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Analysis of Cartographic Symbols as Visual Support in Interactive VR Geovisualizations

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Abstract:
Game engines and head-mounted displays (HMD) can create interactive virtual reality (VR) cartographies. Many VR geovisualizations try to depict places as close to reality as possible. The scaling is 1:1 for most VR geovisualizations. If VR geovisualizations are too close to reality or complex, users can navigate through them better, but the amount of detail makes it more challenging to target information. With the help of cartographic elements, a more targeted focus can again be acquired. The focus and style of VR cartography depend on the topic. The topics selected were "Floods and heavy rainfall events", "Noise propagation analysis", and "Lighting simulation". These are three topic examples in which 3D city models are used. CityGML models and fictitious 3D objects were used. Different rendering techniques and point signatures were implemented for each of the themes. All three topics were implemented in an application as a serious game. With the help of an interactive interface and motion controllers, users can change and navigate all three themes. Solution-oriented objects can be placed on all three topics as an additional interactive element. These options allow users to learn targeted information through various presentation options and implement solutions.

Keywords: 3D, CityGML, geovisualization, interactive, virtual reality

1. Introduction

In many application areas, geodata in VR scenes are mainly visualized as close to photorealism as possible when using game engines such as Unreal Engine 5 (UE5). However, geovisualizations, considering cartographic concepts, improve efficiency in the communication process.

On the other hand, the viewing perspective with a head-mounted display (HMD) is often a first-person view and not a top-down view, which means the buildings are represented 1:1 in size as they are perceived in reality. This is unusual for cartographic representations and allows, e.g., a 3D city model to appear larger and more realistic to users.

Combining cartography with VR headsets brings a new potential study of landscape visualizations (Vetter, 2020). Using non-photorealistic rendering (NPR) and combining it with modeled assets, it is possible to implement cartographic styles and symbols in a 3D scene. A combination of realistic and cartographic visualization methods can enhance the transfer of information, and users can navigate the VR scene on a 1:1 scale. Here, it is helpful to test existing highlighting methods in the VR context and develop potential new methods.

Furthermore, one task of cartography is to categorize spatial information, which means filtering or reducing information in geovisualizations.

Information reduction can be achieved with the help of alternative or abstract visualization approaches. The opposite of photorealistic visualization is NPR. These visualizations can also be referred to as abstract visualizations or stylized rendering. A non-photorealistic rendering uses a variety of renderings to either reduce complexity in the 3D visualization to mimic an art style or to highlight selected objects (Akenine-Möller et al., 2018).

This contribution aims to present map-like visualization concepts in three different topics. These topics are "Floods and heavy rainfall events", "Noise propagation analysis", and "Lighting simulation". The selection of the three topics could also be compared with the application scenarios of (Coors et al., 2015) and (Biljecki et al., 2015).

A second goal is to prepare views of visualization variants in combination with serious gaming to analyze the effect of cartographic symbols for visual support for interactivity in VR-Environments.

2. Related Work

Various publications deal with the role and significance of VR applications for cartography, like the Opportunities and options of VR in 3D geovisualization or approaches to the visualization of landscapes. Notable examples are (Halik, 2018), (Hochschild et al., 2020), and (Kühne, 2021).

Various approaches to displaying 3D city models in VR always focus on immersion and interaction opportunities (Buyukdemircioglu and Kocaman, 2020; Wagner et al., 2021).

General technical implementation methods were first developed for cartographic representations, such as placing symbols using tables and building metadata (Vetter and Olberding, 2022). Subsequently, NPR methods and animation techniques were developed (Olberding, 2023).

In considering the three topics, the first step was to examine the extent to which other VR studies and developments were available. Flood disaster visualization in VR helps display and share disaster knowledge. For this purpose, cities near a larger river are used for visualization (Fu et al., 2021; Hu et al., 2018; Sidanin and Plavsic, 2019 - 2019). In a noise propagation analysis, urban traffic noise is usually visualized (Berger and Bill, 2019). Lightning is essential for the city's sense of security and mood (Scorpio et al., 2020).

3. Technology

A game engine, or game development environment, is a software framework that enables the development of applications that require real-time visualization. The engines combine several components that can be implemented in the virtual world to be visualized in real-time (Trenholme and Smith, 2008). Various game engines are available for interactive 3D geovisualizations in real-time. Game engines have various possibilities to display detailed landscapes and models. The UE5 version 5.0.3 was used as the game engine. Compared to its predecessor, the UE4, the UE5 allows more polygons and objects to be displayed simultaneously.

The VR hardware used for the HMD was the HTC Vive Pro 2. Besides the HMD, the HTC Vive Pro 2 includes two motion controllers. Every Unreal Engine project automatically recognizes the VR glasses and their motion controllers. This is an advantage during development, as the VR glasses can be constantly used as a control screen for the application.

The VR application is based on open data and free 2D and 3D assets. The applications are entirely generated with Unreal Engine Blueprints, a visual scripting technique. Some developed applications used fictitious 3D landscapes, while others used free geodata to recreate regions. For this purpose, buildings in CityGML format were used, as 3D city models are increasingly available in this format. The purpose of the CityGML standard and the unified object catalog is to define the capture, data storage, provision, and visualization of 3D city models so that they can be used in different domains and application scenarios (Coors et al., 2016). CityGML is an open-source data model built on an XML format based on the ISO 19xx family standards (Gröger et al., 2012). Another essential core component of CityGML is the use of different, clearly defined levels of detail.

With the help of a newly developed plugin, "CityGML Import Plugin", importing CityGML data and its metadata into UE5 is possible. The free plugin was developed in cooperation between the THWS, Department of Geovisualization, and the University of Würzburg, Department of Game Engineering. The plugin serves as an aid to visually enhance CityGML data of LoD 2 with realistic 3D assets and effects (Figure 1). All metadata is stored directly in the respective 3D models in the "Building Data" information. This information can be manually adjusted and changed with visual scripting.

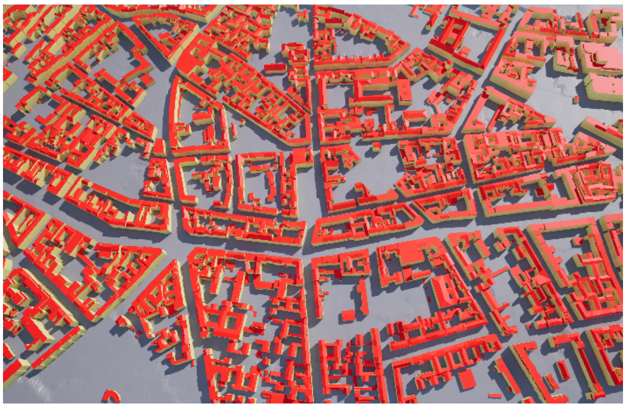

Figure 1. Example of a CityGML model from the city of Berlin from Berlin open geodata.

4. Methods for the Different Symbols

Cartographic symbols and map-like filtering methods are developed to combine realistic and cartographic geovisualization in VR. These visualizations are supplemented with various interaction options, such as rendering adjustment, placement of objects, and user positioning.

4.1 The different variants

Various map symbols have been designed. Map symbols can be divided into three different realizations. The variants are 2D, 3D, and particle symbols. Every symbol can vary in size, shape, color, and pattern. The variants were built so that they can vary in their representation just by changing the input image or 3D model quickly.

The first variant has 2D objects as its basis. These 2D objects contain PNG graphics. For a 2D graphic to be most recognizable in a 3D space, it must be viewed frontally. To ensure that a frontal view is given, the orientation of the symbols is constantly readjusted dynamically to the camera's perspective. This approach was already used in early 3D games of the 90s, like Doom or Duke Nukem 3D. Thus, it is a computationally efficient approach that allows the use of signatures from a 2D map without needing to remodel them for 3D space extensively. The 2D symbols can also comprise several PNG graphics, representing a sprite animation together.

The second variant has 3D objects as its basis. For this purpose, an FBX model is linked to the respective symbol. Besides more complex 3D models, simple spheres or squares can also be used. The material of the 3D objects describes the color representation. Animations can be implemented using rigid hierarchical or morph target animation.

A particle rendering system or particle system handling is a rendering technique. A unique feature of a particle system is the vast number of simple graphic objects (particles) representing sparks, smoke, fire, and water as particle effects. Because of their unique properties, special

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rendering systems are implemented in game engines. Another feature of particles is that they can be animated in different and complex ways. Animations can be created manually or procedurally. In order to display the large amounts of moving particles, they are continuously created and removed. An emitter allows particles to be created in the system at a user-defined rate. When particles move outside a defined zone or their period expires, they will be removed (Gregory, 2019). Personal effects can be played briefly to direct the user's attention to specific points. The unique feature of particles is the possibility of displaying thousands of small animated objects.

The presence and positions of the symbols are based either on a table of metadata or on specified information from the CityGML buildings. Theoretically, changing the shape and color of the symbols dynamically is possible.

Besides the map symbols, additional filtering and highlighting methods were implemented, partially or entirely changing the scene with NPR elements. NPR approaches aim to improve contextual communications using abstract methods. Most developed concepts' foundation is cartosemiotics as a stylistic device. For this purpose, the displayed information and objects are reduced to the most necessary. Depending on the effect of the visualization, filtering, textures, or rendering are adjusted at different points (Semmo et al., 2015).

In UE5, it is possible to use a "PostProcessVolume" for post-processing techniques, like different NPR. A "Volume" is an object that can be placed as a box in a 3D scene. Post Processing allows changing the entire representation of a scene in the last rendering step. The results are only applied when the camera is in the 3D scene within a "PostProcessVolume." The limitation of the "PostProcessVolume" can be deactivated, and then the Volume influences the complete 3D scene. Using the "PostProcessVolume" the most diverse parameters can be adapted. These include simulated effects of physical camera properties such as depth of field and lens reflections, edge smoothing, or color correction is possible (Epic Games, Inc., 2022). Individual post-processing materials can implement additional effects. Mapping methods can be used here, as with the texturing of individual objects. This all occurs in UE5 as materials. An example in this context is a black silhouette that serves as an additional outline for 3D models. Outlines can distinguish 3D objects more clearly from each other. For the creation of such material, e.g., for the detection of geometric edges and borders can implement different filtering methods in the material.

4.2 Interactive visualization

It is possible to implement user interactions that impact the visualization. Interactions can be triggered using a VR headset and motion controller. Motion controllers can map the movements of hand positions. In most applications with VR glasses, the 3D model of hands or the controller is the only thing users see of themselves in the virtual world. With these "hands", it is understandable for various people to point or press on objects, to activate or trigger them. All interactive elements are geared towards these two variants. A head-up display (HUD) is only displayed when the left motion controller is aligned to a specified camera angle. This gives a user the impression that an interactive information surface appears whenever the left hand is held in front of the head. In the HUD, users can now activate highlighting options (Figure 2).

Figure 2. Example of a HUD, which is used in real-time and teleportation visualization settings.

In virtual worlds, movements are simulated for the visual sense that does not correspond precisely to reality in terms of the sense of balance. Motion control was therefore limited within the application to prevent motion sickness. Teleportation is an alternative means of locomotion that does not represent motion visualization. As a result, there is no conflict between the sensory and vestibular systems. The person can move through the 3D scene using teleportation or teleport at fixed points. Fixed teleportation points make it easier to travel greater distances and allow people to be in an ideal or guided position to see specific information better.

With the help of motion controllers, it is possible to implement functions that allow intuitive placement of objects. Users can first see a preview of the object to be placed and change the position of this object using movements. When users have found a desired position for the object, this object can be placed on the scene by pressing a button. In a game engine, this object can take different forms. It can, for example, be a 3D model, a texture, a particle system, or a HUD.

5. Results

There are three levels within the developed application. Each level represents a different geovisualization and considers a different topic. Since all topics are in the same application, technical implementations and customizations can improve all three scenarios. A user can place specific objects for all three topics to visualize potential solutions.

5.1 Flood and heavy rain

Floods can lead to immense property damage because of heavy rainfall events. Simulations help to localize problematic areas and to simulate real cases of damage. With the help of these simulations, preventive measures and optimization of runoff can be tested.

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For this, no simple 2D plane was used, which represents a water surface in most game engine renderings. The water was realized with the help of the plugin "Fluid Flux" (Komisarek, 2021). The plugin allows creating dynamic water simulations based on the Shallow Water Equations, an algorithm developed by (Chentanez and Mueller, 2010). Particularly endangered buildings are colored differently, or symbols are displayed above them. If the water level changes, the buildings' representation changes simultaneously (Figure. 3). As an additional solution, placing sandbags was considered, which should stop the flowing water. For this purpose, 3D models were modeled and added to a selection menu.

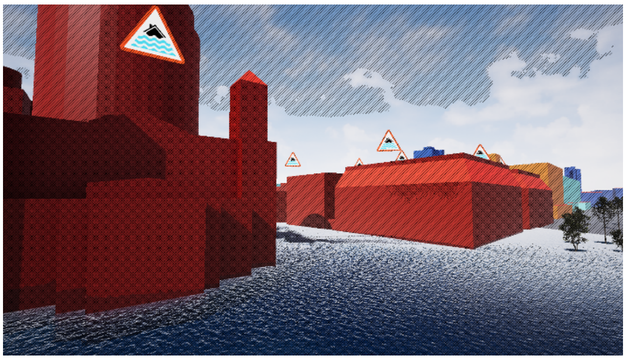

Figure 3. Part of the interactive flooding scenario in Berlin.

5.2 Noise propagation

3D city models can be the basis for modeling sound propagation calculations. This is especially important for building permit procedures and spatial planning procedures.

Arid-based representation of the noise was decided upon and oriented itself after the visualization (Berger and Bill, 2019). Many noise observers, as colored spheres, are placed on a grid in the 3D scene. Besides the coloring of the spheres, additional markers are displayed for critical areas, which are visible even through walls. For the serious game scenario, additional moving vehicles were added to the 3D city. Users can protect the spheres with the help of placeable noise barriers (Figure. 4). Protected areas or spheres are additionally marked depending on the position of the noise barrier.

Figure 4. Part of the noise propagation in a fictitious geovisualization scenario.

5.3 Lighting

These are applications for considering the issues of brightness, shading, and energy efficiency for urban planning and landmarks. The applications are an alternative for the planning phase of various lighting scenarios, rather than using construction crews to set up lamps at night.

Within a game engine, there are many settings for the complexity of light representation. Ray tracing is one of the most complex methods for representing multiple reflections. During the implementation, it became clear early on that a combination of ray tracing and VR is currently impossible at a stable frame rate. However, lumen, ambient occlusion, and volumetric fog can create realistic lighting. Furthermore, lighting effects in VR, such as lens reflections, can create an unpleasant feeling for the user and should be avoided. It is night in the serious game scenario, and lamps can be placed. Symbols exist for the different lamps and important places for lighting design. In addition, shadows can be dynamically colored, for example, in which dark areas are red and lit areas are blue (Figure 5).

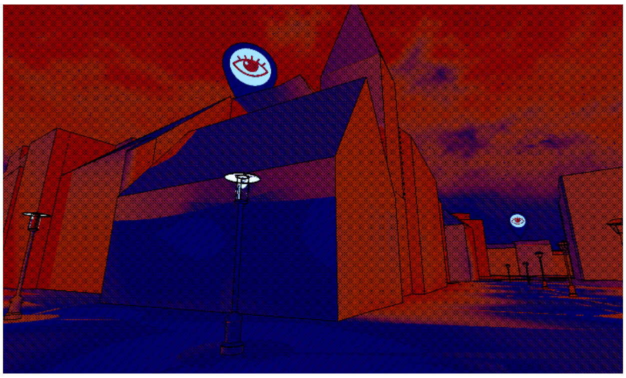

Figure 5. Part of the lighting simulation visualization in Berlin.

6. Conclusion

When using VR glasses as an output device, it is essential to consider the extent to which the new viewing method requires particular adaptations to convey information effectively. Viewing a city model from a first-person perspective differs from most geovisualizations on a desktop screen. Geovisualizations with a desktop screen as the output device have traditionally taken a top-down perspective. Of course, a city model could also be viewed from above in VR, but this means that the added value of VR, the immersion of being in the geovisualization, is lost.

In order to visualize different topics, some basic techniques had to be implemented in the Unreal Engine application. This includes the CityGML plugin and the various dynamically adjustable settings and symbols.

The three topics considered had to deal with different difficulties in their implementation. Realistically rendered water simulations and light simulations are challenging to realize in an interactive application because the required computational effort for rendering is high. A constant frame rate is challenging to achieve. Especially in a VR

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application, a frame rate of 60–90 frames per second is recommended to avoid motion sickness. In particular, motion sickness can affect the user's experience negatively. It makes evaluating the quality of different rendering methods more challenging.

Reducing realism in combination with NPR can improve performance. The rendering of thousands of buildings and hundreds of icons did not prove to be a problem. However, initial research with users found that the 3D scene must not be too abstract to maintain interest and attention.

A task for future research is the implementation of various methods for investigating and improving information transfer quality using different highlighting techniques. One method would be eye tracking, as these capabilities are built into the HTC Vive Pro 2.

7. Acknowledgments

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