Visualising Geospatial Network Data using Virtual Reality Technology

Pointecker, Fabian; Jetter, Hans-Christian; Anthes, Christoph

Citation for published version (APA):
Pointecker, F., Jetter, H.-C., & Anthes, C. (2020). *Visualising Geospatial Network Data using Virtual Reality Technology*. 1-9. Paper presented at ACM CHI '20: Workshop on Immersive Analytics, Hawaii, United States.

Visualising Geospatial Network Data using Virtual Reality Technology

Fabian Pointecker
Hans-Christian Jetter
Christoph Anthes
fabian.pointecker@fh-hagenberg.at
hans-christian.jetter@fh-hagenberg.at
christoph.anthes@fh-hagenberg.at
University of Applied Sciences Upper Austria, Campus Hagenberg
Hagenberg, Austria

ABSTRACT

Immersive analytics, especially for network visualisation, has been gaining more and more attention in the recent years. In this position paper, we describe an example application for visualising real-world geospatial network data and discuss its design combining different immersive analytics techniques from literature. We describe how this composition of different approaches results in a coherent virtual environment for the visual exploration of geospatial network data in a real-world business context.

KEYWORDS

immersive analytics, geospatial data, networks, virtual reality

INTRODUCTION

In our age of "big data", using virtual reality (VR) technology [2] for immersive analytics is a promising step towards visual exploration and analysis of large-scale data sets [7]. Especially for geospatial network data, the visual clutter on non-VR 2D displays can become overwhelming and hide the information inside the data from the observer [15, 36]. Example domains dealing with such data sets

---

Immersive Analytics Workshop at Honolulu '20, April 25–26, 2020, Honolulu, HI

Figure 1: Visual representation of an air traffic network [5]

Figure 2: Visualising the peak volume of permanent virtual circuit traffic [1]

Figure 3: Visualising Facebook friends [1]

are logistics (e.g. transportation networks see Figure 1), telecommunications (e.g. network traffic see Figure 2) or social networks (e.g. interconnection between users see Figure 3).

We present a prototype application for visualising real-world global logistics networks from a research project with industry partners. The application consists of a virtual scene with three different views of the data for visual exploration. We give an overview of our underlying design considerations concerning visualisation and interaction techniques. By this, we would like to contribute first steps towards generalisable design recommendations for the visualisation of geospatial network data that can help to build more productive immersive analytics applications in the future.

RELATED WORK

While there are a vast amount of publications describing network layout and map visualisation in the 2D domain, we here focus exclusively on networks in 3D or VR.

VR visualisation of network data

To determine if a higher degree of realism has an impact on task performance in network graph analysis, Bacim et al. [3] compared a four-sided CAVE (CAVE Automatic Virtual Environment) [11] with a single wall display. They have shown that a more immersive display leads to a lower task completion time. Even lower task completion times for collaborative abstract network data analysis were demonstrated when using a head-mounted display (HMD) instead of projection technology. Cordeil et al. [10] compared a curved walk-in display and an HMD system, with HMD users being faster and the physical engagement to be more balanced. To compare an immersive 3D graph visualisation with planar 2D visualisation, Kwon et al. [26] conducted a study using an HMD displaying 2D and 3D graph layout. The results showed that the 3D data layout provided better results regarding completion time and number of interactions.

Several studies investigated interaction with controllers [23] and gestures [13] in the context of network graphs. Erra et al. compared these input modalities with traditional keyboard and mouse interaction [17]. Different navigation techniques for 3D graph exploration were evaluated by Drogemueller et al. [12].

Geo-Reference for Representation

Having a physical map representation of a known environment (e.g. world map) helps the users to understand distances and spatial relations. Moran et al. visualised the quantity of Twitter messages referenced to the model of a campus to provide enhanced situational awareness [33]. In cases of disaster management, Ready et al. visualised data from weather sensors and used the underlying world map as a known geographical reference [35]. Furthermore, this technique was also used by Nguyen et al. [34] to visualise bee flight behaviour and by Wagner Filho et al. [19] to analyse the

---

[1] https://paulbutler.org/2010/visualizing-facebook-friends/

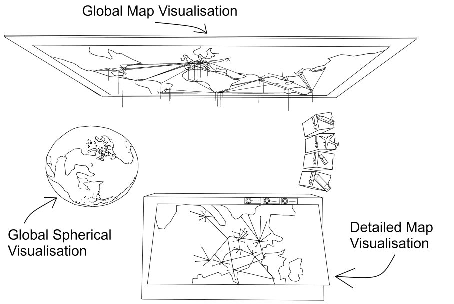

Figure 4: Virtual Environment Layout

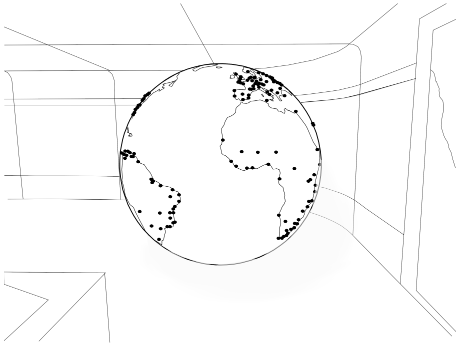

Figure 5: Global Spherical Visualisation

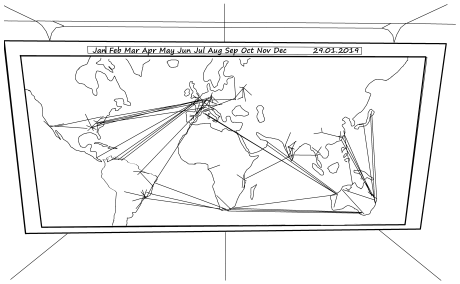

Figure 6: Global Map Visualisation

movements of people in a city. Despite these advantages, using map or globe representations also restricts the use of traditional layout algorithms for graphs (e.g., [20]) that can reduce visual clutter. For this reason, we discuss the use of spatial separation as an alternative approach below.

SETUP OF THE VIRTUAL SCENE FOR GEOSPATIAL NETWORK DATA VISUALISATION

In our test scenario, we have chosen to visualise the global logistics network of a fictional automotive corporation containing 500 nodes connected by 400 edges. The individual nodes contain numerical information, e.g. load of the node, and the edges interconnect the nodes with different loads and transportation types, e.g., ship, aircraft, railway, trucks. The numerical data on the nodes, as well as the edge data can be dynamic.

We designed a virtual environment (VE) to display three different simultaneous views on the data that enable users to rely on familiar real-world metaphors during exploration and analysis. All of them use a world map as a familiar spatial reference. A fourth area contains additional interactive controls for one of the visualisations. Figure 4 gives an overview of the spatial layout of the VE, showing the three different views. In the following, we first introduce the setup of the virtual scene and its views. This is followed by a more detailed explanation of the individual interaction and visualisation techniques in the next section.

Global Spherical Visualisation (Figure 5). This view enables an overview of the nodes of the network. The diameter of the displayed globe in the VE is 2m to support users who view it from greater distances. The edges are omitted in this visualisation to avoid additional clutter. By mapping the data to a globe, the geographical distances between the nodes are preserved and no major map distortion affects the relative distances between them. The data can also be observed continuously, due to the absence of geographical boundaries on a globe. Furthermore, the displayed globe is rotated slowly to act as an overview that also reveals nodes on the far side of the globe. It can also be stopped or manually rotated by the user.

Global Map Visualisation (Figure 6). This view enables an overview of the entire network. The map is displayed on a wall with a size of 3x7m in virtual space. It shows the nodes as well as the interconnecting edges. The nodes are visualised by cuboids instead of cylinders to reduce the amount of rendered polygons. Cuboids stick out of the map with red or green colour coding. Edges are colour-coded by connection type. The interaction space allows to alter dynamic behaviour on the global map and to filter different connection types. The map itself is static.

Detailed Map Visualisation (Figure 7). This view uses a table metaphor for displaying a section of the world map. The table surface is tilted by 20° and either shows a planar projection of the edges onto the section of the world map or their extrusion into the space above map. To clearly distinguish between different height levels, the spatial edge representation uses sharply bent height platforms instead of fully curved edges.

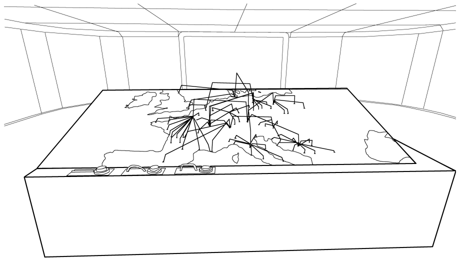

Figure 7: Detailed Map Visualisation (with extrusion)

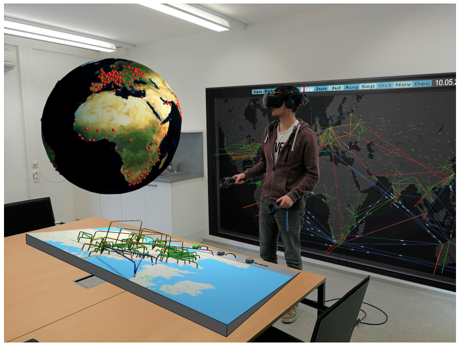

Figure 8: User analysing the data in the simulated workspace

DESIGN CONSIDERATIONS

The design of the VE followed a set of carefully selected techniques and approaches from the information visualisation and immersive analytics literature and merges them into a coherent application. The following five design considerations were used in the application and should be considered first steps towards generalisable design recommendations for the visualisation of geospatial network data, not only for logistics but also including other application domains.

D1. Simulated Workspace

First of all, we provide a real-world metaphor of a workspace to the user in order to support easy orientation and understanding of the different representations of the data. Global maps and globes in general are often perceived as an instrument of overview, while the underlying world maps provide a real-world reference to the abstract network data. Our Detailed Map View implements a virtual desk similar to the approach chosen by Wagner Filho et al. [18]. In general, an abstract representation of the surroundings was chosen to avoid distraction from the actual data representations.

The area is large enough to have the users bodily-engaged as suggested by Cliquet et al. [8]. For navigating the environment, we opted for real walking instead of navigation techniques such as teleportation. Real walking provides vestibular cues [28] which reduces the risk of cybersickness. It also helps spatial understanding [6, 28]. With real walking, an increased degree of presence can be observed [39]. Some researchers claim that a higher degree of presence leads to a better task performance [41] although this topic is still controversial. In general the three scenarios standing, sitting and walking identified by Bellgardt et al. [4] are supported.

For interaction purposes a virtual hand metaphor is used [32]. Buttons for filtering data can be pressed by colliding with the controller and the visual button representation similar to pressing a real world button. The map section in the table view can be shifted by dragging the controller on the visual representation.

D2. Passive Haptic Feedback

Passive haptic feedback [29, 30] in VR is achieved by providing physical props and surfaces, which can be touched by the users. This increases immersion and presence [21, 22, 24, 27] but also provides additional advantages in the context of our visualisation.

Two views of the data make use of passive haptic feedback and implement the concept of substitutional reality [37]. The global map visualisation is aligned with a physical wall since users have a desire to touch areas on maps [25] shown in Figure 9. The detailed map visualisation is aligned with a physical table that allows the user to lean on the physical table shown in Figure 10. This provides posture stability while observing the different network layers.

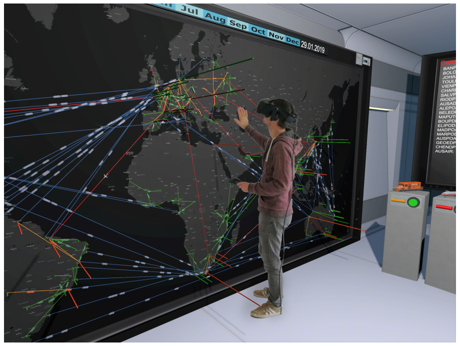

Figure 9: User at the Global Map Visualisation using passive haptic feedback

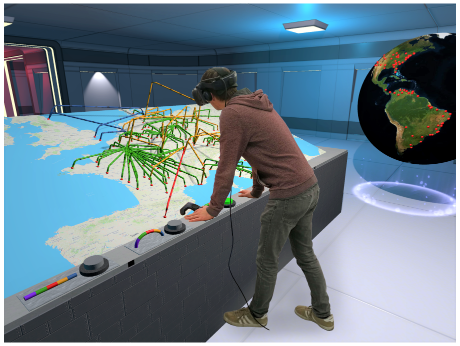

Figure 10: User at the Detailed Map Visualisation using passive haptic feedback

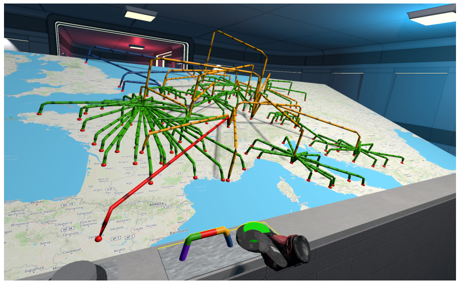

Figure 11: Using spatial separation to map an additional edge attribute

These physical props (table and wall) have to be registered correctly with their virtual representations in an initial calibration step. Table and wall also act as a natural restriction of the users physical movement space.

D3. Spatial Separation

A common issue with representation of big data is visual clutter [36], which can be reduced by separating the data sets into individual clusters that are spatially offset [31]. Spur and Tourre achieve this separation by bending the data upwards from the ground level to make distant data visible [38].

In our prototype, we use two approaches for spatial separation. First, we are able to reduce the visual clutter by separating the data in individual layers based on the edge type. Second, we use the spatial dimension to map an additional edge attribute like load resulting in separate high load areas and areas of little load shown in Figure 11. A similar technique is used by Yang et al. where they used the height to visualise the quantity of the international migration flows between countries. [42]. The spatial separation of the data is only performed on the detailed map view, which is also tilted. This arrangement of data allows the user to easily perceive the interconnection of the network, but also provides a clear separation in 3D space. A central finding of Yang et al. was that people tend to look at the spatially separated data from the side [42]. To support this finding, we have given the possibility of leaning on the table with the help of passive haptics. By incorporating head tracking, different perspectives on the data can easily be taken.

D4. 3D Globe

Using a globe visualisation provides the advantage of the display of correct distance and size relationships opposed to maps which are distorted. The major disadvantage of a globe is the limited visibility. The user is only able to observe one hemisphere of the globe.

A user study by Yang et al. also states that in overall an exocentric globe representation compared to flat or curved maps or an egocentric globe representation performs best in terms of accuracy and direction estimation [43].

The globe acts in our application as an important overview visualisation to estimate distances between different nodes and sub-networks. It is the only display in the presented prototype not using passive haptic feedback.

D5. Multiple Views

Different views act as a natural reference to well known real world metaphors in the scene. They provide different degrees of detail as well as different visualisation and interaction types.

The user can switch between these different views, without using a virtual or physical interface. Only head tracking is used, which again supports the mental map of the user of the scene. A similar

Figure 12: Global Spherical Visualisation showing the geoposition of the nodes

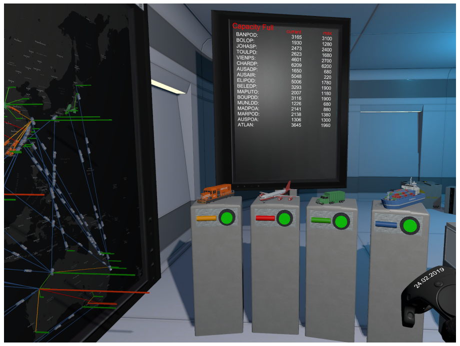

Figure 13: Physical objects providing a common reference

approach was used by Cordeil et al. where the user can freely place different views of data and users tend to place them in a circular pattern around them [9].

We designed a consistent colour scheme over the different views to support a smooth transition between the views. In our specific use case, the colours also support the type of connection by providing natural colours (e.g. land in green, sea in blue).

Additional Aspects

For additional separation and untangling of the different edges, we indicated the direction of an edge flow by showing icons moving along the edges [40].

The icons used in our prototype resemble well known physical objects to provide a common reference shown in Figure 13. This representation scheme is also used by Durbin et al. where they used realistic 3D models to rapidly identify a model based on shape and colouring [14].

CONCLUSIONS AND FUTURE WORK

In this contribution we presented an initial prototype of a generic approach for network visualisations of global network data. Existing techniques from traditional information visualisation, VR and immersive analytics were joined together in an interactive prototype.

The prototype was presented in different development stages at three events and initial user feedback was gathered.

- Cybersickness does not seem to be an issue at all, since no virtual navigation through the scene is required. Users can easily build up a mind map of their virtual environment.
- The interface was simplified after initial feedback. Controller interaction was reduced to pushing of virtual buttons and shifting of the detailed map view.
- Users make extensive use of leaning on the detailed map view to look through the different data layers. Passive haptic feedback of the wall is used.

We plan to refine the prototype and evaluate it in controlled user studies. Additional passive haptic globe as with Englmaier et al. [16] and buttons are planed. For text input, e.g. for searching specific items, we could incorporate a physical keyboard as suggested by Zielasko et al. [44]. Visual interconnection between selected data points or areas between the views might help the orientation of the user in the data set.

ACKNOWLEDGMENTS

This work was supported by the government of Upper Austria as part of the “Basisfinanzierung” funding initiative by the University of Applied Sciences Upper Austria, project title: “CalmAn - Casual Immersive Analytics”.

REFERENCES

[1] James Abello, Emden R Gansner, Daniel A Keim, Eleftherios E Koutsofios, Stephen C North, and Russ Truscott. 1999. Visualizing Large-Scale Telecommunication Networks and Services. In *AT & T Software Symposium*.

[2] Christoph Anthes, Ruben Jesus Garcia-Hernandez, Markus Wiedemann, and Dieter Kranzlmuller. 2016. State of the art of virtual reality technology. In *2016 IEEE Aerospace Conference*. IEEE. https://doi.org/10.1109/aero.2016.7500674

[3] Felipe Bacim, Eric Ragan, Siroberto Scerbo, Nicholas F Polys, Mehdi Setareh, and Brett D Jones. 2013. The effects of display fidelity, visual complexity, and task scope on spatial understanding of 3D graphs. In *Proceedings of Graphics Interface 2013*. Canadian Information Processing Society, 25–32.

[4] Martin Bellgardt, Sebastian Pick, Daniel Zielasko, Tom Vierjahn, Benjamin Weyers, and Torsten W. Kuhlen. 2017. Utilizing immersive virtual reality in everydaywork. In *2017 IEEE 3rd Workshop on Everyday Virtual Reality (WEVR)*. IEEE. https://doi.org/10.1109/wevr.2017.7957708

[5] Alessio Cardillo, Jesús Gómez-Gardeñes, Massimiliano Zanin, Miguel Romance, David Papo, Francisco del Pozo, and Stefano Boccaletti. 2013. Emergence of network features from multiplexity. *Scientific Reports* 3, 1 (feb 2013). https://doi.org/10.1038/srep01344

[6] Sarah S. Chance, Florence Gaunet, Andrew C. Beall, and Jack M. Loomis. 1998. Locomotion Mode Affects the Updating of Objects Encountered During Travel: The Contribution of Vestibular and Proprioceptive Inputs to Path Integration. *Presence: Teleoperators and Virtual Environments* 7, 2 (apr 1998), 168–178. https://doi.org/10.1162/105474698565659

[7] Tom Chandler, Maxime Cordeil, Tobias Czauderna, Tim Dwyer, Jaroslaw Glowacki, Cagatay Goncu, Matthias Klapperstueck, Karsten Klein, Kim Marriott, Falk Schreiber, and Elliot Wilson. 2015. Immersive Analytics. In *2015 Big Data Visual Analytics (BDVA)*. IEEE. https://doi.org/10.1109/bdva.2015.7314296

[8] Gregoire Cliquet, Matthieu Perreira, Fabien Picarougne, Prié Yannick, and Toinon Vigier. 2017. Towards HMD-based Immersive Analytics. In *Immersive analytics Workshop, IEEE VIS 2017*. IEEE.

[9] Maxime Cordeil, Andrew Cunningham, Tim Dwyer, Bruce H. Thomas, and Kim Marriott. 2017. ImAxes Immersive Axes as Embodied Affordances for Interactive Multivariate Data Visualisation. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology - UIST '17*. ACM Press. https://doi.org/10.1145/3126594.3126613

[10] Maxime Cordeil, Tim Dwyer, Karsten Klein, Bireswar Laha, Kim Marriott, and Bruce H. Thomas. 2017. Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display? *IEEE Transactions on Visualization and Computer Graphics* 23, 1 (jan 2017), 441–450. https://doi.org/10.1109/tvcg.2016.2599107

[11] Carolina Cruz-Neira, Daniel J Sandin, Thomas A DeFanti, Robert V Kenyon, and John C Hart. 1992. The CAVE: audio visual experience automatic virtual environment. *Commun. ACM* 35, 6 (1992), 64–73.

[12] Adam Drogemuller, Andrew Cunningham, James Walsh, Maxime Cordeil, William Ross, and Bruce Thomas. 2018. Evaluating Navigation Techniques for 3D Graph Visualizations in Virtual Reality. In *2018 International Symposium on Big Data Visual and Immersive Analytics (BDVA)*. IEEE. https://doi.org/10.1109/bdva.2018.8533895

[13] Adam Drogemuller, Andrew Cunningham, James Walsh, William Ross, and Bruce H Thomas. 2017. VRige: exploring social network interactions in immersive virtual environments. In *Proceedings of the international symposium on big data visual analytics (BDVA). IEEE NJ, USA*.

[14] J. Durbin, J.E. Swan, B. Colbert, J. Crowe, R. King, T. King, C. Scannell, Z. Wartell, and T. Welsh. 1998. Battlefield visualization on the responsive workbench. In *Proceedings Visualization '98 (Cat. No.98CB36276)*. IEEE. https://doi.org/10.1109/visual.1998.745344

[15] G. Ellis and A. Dix. 2007. A Taxonomy of Clutter Reduction for Information Visualisation. *IEEE Transactions on Visualization and Computer Graphics* 13, 6 (nov 2007), 1216–1223. https://doi.org/10.1109/tvcg.2007.70535

[16] David Englmeier, Isabel Schonewald, Andreas Butz, and Tobias Hollerer. 2019. Feel the Globe: Enhancing the Perception of Immersive Spherical Visualizations with Tangible Proxies. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE. https://doi.org/10.1109/vr.2019.8797869

[17] Ugo Erra, Delfina Malandrino, and Luca Pepe. 2019. Virtual Reality Interfaces for Interacting with Three-Dimensional Graphs. *International Journal of Human–Computer Interaction* 35, 1 (jan 2019), 75–88. https://doi.org/10.1080/10447318.2018.1429061

[18] J. A. Wagner Filho, C.M.D.S. Freitas, and L. Nedel. 2018. VirtualDesk: A Comfortable and Efficient Immersive Information Visualization Approach. *Computer Graphics Forum* 37, 3 (jun 2018), 415–426. https://doi.org/10.1111/cgf.13430

[19] J. A. Wagner Filho, Wolfgang Stuerzlinger, and Luciana Nedel. 2019. Evaluating an Immersive Space-Time Cube Geovisualization for Intuitive Trajectory Data Exploration. *IEEE Transactions on Visualization and Computer Graphics* (2019), 1–1. https://doi.org/10.1109/tvcg.2019.2934415

[20] Thomas M. J. Fruchterman and Edward M. Reingold. 1991. Graph drawing by force-directed placement. *Software: Practice and Experience* 21, 11 (1991), 1129–1164. https://doi.org/10.1002/spe.4380211102 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/spe.4380211102

[21] H.G. Hoffman. 1998. Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments. In *Proceedings. IEEE 1998 Virtual Reality Annual International Symposium (Cat. No.98CB36180)*. IEEE Comput. Soc. https://doi.org/10.1109/vrais.1998.658423

[22] Matthias Hoppe, Pascal Knierim, Thomas Kosch, Markus Funk, Lauren Futami, Stefan Schneegass, Niels Henze, Albrecht Schmidt, and Tonja Machulla. 2018. VRHapticDrones. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia - MUM 2018*. ACM Press. https://doi.org/10.1145/3282894.3282898

[23] Yi-Jheng Huang, Takanori Fujiwara, Yun-Xuan Lin, Wen-Chieh Lin, and Kwan-Liu Ma. 2017. A gesture system for graph visualization in virtual reality environments. In *2017 IEEE Pacific Visualization Symposium (PacificVis)*. IEEE. https://doi.org/10.1109/pacificvis.2017.8031577

[24] Brent Edward Insko, M Meehan, M Whitton, and F Brooks. 2001. *Passive haptics significantly enhances virtual environments*. Ph.D. Dissertation. University of North Carolina at Chapel Hill.

[25] Alexander J. Kent. 2019. Maps, Materiality and Tactile Aesthetics. *The Cartographic Journal* 56, 1 (2019), 1–3. https://doi.org/10.1080/00087041.2019.1601932

[26] Oh-Hyun Kwon, Chris Muelder, Kyungwon Lee, and Kwan-Liu Ma. 2016. A Study of Layout, Rendering, and Interaction Methods for Immersive Graph Visualization. *IEEE Transactions on Visualization and Computer Graphics* 22, 7 (jul 2016), 1802–1815. https://doi.org/10.1109/tvcg.2016.2520921

[27] Antoine Lassagne, Andras Kemeny, Javier Posselt, and Frederic Merienne. 2018. Performance Evaluation of Passive Haptic Feedback for Tactile HMI Design in CAVEs. *IEEE Transactions on Haptics* 11, 1 (jan 2018), 119–127. https://doi.org/10.1109/toh.2017.2755653

[28] Joseph J LaViola Jr, Ernst Kruijff, Ryan P McMahan, Doug Bowman, and Ivan P Poupyrev. 2017. *3D User Interfaces: Theory and Practice (Usability)*. Addison-Wesley Professional. https://www.amazon.com/3D-User-Interfaces-Practice-Usability-ebook/dp/B06XYCNQ2L?SubscriptionId=AKIAIOBINVZYXZQZ2U3A&tag=chimbori05-20&linkCode=xm2&camp=2025&creative=165953&creativeASIN=B06XYCNQ2L

[29] Robert William Lindeman. 1999. *Bimanual interaction, passive-haptic feedback, 3 D widget representation, and simulated surface constraints for interaction in immersive virtual environments*. Ph.D. Dissertation. George Washington University.

[30] Robert W Lindeman, John L Sibert, and James K Hahn. 1999. Hand-held windows: towards effective 2D interaction in immersive virtual environments. In *Proceedings IEEE Virtual Reality (Cat. No. 99CB36316*. IEEE, 205–212.

[31] Karen McDonough. 2012. GeoTime Visualization Software. *Law and Order Magazine* (Nov. 2012).

[32] Mark R Mine. 1995. Virtual environment interaction techniques. *UNC Chapel Hill CS Dept* (1995).

[33] Andrew Moran, Vijay Gadepally, Matthew Hubbell, and Jeremy Kepner. 2015. Improving Big Data visual analytics with interactive virtual reality. In *2015 IEEE High Performance Extreme Computing Conference (HPEC)*. IEEE. https://doi.org/10.1109/hpec.2015.7322473

[34] Huyen Nguyen, Florence Wang, Raymond Williams, Ulrich Engelke, Alex Kruger, and Paulo de Souza. 2017. Immersive Visual Analysis of Insect Flight Behaviour. *Immersive analytics Workshop, IEEE VIS 2017* (2017).

[35] Matthew Ready, Tim Dwyer, and Jason H. Haga. 2017. Immersive Visualisation of Big Data for River Disaster Management. In *Immersive analytics Workshop, IEEE VIS 2017*.

[36] Ruth Rosenholtz, Yuanzhen Li, Jonathan Mansfield, and Zhenlan Jin. 2005. Feature Congestion: A Measure of Display Clutter. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '05*. ACM Press. https://doi.org/10.1145/1054972.1055078

[37] Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. 2015. Substitutional Reality. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*. ACM Press. https://doi.org/10.1145/2702123.2702389

[38] Maxim Spur and Vincent Tourre. 2018. Urban DataSphere: Exploring Immersive Multiview Visualizations in Cities. *IEEE VIS Poster* (2018).

[39] Martin Usoh, Kevin Arthur, Mary C Whitton, Rui Bastos, Anthony Steed, Mel Slater, and Frederick P Brooks Jr. 1999. Walking> walking-in-place> flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*. ACM Press/Addison-Wesley Publishing Co., 359–364.

[40] Colin Ware. 2012. *Information Visualization*. Elsevier LTD, Oxford. https://www.ebook.de/de/product/18589637/colin_ware_information_visualization.html

[41] Bob G Witmer and Michael F Singer. 1994. *Measuring presence in virtual environments*. Technical Report. US Army Research Institute for the Behavioral and Social Sciences, Alexandria VA.

[42] Yalong Yang, Tim Dwyer, Bernhard Jenny, Kim Marriott, Maxime Cordeil, and Haohui Chen. 2019. Origin-Destination Flow Maps in Immersive Environments. *IEEE Transactions on Visualization and Computer Graphics* 25, 1 (jan 2019), 693–703. https://doi.org/10.1109/tvcg.2018.2865192

[43] Yalong Yang, Bernhard Jenny, Tim Dwyer, Kim Marriott, Haohui Chen, and Maxime Cordeil. 2018. Maps and Globes in Virtual Reality. In *Eurographics Conference on Visualization (EuroVis) 2018 Volume 37 (2018)*. 427–438.

[44] Daniel Zielasko, Martin Bellgardt, Alexander Meißner, Maliheh Haghgoo, Bernd Hentschel, Benjamin Weyers, and Torsten W. Kuhlen. 2017. buenoSDIAs: Supporting Desktop Immersive Analytics While Actively Preventing Cybersickness. In *Immersive analytics Workshop, IEEE VIS 2017*.