GeoBoardXR: A WebXR-Based Immersive Terrain and Geospatial Data Viewer

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Introduction

Climate change is reshaping ecosystems, economies, and coastal communities worldwide. Nature-based solutions (NbS) have emerged as important interventions for strengthening social-ecological resilience and supporting climate adaptation (Turner et al., 2022). Effectively communicating such interventions by translating complex climate data and geospatial models into comprehensible representations is important for stakeholder engagement and planning. Visualization can support this process by communicating spatial information, potential impacts, and alternative scenarios (Wissen et al., 2008; Bohman et al., 2015).

Three-dimensional (3D) terrain visualization can complement traditional 2D cartography by providing spatially explicit representations of landscape characteristics and relationships (Lovett et al., 2015). Extending these capabilities, fully immersive digital twins further enable interactive exploration of complex 3D geospatial datasets within spatially organized virtual environments (Zhao et al., 2019). The development and application of such systems can further benefit from open-source approaches, which promote accessibility, transparency, reproducibility, and adaptability across different contexts (Schlögl et al., 2026).

In this context, GeoBoardXR[1] is introduced as an interactive, tabletop-scale virtual reality (VR) terrain viewer built on a WebXR-compatible framework. Being a foundational component of the EU RESIST project's Ocean Model platform[2], GeoBoardXR was developed as a fully immersive tool for communicating climate adaptation scenarios and NbS in the coastal and marine landscapes of Norway's Vesterålen region. More broadly, GeoBoardXR enables researchers, practitioners, and stakeholders to develop and explore high-resolution digital terrain models and layered geospatial datasets within an immersive 3D environment. By combining open-source development practices with accessible WebXR deployment, GeoBoardXR aims to support evidence-based decision-making through immersive, spatially grounded visualization.

[1] Code repository: https://github.com/SINTEF/GeoBoardXR, video: https://xrlab.no/geoboardxr/video/
[2] RESIST Ocean Model: https://github.com/SINTEF/oceanwebxrmodel, https://doi.org/10.5281/zenodo.22041952

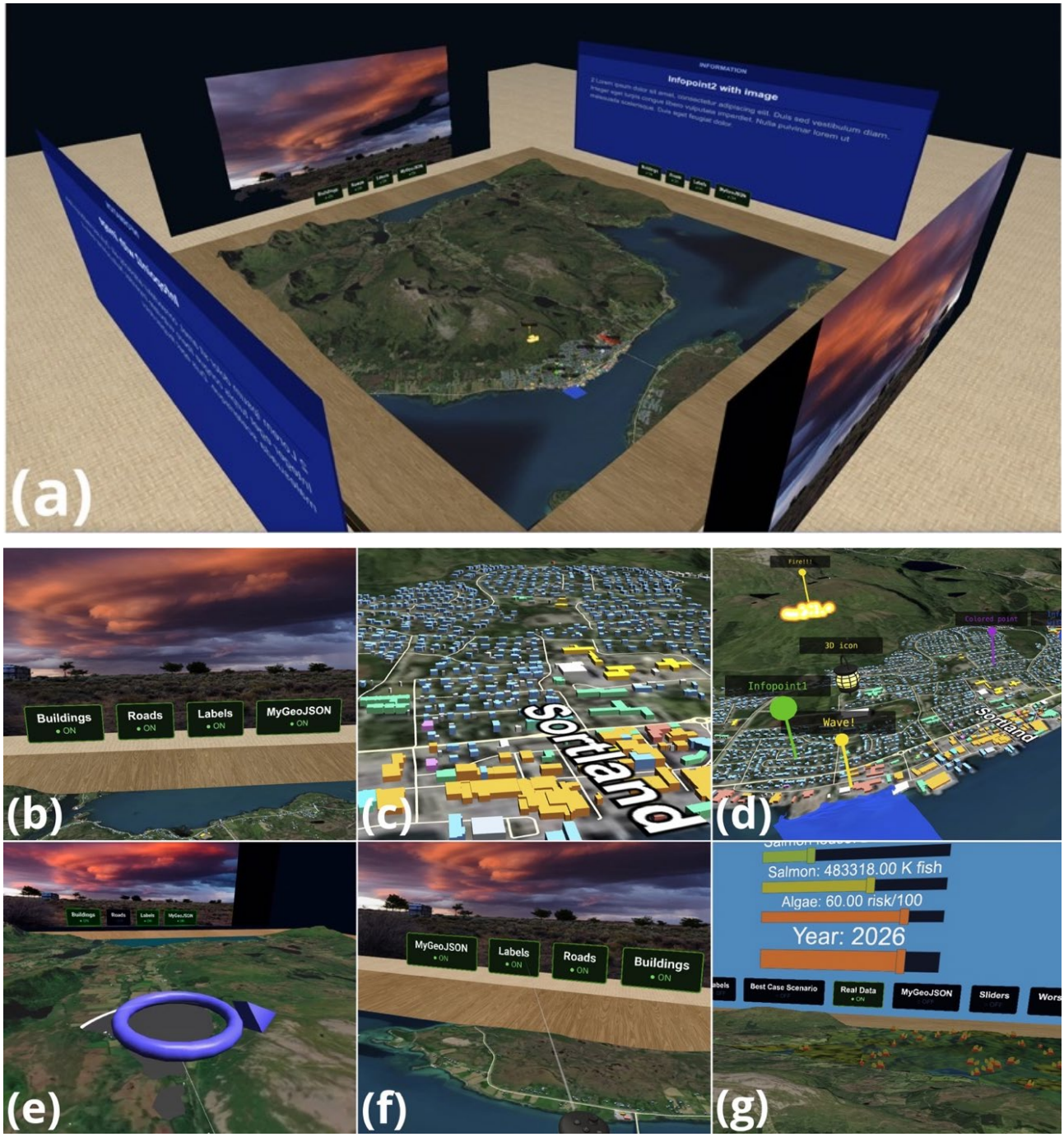


Figure 39. *(a) Overview of the GeoBoardXR virtual scene. (b) Toggle buttons managing geospatial content. (c) Overview of the OpenStreetMap Overpass API content with 3D buildings, roads and place labels. (d) Visualized user-created GeoJSON dataset. (e) GeoBoardXR's teleportation locomotion technique. (f) GeoBoardXR's raycasting-based "aim-and-shoot" input technique. (g) Visualization of a fuzzy cognitive map.*

Development Framework

GeoBoardXR is implemented as an open-source, browser-based XR application using TypeScript and Babylon.js, with Vite providing the development and build environment. Immersive functionality is implemented through the WebXR API and Babylon.js WebXR components, allowing the same application to be accessed directly through a URL without installation, while using the same codebase across desktop browsers and supported VR headsets. The application is served over HTTPS and requires no backend infrastructure beyond static file hosting. The current implementation has been tested using the Meta Quest 2 and Quest 3 headsets and Chromium-based web browsers.

Virtual Scene

GeoBoardXR organizes geographic content around a three-dimensional terrain surface. Terrain geometry is generated from Mapbox Terrain-RGB elevation tiles. The raw elevation grid is simplified using Martini, a real-time implementation of the Right-Triangulated Irregular Network (RTIN) method. The algorithm preserves geometric detail in areas where elevation varies while simplifying comparatively uniform regions. Mapbox satellite imagery is subsequently applied to the resulting terrain mesh as a surface texture.

From a design perspective, the terrain is positioned on a virtual table, which users can directly navigate by moving across its surface. Along the edges of the tabletop, interactive toggle buttons control the visibility of associated geospatial content, while “projection screens” around the tabletop display supplementary information (Fig. 1a). The buttons (Fig. 1b) and projection screens are instantiated on multiple sides of the table to remain accessible as users change position around the model.

The tabletop and projection screens interaction metaphor was inspired by the physical installation of the Gaia Projection Mapping System, which was created in a previous project for the Vesterålen region (Boletsis & Prillard, 2025). The tabletop provides a clearly defined spatial boundary for the virtual environment while limiting the geographic extent that must be rendered, thereby reducing computational demands. Moreover, users can move across the tabletop to inspect the terrain and the geospatial content at closer range, supporting spatial understanding of local features and their broader geographic context. The projection screens provide dedicated surfaces for presenting supplementary textual and visual information without occluding the terrain or its content.

Geospatial Content

Geospatial content is provided in two forms. Upon loading the terrain, API-sourced contextual data are obtained through the OpenStreetMap (OSM) Overpass API with a sequential mirror-fallback strategy. Separate loaders retrieve buildings, roads, and place labels (names). For buildings, their footprints are extruded from 2D outlines into 3D objects and they are color-coded according to their type (e.g., residential, commercial, office, and garage). Roads are represented using ribbon geometry, while place names are rendered using billboarded labels (Fig. 1c). Retrieved OSM responses are cached in the browser’s localStorage for seven days based on the geographic tile coordinates, minimizing redundant network requests. These three data layers can be activated or deactivated using the corresponding toggle buttons on the tabletop.

GeoBoardXR accepts user-defined geospatial data as GeoJSON FeatureCollections stored in the application’s public asset directory. Point, Polygon, and LineString geometries are parsed at load time and rendered as interactive 3D scene objects, with user-defined colors and labels (Fig. 1d). Points are positioned by geographic coordinates and displayed as pins or optional GLB 3D models. Each point can also function as an “infopoint”, enriched with text, images, and videos shown on the projection screens surrounding the tabletop. Polygon coordinates are transformed into scene coordinates, with color and opacity defined by GeoJSON properties, and can also serve as spatial boundaries for procedural fire and wave animations developed to communicate hazards such as forest fires and sea-level rise. LineStrings follow the supplied geographic coordinate sequence, while width and height properties control whether they appear as flat ribbons or vertical walls. All visual and informational attributes are defined through GeoJSON Feature properties, and each FeatureCollection can be activated or deactivated using a tabletop toggle button.

Together, these geospatial layers can support applied planning scenarios. For example, a local planner can combine terrain, buildings, roads, and a user-provided flood or sea-level-rise layer to identify potentially exposed infrastructure and inspect affected locations across spatial scales. Associated infopoints can provide contextual information on potential adaptation measures, supporting discussion of alternative interventions within the shared spatial representation.

User Interaction

In GeoBoardXR, users navigate the terrain by combining on-table teleportation locomotion (Fig. 1e) with real-walking within their available physical space. Teleportation locations are selected using the controller's joystick. Using a single VR controller, users interact with scene elements through a raycasting-based "aim-and-shoot" technique (Fig. 1f). This technique is used for triggering actions, e.g., to activate toggle buttons, activate infopoints by "shooting" at the pin heads or the 3D models attached to the point data, and play or pause videos. WebXR input profiles support consistent interaction across different VR controller configurations.

Conclusion: Limitations & Future Work

The current implementation has certain limitations related to its architectural design. WebXR performance depends on browser and headset support and may decrease with higher terrain resolutions or when large numbers of complex geospatial objects are rendered simultaneously. The accuracy and completeness of contextual layers also depend on external API sources and user-provided datasets, thereby retaining the uncertainties inherent in those original data sources. In addition, the current interaction design primarily targets controller-based VR and has not yet been systematically evaluated for accessibility or for users requiring alternative interaction modalities.

GeoBoardXR is under continuous development, with an emphasis on extending its geospatial capabilities for different use cases. Future work will focus on applying the tool across diverse scenarios to evaluate its effects on spatial understanding, communication, and decision-support activities, while identifying gaps and opportunities for improvement, particularly regarding usability and user experience, API integrations, and user-provided datasets. Another direction is the integration of fuzzy cognitive maps (FCMs), with nodes and weighted edges visualized as an interactive 3D graph layer on the terrain. Initial work on this visualization has been completed in a new fork (Fig. 1g). Planned developments also include GeoJSON-driven animations; dedicated layers for bathymetry, ocean currents, and water-column data; AI-assisted data curation; and improved AR calibration for table-scale placement.

Given its open-source nature and ongoing development, researchers and practitioners within and beyond the XR community are encouraged to fork GeoBoardXR, apply it to their own use cases, and provide feedback on potential features and software issues.

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