geographies

Editorial

Geovisualization: Current Trends, Challenges, and Applications

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1. Introduction

Geovisualization (or *Geographic Visualization*) represents an interdisciplinary scientific field spanning cartography, geographic information science (GIScience) and technology, computer science and human–computer interaction (HCI), psychology, and cognitive science. All of these diverse specialisms have fostered the development of the robust methodological frameworks implemented in this field over the years. Geovisualization utilizes several spatial data representation techniques, including qualitative and/or quantitative attribute representation, which can be associated with a specific timestamp or considered in terms of periodic changes. In any case, geovisualization products permit users to visually explore the existing or potential relationships (i.e., spatial interactions), patterns, and/or trends connected to geographic entities and phenomena. Archetypal geovisualization digital products involve different types of maps, including static, animated, multimedia, and/or interactive spatial configurations, working either in local environments (as standalone applications) or across the Internet. Equally, these products can translate into virtual or augmented reality environments.

The implementation of geovisualization methods and techniques is vital to educational and professional research that aims to study geographical spaces. Hence, geovisualization is integral to spatial analysis and planning, hydrology, as well as history and archaeology. At present, the vast number of geospatial data collected by terrestrial, aerial, and satellite sensors is the principal challenge to tackle. Geovisualization products are the "vehicles" that support the communication between designers and users. However, the effectiveness of these spatial representations is inextricably linked with the principles followed during the cartographic design process.

This Special Issue (SI) collected eight different contributions to the geovisualization domain. In Section 2, the published papers are briefly introduced. In this section, the major points and outcomes of each contribution are highlighted and discussed. Finally, Section 3 reflects on the SI based on the contributions provided, as well as the existing challenges and opportunities in geovisualization. A complete list of the published papers is reported at the end of the editorial.

2. An Overview of the Published Papers

Goebbels and Pohle-Fröhlich's article (contribution 1) delves into an examination of paper models as a cost-effective and user-friendly tool for urban planning, offering an alternative to virtual 3D visualization and traditional architectural models. The study introduces an innovative algorithm tailored to automatically unfolding CityGML models into precise, scaled paper model kits, facilitating straightforward assembly using a single

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sheet of paper. The focus of the algorithm is generating CityGML building parts that unfold without overlap, as accomplished by establishing a graph based on the vertices and edges of the polygons within the CityGML building, subsequently creating a dual graph representing the ground, wall, and roof polygons. Prospective developments include the application of inpainting algorithms for vegetation removal, the simplification of CityGML models for their ease of assembly, and exploration of the potential of streamlining the production process using 2D laser cutting to enhance the texture patterns. The primary drawback associated with paper models is the manual effort required for assembly, despite each model taking less than five minutes. Although 3D printing is time-consuming, paper models require manual tasks that use smaller areas and simple geometries, as constrained by paper size and the space for 3D printing and building.

Furthermore, Leda Stamou's article (contribution 2) discusses the relationship between colors in maps and colors in artistic movements in order to investigate whether color can be used to identify artistic trends and their corresponding time periods. The study addresses the artistic period from the end of the Middle Ages to the 21st century that took place in Western Europe, including in Italy, incorporating both descriptive and quantitative color comparisons. Initially, color is examined according to properties such as hue, brightness, and saturation. Additionally, map and painting colors are plotted on the color wheel in order to visualize the range and location of color sequences. Despite the subjective selection method for the maps and paintings included, the reasonable assertion that the results may not be universally applicable, and the fact that colors differ over time, the research findings are interesting and significant enough to support its conclusions. The study verifies that in almost all of the comparisons made, the color sequences of the paintings and selected maps reside in the same part of the color wheel, across the same range. The author also points out that the color similarity is supported both for the colors used and for the color character resulting from saturation and brightness. In summary, the selected paintings and maps examined support the correlation between the use of color in paintings and maps, without implying intentionality.

Next, Iliopoulou and Feloni (contribution 3) utilized geovisualization techniques in order to visualize and interpret spatial analysis results for houses on the market. The authors considered both the structural and locational characteristics of houses in the Greater Athens Region, Greece. The geovisualization process was founded on the implementation of kriging interpolation techniques. Equally, these geovisualization techniques supported the depiction of both Moran's and Getis–Ord Gi* coefficients, which were calculated to examine the existing spatial autocorrelation, as well as to identify existing hot and cold spots, that is, clusters, of houses with similar characteristics, correspondingly. A Geographically Weighted Regression (GWR) model was developed to predict house prices based on their characteristics. The model was employed to calculate a regression equation for each house under study. Spatial variation in both the size and age coefficients was also depicted using typical geovisualization techniques. Hence, the mapping process supported the visual exploration and interpretation of both positive and negative coefficient allocation within the study area.

The piece authored by Zhang et al. (contribution 4) investigated the cartographic visualization of construction cost indexes (CCIs) at the national level, recognizing the limitations of the current tabular formats for 649 cities in the conterminous United States. The data utilized for the CCIs spanned from 2004 to 2015 and was sourced from RSMeans. Construction cost maps at the national level were generated using the NN (Nearest Neighbor), CNN (Condensed Nearest Neighbor), and IDW (inverse distance weighting) methods. These maps offered a complete picture of the construction costs, aiding construction practitioners, real estate developers, and the general public in identifying regional patterns and hotspots. The article also discusses the accessibility of these national construction cost maps via WebGIS technologies, which offer interactive and dynamic visualization to a broad audience. They concluded that potential future research directions include the broader applicability of interpolation methods in geovisualization, and suggested extending this approach to mapping other construction-related costs at a similar scale.

Moreover, the article by Li et al. (contribution 5) elaborates on the use of a hexagonal grid for hydrological flow calculation and geovizualization. Indeed, flow calculation is highly pertinent in supporting hydrological analysis, as applies to flow accumulation, watershed delineation, stream networks, and so on. While hexagonal grids have been lauded over rectangular grids, calculation methods have not adapted to accommodate this. In this workflow, the water flow direction was computed using five methods based on slope aspect calculation in the ISEA3H DGGS: the Maximum Adjacent Gradient (MAG), Maximum Downward Gradient (MDG), Multiple Downhill Neighbors (MDN), Finite-Difference Algorithm (FDA), and Best-Fit Plane (BFP) methods. Both visually and quantitatively, this study investigated the flow accumulation and hydrological indices, proving that the results vary among the different approaches, and that ultimately the impact of these variations propagates to hydrological products. As the outcome of the study, the D6 algorithm is endorsed for its ability to eliminate close loops after pit-filling processes. According to the authors, this research can be used to supplement future flood inundation modeling or susceptibility modeling in a pure hexagonal DGGS environment.

In addition, the mixed-methods study conducted by Wada et al. (contribution 6) explores the efficacy of map-based visualizations containing vitality data in supporting visual analysis processes in government, business, and research. Accordingly, it confirms that map-based data visualization is an visual analysis effective tool for domain experts in the context of vitality due to its coherent data presentation, the ease of spatial analysis, and its interactivity. The expert consensus deems geovisualization suitable for both quick novice insights and the deeper analysis conducted by intermediate or advanced users. However, it remains challenging to thematically tailor geovisualization to real-world domain expert projects and their in-depth and specific analysis requirements. To enhance its adaptability to diverse use cases, this study suggests aggregating datasets by theme and incorporating interactive features into map-based data visualizations.

Blana et al.'s (contribution 7) extended study of their own previous work (Blana and Tsoulos, 2022) presents a constraint-based generalization model that uses constraints to control the detail granularity while implementing a quality control mechanism to produce high-quality topographic maps at any scale; this comprises a structured framework and a thorough method for generalizing linear and area features. The authors take a standardizing approach to the semantic generalization process together, with applying a new quality control mechanism to evaluate the shape of the features. Their model identifies and resolves legibility violations based on quantitative criteria, and simplifies the resolution of geometric conflicts using density reduction techniques and quantitative legibility thresholds. It is also compliant with the ISO 19157 standard [1] on quality and map specifications and compatible with a wide range of GIS environments. The authors advocate for the inclusion of a quality policy and a quality management system (QMS) throughout the map production process, which necessitates evaluating the integrity of the input data and the output product to ensure the quality outcomes of the entire process.

Lampropoulos et al. (contribution 8) presented a new web mapping application for historical cartographic data representation. In particular, the platform provides access to high-resolution map images and geospatial data related to Kaupert's Maps of Attica from the 19th century, which supports the process of overlaying these maps onto modern cartographic backgrounds. Consequently, the application also includes querying, filtering, and measurement tools to aid user in navigating and interrogating the data provided. The application's implementation is based on modern geospatial frameworks (for both the client and server side), which streamline the interactive exploration of the ancient topography of Attica. The platform showcases a working example of how modern geovisualization techniques and digital technologies offer a modern approach to the digital humanities and cultural heritage.

3. Concluding Remarks

This SI collates eight contributions illustrating varied forms of geovisualization (i.e., building models, cartography and art, spatial modeling, constructions, hydrology, decision-making processes, cartographic generalization, and cartographic heritage), highlighting the existing trends and challenges in this scientific field. This variety proves that geovisualization is an active field significantly supporting geospatial modeling in the modern day. As indicated by prior studies (e.g., [2–6]), geovisualization meets a number of germane challenges, such as effectiveness and efficiency analysis [7] based on behavioral research methods and/or artificial intelligence (AI) techniques [8,9], as well as adaptation to modern virtual environments [10]. Undoubtedly, in the era of big data and AI, geovisualization will be crucial in conveying meaningful information to map users.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

The SI contains seven research articles and one technical note (contribution 4):

1. Goebbels, S.; Pohle-Fröhlich, R. Automatic Unfolding of CityGML Buildings to Paper Models. *Geographies* **2021**, *1*, 333–345. https://doi.org/10.3390/geographies1030018.
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8. Chen, M.; Claramunt, C.; Çöltekin, A.; Liu, X.; Peng, P.; Robinson, A.C.; Wang, D.; Strobl, J.; Wilson, J.P.; Batty, M.; et al. Artificial intelligence and visual analytics in geographical space and cyberspace: Research opportunities and challenges. *Earth-Sci. Rev.* **2023**, *241*, 104438. [CrossRef]

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