VRoadworks - Interactive Data Visualization for Coordinating Construction Sites in Virtual Reality

Manuela Uhr
Human-Computer Interaction
Universität Hamburg
Hamburg, Germany
uhr@informatik.uni-hamburg.de

Sina Haselmann
Human-Computer Interaction
Universität Hamburg
Hamburg, Germany
6haselma@informatik.uni-hamburg.de

Lea Steep
Human-Computer Interaction
Universität Hamburg
Hamburg, Germany
6steep@informatik.uni-hamburg.de

Chia Bretschneider
Human-Computer Interaction
Universität Hamburg
Hamburg, Germany
5bretsch@informatik.uni-hamburg.de

Joschka Eickhoff
Human-Computer Interaction
Universität Hamburg
Hamburg, Germany
5eickhof@informatik.uni-hamburg.de

ABSTRACT

This work describes the use case, design and development of a virtual reality application for the visualization of multi-dimensional road works data. For coordinating construction sites affecting roads and traffic, spatial and temporal dependencies need to be considered. In widely used 2D visualizations such as Gantt charts and digital map tools, the relevant data and dependencies cannot be shown simultaneously or in a well-associated way resulting in high cognitive load. Therefore an interactive 3D visualization with multiple map layers in virtual reality was designed and developed. The usability of the prototype was evaluated in a small user study and expert interview.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Information visualization**; Visual analytics; Geographic visualization.

KEYWORDS

Virtual reality, application, road works, data visualization

ACM Reference Format:
Manuela Uhr, Sina Haselmann, Lea Steep, Chia Bretschneider, and Joschka Eickhoff. 2019. VRoadworks - Interactive Data Visualization for Coordinating Construction Sites in Virtual Reality. In *Mensch und Computer 2019 (MuC '19), September 8–11, 2019, Hamburg, Germany.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3340764.3345364

MuC '19, September 8–11, 2019, Hamburg, Germany

ACM ISBN 978-1-4503-7198-8/19/09.
https://doi.org/10.1145/3340764.3345364

1 INTRODUCTION

This work is part of the research project iPlanB, a German acronym for 'Interactive Big Data Analysis for the Planning of Construction Sites'. The overall project focuses on interactive data visualizations for traffic engineers in the city of Hamburg.

The iPlanB tabletop prototype is built on top of a software application, which is already in use by the public department for roadworks coordinating at the Landesbetrieb für Straßen, Brücken und Gewässer (LSBG), the engineering authority in the city of Hamburg. During the iPlanB project we found more use cases for a GIS tabletop application, e.g. traffic lights planning as well as designing future workplaces with 3D data visualization for the public departments of the LSBG. The 2D prototype developed for an interactive tabletop gives an overview of the city's traffic-related data, including traffic simulation and collection of time-dependent data. By visualizing the data in an well-arranged way, experts are supported in discovering bottle-necks and discussing opportunities for improvement in construction site planning.

In the following, we describe an interactive 3D visualization approach for investigating multi-dimensional dependencies between roadworks using virtual reality technology.

2 TOOLS IN THE COORDINATION PROCESS

The process of coordinating construction sites and traffic planning has been studied during the previous 1.5 year long project phase of the research project iPlanB in monthly meetings with engineering experts from the planning departments of the LSBG. Additionally the research team has been organizing workshops and observing up to three coordination discussions on-site to study the users' environment and working methods in depth. Project-supporting students have been analyzing the process of coordinating data management, which provided detailed insight based on expert interviews. The collected knowledge was the groundwork for the visualization's use case described in the following.

During the project period, we also designed a hybrid decision-support system for traffic engineers [6] in cooperation with roadworks coordinating experts at the LSBG.

In the city of Hamburg the public department of transportation engineering, the LSBG, plans and coordinates more than 25,000 construction sites per year. Coordinating a large number of construction sites that affect traffic is a difficult and demanding task requiring plenty of expertise. One of the main reasons is the underlying complex, multi-dimensional data that need to be considered during the planning process. Traffic-affecting construction sites do not only have a spatial dimension but also a temporal one. They can influence separate lanes and/or different road sections. Other spatial dependencies are e.g. that a site should not affect or block the detour of a site close by. Coordinated sites can take up to several years or only a few months or weeks to complete. They can be interconnected by different dependencies such as the requirement to take place simultaneously or serially. Giving an overview of all the partially hidden dependencies is therefore essential for successful coordination.

A case by Prouzeau, Bezerianos and Chapuis discusses data visualization for operative control of road traffic using wall displays [5]. Interactive ways of analyzing spatio-temporal data sets in the context of road traffic were explored by T. Nagel in several publications, e.g. [2] [3]. Visual Analytics [1] is also important in the applied context of spatio-temporal construction site investigations.

For data management and coordination meetings, traffic engineers at the LSBG are already equipped with software offering a 2D map view and a coherent Gantt-chart like timeline giving an overview to all past and future construction sites in the city of Hamburg. An extended version built in our research project also features historical traffic data.

However, to improve exploration of the different variants of temporal and spatial dependencies between construction sites, we were looking for a custom, more understandable visualization than the ones used by then. It should also allow simultaneous exploration of different map layers representing different points in time and show all the relevant connections in between. As the investigation of conflicts was done by one person in the organisation's workflow at the given date, the system was designed for a single-user workplace.

We designed an interactive 3D visualization of multi–dimensional dependencies using virtual reality technology. By visualizing the temporal and spatial dependencies between sites, it fills the gap of currently available tools at the LSBG and eventually other construction site departments.

3 DESIGN & IMPLEMENTATION

After sketching paper prototypes, the concept phase continued with sketching in 3D using Tilt Brush[1]. The sketch shown in figure 1 was an early version using a Gantt-chart approach for time-related dependencies.

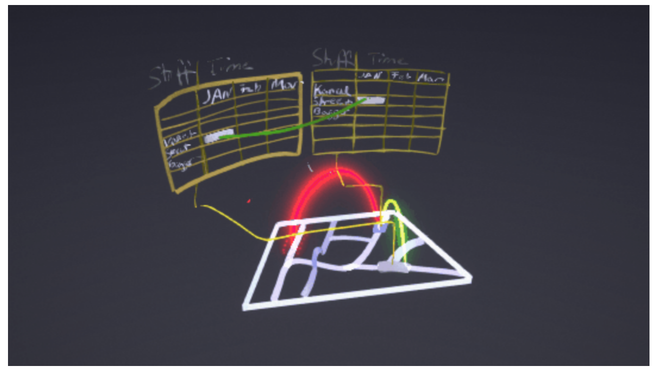

Figure 1: Early sketch of the 3D visualization

To combine the location and time-related connections we took advantage of the layered approach in a map visualization showing flight data in between two maps (departure and destination) by Q. Liu & Y. Teng in [4]. By visualizing interconnections between geographic map layers, both location-based and time related-dependencies can be displayed in the same graphic representation.

As an example, a construction site in 2022 needs to be finished before another site. The other site was originally planned in the far future in 2028 and is therefore shown on the future temporal plane, the map layer above. They have a visible connection between the two map layers in neutral color showing that there is no temporal overlap. If the construction time of the earlier site will be postponed, a temporal overlap will cause a conflicting dependency state which results in a warning color in the visualization. The multiple layers visualization can also be used for a three sites series as shown in figure 2.

In the overall coordination process, data exploration takes place in the preparation phase before group discussions and is therefore designed as a single-user workplace at the given time. Thus the decision which display hardware to use for the visualization was made in favor of virtual reality, specifically the Oculus Rift system[2]. One of the benefits of using VR hardware besides the immersive 3D view of the visualization is the lower environmental distraction in crowded office workplaces. The benefit of the Oculus Rift compared to other systems is its light weight and portability, which

[1]Google Tilt Brush: virtual reality sketching tool https://www.tiltbrush.com/
[2]Oculus Rift, https://www.oculus.com/rift/

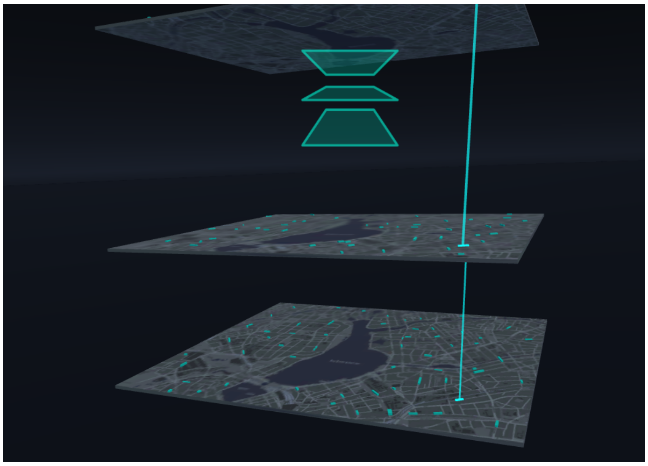

Figure 2: Several map layers representing points in time

was also useful for the evaluation in the facilities of the public department. Another positive aspect is its comparatively low price, which makes the system more affordable when ordering it as work equipment in the public sector.

The described visualization was implemented using the game engine Unity[3]. Whereas VR functionality is a native part of the game engine, features of the Oculus SDK[4] were imported for controller functionality and 3D hand models and animations.

The core functions of the prototype include a set of representative construction sites with coherent temporal and spatial dependencies on three map layers (interactive map, previous time layer, far future time layer) and basic interactions supporting exploration tasks.

Construction sites are represented by cyan building blocks on the road network of the map. Dependencies are shown as arcs between the blocks. Using the color cyan as the neutral color has its roots in the wide usage of the color in the Oculus software at the given date, both for the play area border visualization and for highlighting UI elements in the Home menu. The map design was adapted from the former 2D application described in the last chapter. The dark theme avoids eye strain caused by the eyes being exposed to large light areas in virtual reality displays.

Two illustration were created explaining the legend of the data and the available controller interactions. They appear on a screen overlay when pressing the thumb stick of the controllers and serve as a simple tutorial and reminder of the application’s features.

To notify users of visible connections to other map layers, a small UI widget is shown in the upper area of the field of view (see fig. 2). It is anchored to the movements of the head and therefore always visible in the view field.

Controls & Interaction

During test sessions, the following explanation was given to the participants to immerse them into the tool’s context: "Imagine yourself working at a construction site planning authority. You are interested in road construction sites taking place in 2022 because you are involved in the planning of other sites in the same year. Your intention is to manage the traffic flow as well as possible and to coordinate sites near existing ones so they can share resources such as excavators. You take a look at the planning situation in our new planning tool."

Basic interaction techniques we have implemented are selecting construction sites, zooming and rotating map layers and selecting sites for displaying/hiding connections.

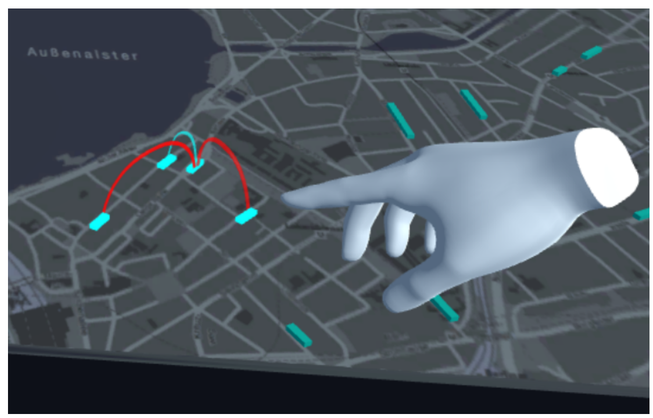

Figure 3: Selecting sites by pointing with the index finger

Selecting sites. Selecting of a construction site is implemented by touching the site or the area around it with the extended index finger (see fig. 3). This is an out-of-the-box implementation using the Oculus Touch controller sensors which are tracking tactile touch on the controller buttons. Thereby the system recognizes if the index finger is not in contact with the so-called "Trigger" button. If this state occurs, due to the physical structure of the hand, the resulting position of the index finger is (almost) stretched out, which correlates to finger pointing. The virtual hand therefore displays a pointing (or non-pointing) gesture.

To notify the user that construction sites have been successfully selected, the respective block is highlighted and the active controller responds with subtle vibration as tactile feedback.

Zooming & Rotating the map. The size and rotation of the map can be altered by touching the map with the controllers

[3]Unity game engine: https://unity.com/

[4] https://developer.oculus.com/downloads/

and pushing the Trigger buttons for grabbing it (see fig. 4). The implemented movements are similar to zooming and rotating with two fingers on a 2D touch device. Zooming in is implemented by moving the hands away from each other and zooming-out by bringing the hands together. By moving the hands in a circular motion, the map is rotated.

Figure 4: Zooming and Rotating the map by using both Touch controllers

Navigating between layers. Grabbing the map by pressing the Trigger button on one or both controllers close to a map allows navigating around the map or maps 5). In this mode, maps can be moved horizontally to navigate between different areas on a map. Any map can also be moved vertically to change between map layers, e.g. for following temporal connections between maps or reaching the map layer above or below the grabbed map.

Figure 5: Grabbing a map for navigating on and between maps

4 USER STUDY

A short user study was conducted to find major and minor usability issues. 7 participants were invited to test the prototype by resolving 9 example tasks with increasing difficulty in the area of roadworks coordination. Additionally, a roadworks expert from the coordination department at the LSBG tested the application and took part in a semi-structured interview. By using qualitative Thinking Aloud methods and screen recording, the major usability issues could be identified for further development.

Figure 6: Test session in the facilities of the LSBG

5 DISCUSSION & NEXT STEPS

The Thinking Aloud study showed several issues when using the prototype (for easy coordination tasks), however, the interaction design was rated positively by all participants. The interviewed employee of the LSBG was missing detour routes and exact building periods for effective road works coordination. The next iteration of the prototype will therefore need to expand on displaying detour data for all construction sites.

Using a vertical line as a discrete time axis, the shown map layers may represent specific points in time. This would make room for a Gantt-chart visualization approach with concrete building periods along the vertical axis. Therefore road works would be represented not as flat cubes with same height but as 'skyscrapers' reaching variable from one layer to another depending on the length of the building period. By manually rotating the whole visualization to the side using the VR controllers, the time series of roadworks could be compared as on a timeline graph. This approach should be tested in the near future to include more complex time-oriented data and the ability to compare building periods in detail.

As readability of text and road names on the map was a frequent issue during the user study, using a VR system with higher display resolution is highly recommended.

ACKNOWLEDGMENTS

This project is funded by the ERDF — European Regional Development Fund, the Hamburgische Investitions- und Förderbank and the Free and Hanseatic City of Hamburg.

REFERENCES

[1] J. Kielman and J. (Guest Eds.) Thomas. 2009. Special Issue: Foundations and Frontiers of Visual Analytics. *in: Information Visualization* 8 (2009), 239–314.

[2] Till Nagel, Joris Klerkx, Andrew Vande Moere, and Erik Duval. 2013. Unfolding–a library for interactive maps. In *International Conference on Human Factors in Computing and Informatics*. Springer, 497–513.

[3] Till Nagel, Christopher Pietsch, and Marian Dörk. 2016. Staged Analysis: From Evocative to Comparative Visualizations of Urban Mobility. *Proceedings of the IEEE VIS Arts Program (VISAP)* (Oct. 2016), 23–30.

[4] M. Nix. 2013. *Visual Simplexity: Die Darstellung großer Datenmengen*. entwickler Press.

[5] Arnaud Prouzeau, Anastasia Bezerianos, and Olivier Chapuis. 2016. Towards Road Traffic Management with Forecasting on Wall Displays. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces (ISS '16)*. ACM, New York, NY, USA, 119–128. https://doi.org/10.1145/2992154.2992158

[6] M. Uhr, J. Nitschke, J. Zhang, and F. Steinicke. 2018. Hybrid Decision Support System for Traffic Engineers. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 713–714. https://doi.org/10.1109/VR.2018.8446141