework, a multi-lane intersection in the German city of Erfurt was modelled and the microscopic traffic flow simulated.

### 2.1. Urban model

For perception close to reality, an urban environment model is set up. In the current version of the framework, the model includes boundaries of different surfaces, terrain data, building models, and simple elements such as trees and walkways. Since the modelled area is to be further expanded, an attempt is made to build an

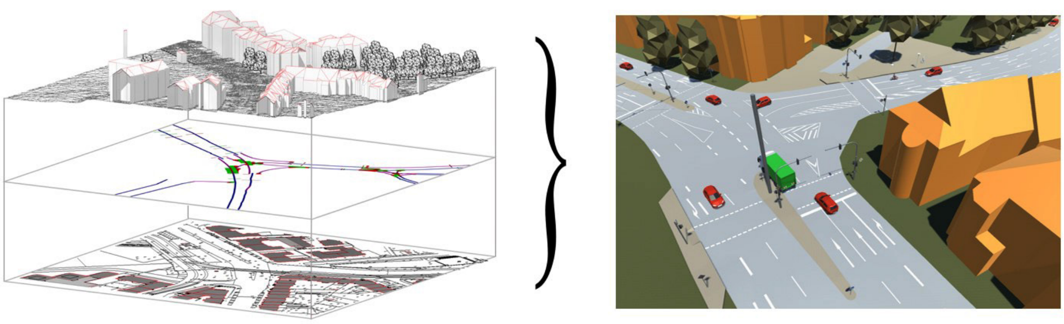

Figure 1. Exposure drawing of the intersected data (signal site plan, simulation net and urban model) for the Virtual Reality environment and the resulting environment with simulated vehicles

automatable and scalable framework. For this purpose, the freely available geo data of the state office of Thuringia[1] are the basis for the construction. More precisely, the terrain data provided in the DGM format and LoD2 3D building data in the GML format. Here it has to be mentioned that the availability and accessibility of geo data depends on the local authorities.

The BIM-capable CAD software Autodesk Revit is used as the central tool for building the urban model. Unlike in simple CAD programs, all inserted elements are stored with properties, for example the partial surface areas which are saved directly with information such as the materials, structure, and texture representing a certain terrain-area. Script-based macros and APIs offer options for automation and are used for, among others, the insertion of terrain data as a surface object. For integrating geo data into the model, the scripts and processes of the project VREVAL provided a basis for development (Schneider et al., 2021). In VREVAL, BIM data are embedded in VR for a virtual user-evaluation of architectural design.

## 2.2. Microscopic traffic model

A microscopic traffic model is built for a realistic modelling of the local traffic and in particular the driving behaviour. This model is based on signal site plans as well as extensive data collected as part of the Bauhaus. Mobility Lab research project. In contrast to macroscopic traffic simulations, the microscopic traffic flow simulation focuses on the behaviour of individual traffic participants (Bungartz et al., 2013; Fellendorf & Vortisch, 2010). The calibration of the driving behaviour by the associated car-following model is of importance here, as Treiber & Kersting (2013) state that the behaviour of each individual vehicle depends on its surrounding traffic.

The traffic model is calibrated using calibration parameters provided by a video-based vehicle detection system. It provides cross-sectional data for traffic volumes, fleet compositions and traffic flow relations at the intersection with intervals of 1 Hz. A novel feature in the creation of the simulation network is the elevation profile, that is, the longitudinal inclinations in the network. By intersecting the model with digital terrain models, all spline points of the simulation mesh in their elevation are adjusted, which was previously documented for PTV VISSIM by Marticorena (2015).

For the vehicle movement to look realistic in VR, the simulation-resolution in PTV VISSIM is set to 20 Hz. This is, at the time of writing, the maximum simulation-frequency and is chosen to reduce the influence of interpolation in the rendering to a minimum. The simulated vehicle movements are tracked as vehicle trajectories. These includes the vehicle ID, the simulation time stamp, the vehicle type, and the *x*- and *y*-coordinates of the front and rear bumpers.

## 2.3. Virtual Reality environment

To build the Virtual Reality environment, as the final step of the framework, the game engine Unity is used. First, the urban model of the intersection is imported. Second, the simulated vehicle behaviour is read in and processed.

For the VR environment, the urban model is exported from Autodesk Revit as an FBX file. This file can be imported into Unity without any further steps. However, the 3D urban model must be aligned in Unity to match its position in the PTV VISSIM coordinate system. This currently has to be done manually. The final step is to place traffic signs and signals in the environment. In the present framework, this is done with the help of photographs. However, if digital plans are available, this step can also be automated.

The workflow for the import of PTV VISSIM trajectories iterates over the data and calculates centre and direction of each vehicle for all timestamps. For every vehicle, the displayed 3D model depends on the vehicle type in PTV VISSIM. If the time since loading the virtual environment corresponds to the spawn time of a vehicle, the vehicle model is placed in the world and its positions are passed to the object, which then follows the positions in order. Between the timestamps the positions are interpolated. The speed of the vehicles is calculated by the time between the timestamps and the distance to be covered, thereby replicating the speed of the vehicles in PTV VISSIM. After reaching their final position, the vehicle models get removed. The vehicles do not react to the user yet. Since the imported trajectories do not contain sufficient elevation data, the elevation position is determined using ray casting so that the vehicles are placed directly on the road surface.

The user starts the compiled environment and is presented with a file browser to select an exported PTV VISSIM trajectory file. The file is then processed in the background while the 3D scene loads. After loading, the user sees the modelled environment and the simulated trajectories are replayed in real-time on the correct positions. The user sees different vehicle types with rotating wheels and hears engine sounds, whose volumes depend on the distance from the vehicle. The user can navigate with a person on a bike, both in a third-person or a first-person perspective.

# 3. Discussion and outlook

The presented framework is very promising, but has potential for further improvement. Some approaches for improvement can be adopted from the literature.

1 https://www.geoportal-th.de/de-de/Downloadbereiche/Download-Offene-Geodaten-Th%C3%BCringen

Similar to the presented framework, others have also constructed their 3D models with data from local authorities (Maheshwari et al., 2016). Keler et al. (2018) and Busch et al. (2019) have used pre-existing building models and based the landscape on OpenStreetMap data. Erath et al. (2017) on the other hand have generated their model procedurally. The most elaborate approach was taken by Wahbeh et al. (2021). They blended specially taken photos with existing models. A similar approach will be tested for the presented methodology. Brenner & Haala (1998) presented a good approach if a robust building model is not available, however, it would increase the complexity of the framework. The use of photographs as textures to increase the level of detail should be explored. Looking at other publications shows that using and merging building and terrain models to build a virtual environment is a proven approach. The automated blending of the presented framework, however, is novel. Compared to the more conventional methods that involve manual work, the framework offers a supposedly high time advantage, which, however, cannot be quantified yet. Without the framework, or comparable methods, the urban model must be imagined and manually constructed or reconstructed by hand using photos. This time-intensive work leads to higher development costs and is not reproducible. Due to the scalability of the presented framework, the costs remain constant, while with manually created models, the costs increase with the size of the model. Furthermore, the traffic network does not have to be constructed manually.

Like most of the related work (Maheshwari et al., 2016; Erath et al., 2017; Ullmann et al., 2020; Wahbeh et al., 2021; Hasan et al., 2021), the presented framework relies on PTV VISSIM for the traffic simulation. Only two publications (Keler et al., 2018; Busch et al., 2019) are based on SUMO. However, both of these simulate the traffic in real-time, which allows for interactive traffic behaviour. With regards to PTV VISSIM, only Ullmann et al. (2020) and Hasan et al. (2021) take this approach, while others (Maheshwari et al., 2016; Erath et al., 2017) plan to develop such a real-time integration. Yu et al. (2013) have developed their own simulation tool, however, the usage of PTV VISSIM has the advantage of it being an out-of-the-box solution. The presented framework should include an interactive simulation in its final stage, so that the vehicles react realistically to the user and the immersion gets further increased. The work of Hasan et al. (2021) gives reason to expect that real-time simulation is possible to be integrated in the presented framework. Wahbeh et al. (2021) built a sophisticated 3D model but, unlike the framework presented here, did not integrate it in the microscopic traffic simulation. In relation to the simulation software used, it is to be examined whether SUMO, as an open-source alternative to PTV VISSIM, should be used. The goal is to make the presented methodology freely applicable, i.e., including the software used.

As the engine for the Virtual Reality environment, Maheshwari et al. (2016), Erath et al. (2017), Ullmann et al. (2020), Wahbeh et al. (2021) and Hasan et al. (2021) used Unity, while Keler et al. (2018) and Busch et al. (2019) relied on other solutions. The alternatives used are not viable options for the methodology presented, however, further options should be explored. Maheshwari et al. (2016) and Hasan et al. (2021) interpolated the trajectories in Unity with a self-developed script. Since the current interpolation in the presented framework is not yet satisfactory, it should be checked whether a similar approach would make the driving behaviour smoother.

The works in which pre-simulated data are reproduced all develop the urban model first and then integrate the traffic (Maheshwari et al., 2016; Erath et al., 2017; Wahbeh et al., 2021). The works with interactive simulations take a slightly different approach, as the VR engine communicates in a loop with the traffic simulation tool. The presented framework will also be extended from a static pipeline to a dynamic loop in the future, so that direct communication between Unity and PTV VISSIM becomes possible.

The advantage of the developed framework is that the realistic driving behaviour can be embedded in a realistic 3D environment with only few steps and on the basis of public data. Incorporating traffic simulations is an easy way to increase realism, for example, the traffic volume can be easily adjusted to different times of day. Integrating a proven simulation tool, there is no need to develop a new engine from scratch. With the current state of development, a lot of manual work is removed by automation already, while further automation is planned. However, the quality of the resulting 3D environment highly depends on the quality, e.g., the resolution, of the input data, which are blended, but not procedurally extended. Furthermore, mainly commercial tools are currently used in the framework. In the spirit of openness, it should be examined whether open-source tools could be used.

In the future, the weather, lighting and sun position in the Virtual Reality environment will be displayed based on the simulation time and day of the trajectories. This should further increase the feeling of realism. Furthermore, the interpolation between simulation steps should be improved for a more pleasant viewing experience. In general, the realism is to be improved by means of textures and shaders. For real-time interaction with the surrounding traffic, the PTV VISSIM Driving Simulator API is to be used. In cooperation with other working groups, VR evaluation methods from architecture are to be adapted to the transport sector, the LoD2 building models are to be extended to LoD3, and the road space is to be photogrammetrically measured with geodesics for a more accurate replica.

## Conclusions

A novel framework for creating 3D environments for Virtual Reality with a focus on realistic traffic behaviour was presented. The framework lays the foundation for further innovations, for example, in the area of examining traffic safety with digital means. In its current state, real urban locations can be experienced in Virtual Reality with comparatively little effort. Realistic, simulated traffic behaviour can be presented in its urban context in a visually appealing way. The resulting environment can be used, among others, in planning processes for communication with residents or the evaluation of traffic safety. The advantages of the presented approach are the use of publicly available geodata for fast model generation and the possibility to base different model types on top of each other. Besides being reproducible and scalable, the approach saves time over traditional methods.

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The Authors declare no competing financial, professional, or personal interests from other parties.

## References

Alvarez Lopez, P., Behrisch, M., Bieker-Walz, L., Erdmann, J., Flötteröd, Y.-P., Hilbrich, R., Lücken, L., Rummel, J., Wagner, P., & Wießner, E. (2018). Microscopic Traffic Simulation using SUMO. *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 2575–2582. https://doi.org/10.1109/ITSC.2018.8569938

Brenner, C., & Haala, N. (1998). Fast Production of Virtual Reality City Models. *IAPRS*, *32*(4), 77–84.

Bungartz, H.-J., Zimmer, S., Buchholz, M., & Pflüger, D. (2013). Mikroskopische Simulation von Straßenverkehr. In H.-J. Bungartz, S. Zimmer, M. Buchholz, & D. Pflüger, *Modellbildung und Simulation* (pp. 163–192). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-37656-6_8

Busch, F., Kaths, H., Keler, A., Hosseini, S. A., Grigoropoulos, G., & Kaths, J. (2019). *Fahrradsimulator: Anwendungsorientierter Erfahrungsbericht zu Aufbau und Nutzung* [PDF]. Technical University of Munich. https://doi.org/10.14459/2019MD1575160

Erath, A., Maheshwari, T., Joos, M., Kupferschmid, J., & van Eggermond, M. A. B. (2017). Visualizing transport futures: The potential of integrating procedural 3D modelling and traffic micro-simulation in Virtual Reality applications. *TRB 96th Annual Meeting Compendium of Papers*. https://doi.org/10.3929/ETHZ-B-000240771

Fellendorf, M., & Vortisch, P. (2010). Microscopic Traffic Flow Simulator VISSIM. In J. Barceló (Ed.), *Fundamentals of Traffic Simulation*, *145*, 63–93) Springer New York. https://doi.org/10.1007/978-1-4419-6142-6_2

Hale, D. K., Li, X., Ghiasi, A., Zhao, D., Khalighi, F., Aycin, M., & James, R. (2021). *Trajectory Investigation for Enhanced Calibration of Microsimulation Models* (FHWA-HRT-21-071). United States. Federal Highway Administration. Office of Operations Research and Development. https://rosap.ntl.bts.gov/view/dot/57959

Hasan, M., Perez, D., Shen, Y., & Yang, H. (2021). Distributed Microscopic traffic simulation with human-in-the-loop enabled by virtual reality technologies. *Advances in Engineering Software*, *154*, 102985. https://doi.org/10.1016/j.advengsoft.2021.102985

Keler, A., Kaths, J., Chucholowski, F., Chucholowski, M., Grigoropoulos, G., Spangler, M., Kaths, H., & Busch, F. (2018). A bicycle simulator for experiencing microscopic traffic flow simulation in urban environments. *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 3020–3023. https://doi.org/10.1109/ITSC.2018.8569576

Maheshwari, T., Kupferschmid, J., Erath, A., & Joos, M. (2016). Virtual Reality as a tool to assess perception of safety and comfort for cyclists in Singapore. In H. C. Kiang & Z. Ye (Eds.), *Crossroads: Asian Street in the Dynamics of Change. GASS 2016 Great Asian Streets Symposium Proceedings* (pp. 59–66). Department of Architecture, School of Design & Environment, National University of Singapore (NUS). http://hdl.handle.net/20.500.11850/129870

Marticorena, S. (2015, November 11). *Sketchup + Vissim Workflow*. https://fatpencilstudio.com/blog/sketchup-vissim-workflow/

Schneider, S., Kammler, O., Weiser, R., Bailey, G., & Fuchkina, E. (2021). Virtual Reality für eine nutzerzentrierte Architektur—Integration von VR-basierten Nutzerstudien in der Entwurfsausbildung von Architekten. In H. Söbke & M. Weise (Eds.), *Wettbewerbsband AVRiL 2021* (pp. 11–17). Gesellschaft für Informatik e.V. https://dl.gi.de/handle/20.500.12116/37436

Treiber, M., & Kesting, A. (2013). *Traffic Flow Dynamics: Data, Models and Simulation*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-32460-4

Ullmann, D., Kreimeier, J., Götzelmann, T., & Kipke, H. (2020). BikeVR: A Virtual Reality Bicycle Simulator towards Sustainable Urban Space and Traffic Planning. *MuC '20: Proceedings of Mensch Und Computer 2020*, 511–514. https://dl.acm.org/doi/10.1145/3404983.3410417

Wahbeh, W., Ammann, M., Nebiker, S., van Eggermond, M. A. B., & Erath, A. (2021). Image-based reality-capturing and 3d modelling for the creation of VR cycling simulations. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *V-4–2021*, 225–232. https://doi.org/10.5194/isprs-annals-V-4-2021-225-2021

Yu, M., & Fan, W. (D.). (2017). Calibration of microscopic traffic simulation models using metaheuristic algorithms. *International Journal of Transportation Science and Technology*, *6*(1), 63–77. https://doi.org/10.1016/j.ijtst.2017.05.001

Yu, Y., El Kamel, A., & Gong, G. (2013). Modeling intelligent vehicle agent in virtual reality traffic simulation system. *2nd International Conference on Systems and Computer Science*, 274–279. https://doi.org/10.1109/IcConSCS.2013.6632060