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Comparative Analysis of Two - Dimensional and three - Dimensional Spatial Representations in Cartography

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Abstract
As technological advancements continue to reshape the field of cartography, it's vital to understand the strengths and limitations of both 2D and 3D approaches to make informed decisions about their applications. This article presents a comparative analysis of two-dimensional (2D) and three-dimensional (3D) spatial representations in cartography, focusing on five key subthemes: historical evolution, technical implementation, cognitive implications, practical applications, and future trends. The findings reveal that while 2D maps are effective for simplicity and efficiency in various contexts, 3D representations significantly enhance spatial understanding in more complex environments. The study emphasizes the complementary relationship between these methods and posits that the future of cartography will involve their integration. By synthesizing current research and advancements in technology, this paper aims to provide valuable insights for cartographers, GIS specialists, and spatial data scientists, ultimately facilitating more intuitive and informative spatial visualizations.

Keywords: *2D Cartography, 3D Spatial Representation, Spatial Visualization, Cognitive Implications, GIS Technology*

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Introduction

Cartography, the art and science of map-making, has evolved significantly over time due to technological advancements and changing user needs. The shift from traditional 2D maps to interactive 3D visualizations is one of the most profound changes in the field. It challenges long-standing practices and opens new possibilities for spatial representation (Li et al., 2023). Two-dimensional maps have been fundamental in cartography for thousands of years, providing a simple yet effective way to convey geographic information. These flat representations have been invaluable for navigation, spatial analysis, and communicating geographic concepts. However, the limitations of 2D maps in representing complex three-dimensional landscapes have long been recognized (Roth et al., 2022).

The emergence of 3D cartography, made possible by advancements in computer graphics and geospatial technologies, has introduced new ways of representing space. Three-dimensional maps offer the potential for more intuitive visualization of terrain, urban environments, and complex spatial relationships. However, they also present challenges in terms of data management, user interaction, and cognitive load (Çöltekin et al., 2020).

This paper aims to conduct a comprehensive comparative analysis of 2D and 3D spatial representations in cartography. By examining historical contexts, technical aspects, cognitive considerations, practical applications, and future trends, aims to provide a nuanced understanding of the strengths and limitations of each approach. The paper's analysis is structured around five main subthemes: historical context and evolution of cartographic representations, technical aspects and implementation, cognitive and perceptual considerations, applications and use cases, and future trends and integrative approaches representing section 1 to 5 respectively. Section 6 is the discussion while the last section is the conclusion and recommendation. Through this multifaceted exploration, we aim to contribute to the ongoing discourse on the role of dimensionality in cartographic representation and provide insights that can guide future developments in the field.

1 Historical Context and Evolution of Cartographic Representations

The history and development of mapmaking have evolved from simple depictions in ancient times to more complex visualizations in the modern era (Thrower, 2008). According to Harley & Woodward (1987), early maps were basic and symbolic representations of known areas, reflecting the limited geographical knowledge and artistic styles of the time. Over the centuries, as exploration expanded and printing technologies advanced, maps became more detailed and accurate, incorporating mathematical principles such as geometry and projection (Monmonier, 2015). The 20th century brought a significant advancement with the introduction of digital mapping, leading to the creation of highly precise 2D maps (Goodchild, 2000). Today, the integration of Geographic Information Systems (GIS) and advancements in computing power have given rise to 3D cartography, allowing for the visualization of spatial data in more dynamic and interactive ways (Li et al., 2011). This evolution reflects the increasing complexity of the world and the need for more advanced tools to understand and navigate it (MacEachren & Kraak, 2001).

1.1 The Development of 2D Cartography

The history of 2D cartography spans thousands of years, reflecting humanity's enduring quest to understand and represent the world around us. Early map-making techniques can be traced back to ancient civilizations, with some of the oldest known maps dating to the 6th century BCE in Babylonia (Thrower, 2008). Throughout history, 2D cartography has seen numerous innovations. In *the ancient Period,* early maps were often simple sketches on clay tablets or papyrus, focusing on local areas and lacking standardized scales or projections. Moreso in the *medieval era*, the development of the Mappa Mundi exemplified the blending of geographic knowledge with religious and cultural beliefs. The *Renaissance* period saw significant advancements in mathematical cartography, culminating in Gerardus Mercator's revolutionary projection in 1569, which allowed for accurate navigation across long distances (Monmonier, 2004). Further is the *age of exploration* which improved surveying techniques and the influx of new geographic data led to more accurate and comprehensive world maps. *Also is the 19th-20th Centuries* that culminated the advent of aerial photography, photogrammetry, and later, satellite imagery, dramatically enhanced the accuracy and detail of 2D maps.

Furthermore, the *digital age* which came with the introduction of Geographic Information Systems (GIS) in the 1960s marked the beginning of the digital cartography era, enabling complex spatial analysis and dynamic map creation (Goodchild, 2018). As we moved into the 21st century, cartography continued to evolve rapidly, driven by technological advancements and the increasing availability of geographic data. This period witnessed the rise of interactive and web-based mapping platforms such as Google Maps and OpenStreetMap, which democratized access to geographic information and allowed users to contribute to map-making efforts. The rise in interactive and web-based include *crowdsourced mapping* which emergence of user-generated content transformed the landscape of cartography, enabling real-time updates and local knowledge integration. This ability to collectively create and edit maps has revitalized interest in local geography and fostered a sense of community engagement. So also, m*obile Technology* with the proliferation of smartphones and location-based services, mapping became not only more accessible but also personalized. Apps that leverage GPS technology allow users to navigate, explore, and share geographical data on-the-go, enhancing the user experience through augmented reality (AR) and real-time information overlays. Furthermore, the incorporation of AI and machine learning into cartography is revolutionizing data analysis and map creation by automating processes, predicting trends, and providing deeper insights into spatial phenomena.

The journey of 2D cartography reflects humanity's evolving understanding of our world (Woodward & Lewis, 1998). From rudimentary sketches to sophisticated digital maps that harness collective intelligence and advanced technology, cartography remains an essential tool in navigating the complexities of both our physical environment and societal dynamics (Crampton, 2010; Goodchild, 2007). As we look to the future, the potential for innovation in mapping practices continues to grow, promising to enrich our understanding of geography in ways we have yet to fully imagine (MacEachren & Kraak, 2001; Roth, 2013).

1.2 The Emerg**ence of 3D Cartographic Representations**

While three-dimensional representations of geographic features have existed in various forms throughout history (e.g., relief models), the emergence of true 3D cartography is a relatively recent phenomenon, closely tied to advancements in computer technology. Early 3D representations include relief maps and globes provided early attempts at three-dimensional geographic representation. In the 1960s-1970s, the development of computer graphics laid the groundwork for digital 3D visualization while in the 1980s, the introduction of Digital Elevation Models (DEMs) marked a significant step towards digital 3D cartography. Additionally, in the 1990s, advances in computer processing power and graphics capabilities enabled more sophisticated 3D visualizations. Furthermore, the 2000s brought about the proliferation of LiDAR technology and high-resolution satellite imagery dramatically improved the accuracy and detail of 3D models. Also, in the 2010s the integration of 3D cartography with virtual and augmented reality technologies has opened new frontiers in spatial visualization (Zhang et al., 2023). The evolution of 3D cartographic representations has not only transformed the way we visualize geographic data but has also significantly influenced various fields such as urban planning, environmental management, and disaster response. As we delve deeper into this trajectory, the following developments can be observed.

Finally, in 2020s, the growing advent of cloud computing has facilitated the storage and processing of vast amounts of geospatial data, enabling real-time 3D visualization and collaborative mapping efforts across platforms. As 3D cartographic representations continue to evolve, they not only enhance our understanding of the world around us but also serve as critical tools for addressing contemporary challenges in urban development and environmental sustainability (Zhang et al., 2023).

1.3 Comparative Timeline

To illustrate the parallel development of 2D and 3D cartographic techniques, this paper present the following comparative timeline:

Era	**2D Cartography**	**3D Cartography**
Ancient (pre-500 CE)	Babylonian clay tablet maps (c. 600 BCE)	Relief models (e.g., Aztec stone maps)
Medieval (500-1400 CE)	Mappa Mundi (c. 1300 CE)	Raised-relief maps
Renaissance (1400-1600 CE)	Mercator projection (1569)	Strasbourg globe gores (1538)
Age of Exploration (1600-1800 CE)	Cassini's map of France (1789)	Relief globes
Industrial Age (1800-1960 CE)	USGS topographic mapping program (1879)	Raised-relief plastic maps
Computer Age (1960-2000 CE)	GIS software (1960s)	Digital Elevation Models (1980s)
Digital Age (2000-present)	Web mapping services (e.g., Google Maps, 2005)	LiDAR-based 3D city models (2000s)
Emerging Technologies	AI-enhanced cartography	AR/VR geographic visualizations

Table 1. Parallel Development of 2D and 3D cartographic techniques.

The timeline in Table 1 showcases the extensive history of 2D cartography and the more recent, rapid progress of 3D cartographic methods. It also demonstrates how advancements in one area frequently drive innovations in the other, resulting in a diverse and dynamic cartographic landscape (Kraak & Ormeling, 2020). Moreover, this interplay between 2D and 3D cartography is not merely a linear progression; instead, it reflects an intricate web of influences. For instance, as 3D modeling technologies matured, they inspired fresh approaches to spatial visualization in 2D maps, prompting cartographers to incorporate techniques such as layering and thematic representations. Conversely, the detailed geographic information system (GIS) data gathered from 2D maps has proven invaluable in enhancing the accuracy and aesthetics of 3D representations, creating a feedback loop that continuously enriches both modalities (Li et al., 2011).

2. Technical Aspects and Implementation

2D cartography uses projection systems, vector and raster data models, and advanced symbolization methods to represent spatial information on flat surfaces. 3D cartography utilizes technologies like digital elevation models, 3D modeling software, and real-time rendering engines to create volumetric representations of geographic data. 3D cartography often requires more computational resources and specialized software to handle complex geometries and large datasets.

2.1 2D Cartographic Techniques

Traditional 2D cartography remains a fundamental aspect of spatial representation. Kraak and Ormeling (2020) emphasize the importance of visual variables in 2D map design, including color, shape, and size, which are crucial for effective communication of spatial information. The authors argue that despite technological advancements, the principles of visual hierarchy and semiology in 2D maps continue to be relevant in the digital age. Geographic Information Systems (GIS) have revolutionized 2D cartography. However, Longley et al. (2015) discuss how GIS enables the integration of various data sources, facilitating complex spatial analyses and thematic mapping. They highlight the role of vector and raster data models in representing geographic features and phenomena. 2D cartography involves creating flat representations of the Earth's surface. Key technical aspects include:

Projection systems: Converting the 3D Earth to a 2D surface using mathematical transformations (e.g., Mercator, Lambert Conformal Conic).

Coordinate systems: Defining locations using geographic (latitude/longitude) or projected coordinate systems.

Symbology: Designing and implementing visual representations of features using points, lines, and polygons.

Generalization: Simplifying complex geographic features for different scale levels.

Data management: Storing and processing large volumes of spatial data using Geographic Information Systems (GIS) and spatial databases.

The implementation of web-based 2D cartography has significantly expanded the reach and interactivity of maps. Peterson (2014) explores the technical aspects of web mapping, including tiled map services, SVG graphics, and the use of JavaScript libraries like Leaflet and OpenLayers for creating interactive online maps. Although, these capabilities are not present in 2D.

2.2 3D Cartographic Methods

The transition from 2D to 3D cartography introduces new dimensions of complexity and opportunity. Haeberling (2004) discusses the fundamental principles of 3D cartographic design, emphasizing the importance of perspective, lighting, and texture in creating effective 3D visualizations. Digital Elevation Models (DEMs) form the backbone of many 3D cartographic applications. Li et al. (2005) provides a comprehensive overview of DEM generation techniques, including photogrammetry, LiDAR, and radar interferometry. They discuss the challenges in data acquisition, processing, and quality assessment for accurate 3D terrain representation. 3D cartography extends traditional mapping into three dimensions, incorporating elevation data and volumetric representations. Key technical aspects include:

***Digital Elevation Models (DEMs)**:* Creating and manipulating representations of terrain surfaces.

3D visualization techniques: Rendering 3D landscapes, buildings, and other features using computer graphics techniques.

Level of Detail (LOD): Managing the complexity of 3D models at different viewing distances.

Texture mapping: Applying realistic surface textures to 3D models.

Virtual and Augmented Reality (VR/AR) integration: Implementing 3D cartographic visualizations in immersive environments.

The implementation of 3D city models has gained significant traction in urban planning and smart city initiatives. Biljecki et al. (2015) explore the various levels of detail (LoD) in 3D city modeling, from simple block models to highly detailed architectural models. They discuss the CityGML standard as a means of encoding, storing, and exchanging 3D urban information. Virtual and Augmented Reality (VR/AR) represent cutting-edge applications of 3D cartography. Çöltekin et al. (2020) examine the technical challenges and opportunities in implementing VR/AR for geographic visualization. They highlight issues such as data integration, real-time rendering, and user interaction in immersive cartographic environments. Both 2D and 3D cartography rely on various software tools and technologies: such as GIS software (e.g., ArcGIS, QGIS) for data management, analysis, and 2D mapping, 3D modeling software (e.g., SketchUp, Blender) for creating detailed 3D models, Web mapping libraries (e.g., Leaflet, OpenLayers) for online 2D map implementations, 3D visualization engines (e.g., Unity, Unreal Engine) for interactive 3D cartographic applications, and programming languages and libraries (e.g., Python with GeoPandas, JavaScript with Three.js) for custom cartographic implementations.

2.3 Comparative Workflow

The process of creating 2D and 3D maps as illustrated in Figure 1 starts with collecting data. After this initial step, the process differs depending on whether you want a 2D or 3D map. For 2D maps, the workflow involves selecting a projection, designing symbols, and simplifying complex features to create a flat map. On the other hand, creating 3D maps involves creating or processing a Digital Elevation Model (DEM), 3D modeling of features, and adding textures for realistic visuals. Both 2D and 3D maps are designed for user interaction, with 2D maps allowing actions like panning and zooming, and 3D maps offering more immersive interactions like rotating views and virtual flythroughs. This process highlights the different methods required for 2D and 3D mapping, while emphasizing their shared foundation in data collection and focus on user engagement.

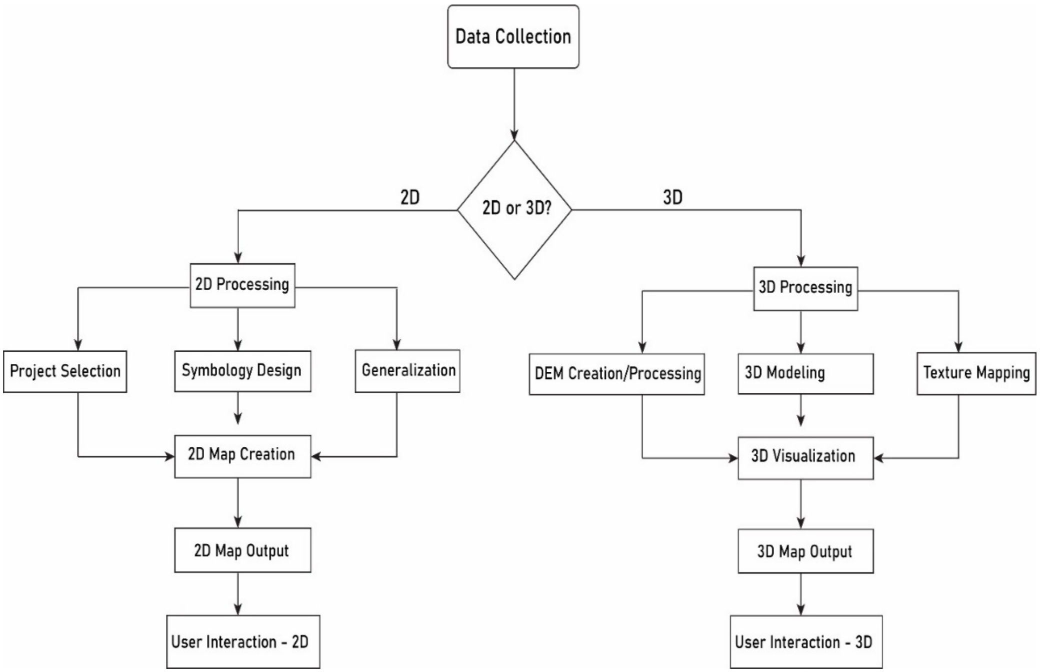

Figure 1. Divergent Workflow for 2D and 3D Cartography

3. Cognitive and Perceptual Considerations

The way people perceive and interpret spatial information is critical in map design. Both 2D and 3D representations have different cognitive implications that affect their effectiveness in various situations.

3.1 Spatial Cognition in 2D Representations

Two-dimensional maps have been the standard for spatial representation for centuries, and human cognitive processes have adapted to interpret these simplified views of space. ***Mental Rotation and Spatial Reasoning*** in 2D maps require users to mentally transform flat representations into a three-dimensional understanding. Research by Uttal et al. (2013) suggests that regular use of 2D maps can improve spatial reasoning skills. The ability to mentally rotate map orientations is crucial for navigation tasks (Lobben, 2004). ***Advantages of Abstraction*** include simplified 2D representations that can reduce cognitive load by eliminating unnecessary details. Thematic maps in 2D can effectively communicate complex spatial patterns and relationships (Roth et al., 2022). The consistent use of symbology and color in 2D maps aids in quick recognition and interpretation of geographic features.

3.2 Spatial Perception in 3D Environments

Three-dimensional cartographic representations provide a more realistic view of space, but they also present unique perceptual challenges:

Depth Perception and Spatial Relationships: 3D visualizations use natural depth cues such as occlusion, perspective, and shading to communicate spatial information. Çöltekin et al.'s studies (2020) show that 3D representations can improve understanding of terrain and complex urban environments. The ability to adjust viewpoints in 3D environments can help in comprehending spatial relationships from various perspectives. ***Challenges of information overload*** of detailed 3D environments can create visual clutter and cognitive overload (Herman & Stachoň, 2016). Occlusion in 3D views may conceal crucial information, requiring thoughtful design considerations. Navigating 3D virtual environments can be disorienting for certain users, potentially affecting task performance (Lokka & Çöltekin, 2019).

3.3 User Studies and Empirical Evidence

Recent research has revealed key insights into the comparative effectiveness of 2D and 3D representations. ***Task-Dependent Efficacy***: A meta-analysis of user studies by Šašinka et al. (2019) found that 2D maps are generally more effective for tasks involving precise measurement and overview. 3D representations excel in tasks requiring terrain understanding and visualization of complex spatial relationships. Hybrid 2D/3D approaches often outperform purely 2D or 3D representations across a range of tasks. ***Learning and memory*** experiment by Liao et al. (2019) showed that 3D visualizations can enhance spatial memory for complex environments. However, 2D maps remain superior for memorizing relative locations and distances over large areas. ***User preferences and expertise***: Novice users often prefer 3D visualizations due to their intuitive nature (Bektaş & Çöltekin, 2019). Expert users tend to perform better with 2D representations, likely due to familiarity and reduced distraction (Roth et al., 2022). To summarize these findings, Table 2 illustrates comparing cognitive aspects of 2D and 3D representations.

Aspect	2D Representations	3D Representations

Spatial Reasoning	Requires mental transformation; improves with practice	More intuitive for terrain and complex structures
Cognitive Load	Generally lower due to abstraction	Can be higher, especially in detailed environments
Task Performance	Better for measurement and overview tasks	Superior for terrain analysis and perspective-dependent tasks
Learning Curve	Steeper initial learning curve	More intuitive for novices
Memory	Effective for relative locations and large areas	Enhances memory for complex, localized environments
Expert Usage	Preferred by experts for many tasks	Valuable for specific complex visualizations

Table 2 Comparing cognitive aspects of 2D and 3D representations.

This comparison emphasizes how 2D and 3D representations complement each other. It suggests that the selection between the two should be based on the specific task requirements, data nature, and the characteristics of the intended user group.

4. Applications and Use Cases

The choice between 2D and 3D cartographic representations often depends on the specific application and use case. Both approaches have their strengths and are suited to different scenarios.2D cartographic representations are typically preferred for their simplicity and ease of readability. They allow for straightforward interpretation of spatial data, making them ideal for maps that require quick comprehension, such as road maps and thematic maps. The flat nature of 2D maps also enables easier printing and sharing, facilitating widespread dissemination of information without the complexities of three-dimensional perspectives. On the other hand, 3D cartographic representations provide a richer context for understanding topography and spatial relationships. They can effectively illustrate elevation differences, making them invaluable for applications in urban planning, geology, and environmental management. The depth dimension allows users to visualize landscape features and structures in a way that reflects their real-world appearances, offering insights that might be lost in a flat representation. Ultimately, the choice between 2D and 3D may hinge on the audience's needs and the data being conveyed.

4.1 2D Cartography Applications

Two-dimensional cartography remains the go-to choose for many traditional and modern mapping applications. ***Navigation and routing of*** 2D maps are great for route planning and navigation due to their clarity and user-friendly design. For example, the London Underground map, designed by Harry Beck in 1931, sacrifices geographic accuracy for schematic clarity, showing the effectiveness of 2D maps in complex navigation scenarios (Vertesi, 2008). Examples of these maps include street maps and road atlases, public transit maps, hiking and trail maps, and marine charts. Furthermore, is the ***thematic mapping and spatial Analysis*** of 2D thematic maps are particularly useful for visualizing spatial patterns and relationships across large areas. Geographic Information Systems (GIS) heavily relies on 2D representations for spatial analysis tasks such as overlay analysis, buffer creation, and spatial interpolation (Goodchild, 2018). Examples include choropleth maps for demographic data, isoline maps for weather and climate, dot density maps for population distribution and network analysis maps.

4.2 3D Cartography Applications

Three-dimensional representations are particularly useful in urban contexts, as they allow planners and architects to visualize and analyze complex spatial relationships. For example, the CityGML standard has enabled the creation of detailed 3D city models that support various urban applications, from assessing solar potential to studying noise propagation (Biljecki et al., 2015). Three-dimensional cartography is being increasingly used in various fields, especially where understanding complex spatial relationships is important. Here are some applications:

Urban Planning and Architecture: Creating 3D city models for urban design,
analyzing visibility and shadows, and integrating Building Information Modeling (BIM)

Geological and Environmental Modeling: 3D visualizations are excellent for representing complex natural phenomena. For instance, 3D geological models have revolutionized our understanding of subsurface structures, helping in resource exploration and geohazard assessment (Burns & Brown, 2018). For instance, mapping subsurface geology, modeling hydrology visualizing climate and atmosphere, and modeling ecosystems.

Virtual and Augmented Reality Applications: The immersive nature of 3D representations makes them ideal for VR and AR applications. For instance, the Virtual Old Prague project uses 3D cartography to recreate historical cityscapes, providing new ways to experience and study urban history (Brejcha et al., 2017). Instances are virtual tourism, educational simulations preserving cultural heritage, and training for emergency response. The immersive nature of 3D representations makes them ideal for VR and AR applications. For instance, the Virtual Old Prague project uses 3D cartography to recreate historical cityscapes, providing new ways to experience and study urban history (Brejcha et al., 2017).

Application Area	**2D Advantages**	**3D Advantages**
Navigation	Clear route visualization; Efficient for large areas	Better landmark recognition; Intuitive for pedestrian

		navigation
Urban Planning	Efficient land use analysis; Zoning visualization	Realistic cityscape visualization; Shadow and visibility analysis
Geology	Clear stratigraphic mapping; Regional trend analysis	Intuitive subsurface visualization; Complex structure modeling
Climate Modeling	Global pattern recognition; Time series analysis	Detailed atmospheric layer analysis; Storm system visualization
Archaeology	Site mapping and artifact location; Spatial distribution analysis	Reconstruction of historical structures; Stratigraphic visualization
Emergency Management	Rapid overview of affected areas; Resource allocation planning	Building-level damage assessment; Flood inundation modeling
Education	Simple concept illustration; Map reading skills development	Interactive spatial learning; Complex system visualization

Table 3. comparative table of applications

Table 3 illustrates the strengths of 2D and 3D representations across various application areas. The table clearly shows that 2D and 3D representations each offer distinct strengths. The choice between them depends significantly on the specific application requirements and the scale of the analysis.

5. Future Trends and Integrative Approaches

As technology continues to advance, the boundaries between 2D and 3D cartography are becoming increasingly blurred. This section explores emerging trends and integrative approaches that are shaping the future of spatial representation.

5.1 Emerging Technologies in Cartography

Augmented Reality (AR) and Mixed Reality (MR) in Mapping: AR and MR technologies bridge the gap between 2D and 3D representations by overlaying digital information onto the real world. Research by Çöltekin et al. (2020) suggests that AR-based cartographic applications can enhance spatial understanding and user engagement, particularly in mobile and field-based scenarios. Applications include navigation systems that project route information onto windshields or sidewalks, urban planning tools that visualize proposed developments in situ, and educational apps that bring 2D maps to life with 3D terrain and landmarks. Another technology is the ***AI and machine learning for map generation and analysis***. Li et al. (2023) demonstrate how deep learning algorithms can significantly improve the accuracy and efficiency of 3D city model generation from LiDAR data and aerial imagery. Artificial Intelligence and Machine Learning are revolutionizing cartographic processes such as automated feature extraction and classification from satellite imagery, style transfer techniques for creating aesthetically pleasing maps, predictive modeling for dynamic map updates (e.g., traffic flow, urban growth).

5.2 Hybrid 2D-3D Representations

The future of cartography likely lies in the intelligent integration of 2D and 3D elements. Zhang et al. (2023) propose a framework for adaptive 3D mapping that adjusts the level of dimensionality and detail based on user needs and device capabilities. ***Adaptive displays*** **of** maps that dynamically switch between 2D and 3D views based on user interaction, zoom level, or task requirements. Context-aware representations that emphasize 3D for local navigation but switch to 2D for broader spatial understanding. ***Integration of 2D and 3D elements for*** multi-scale maps that combine 2D overviews with 3D detail views**.** Layered visualizations that allow users to peel back 2D surfaces to reveal 3D structures beneath.

5.3 Challenges and Opportunities

As cartography advances, various challenges and opportunities come to the forefront: These challenges include ***data management and processing*** of extensive point clouds and high-resolution 3D models and updating 3D environments in real-time to reflect dynamic real-world changes is still a big task. Opportunities in this area include developing more efficient data structures and utilizing cloud computing for processing and rendering (Jakubuwski & Klapa, 2022). Furthermore, ***standardization efforts*** of establishing universal standards for 3D cartographic representations and ensuring interoperability between 2D and 3D geospatial data formats. The Open Geospatial Consortium (OGC) is taking the lead in standardizing 3D geospatial data formats and services, which will be crucial for the widespread adoption of 3D cartography (OGC, 2024). Finally, is the ***user experience and accessibility achieve by*** designing user-friendly interfaces for navigating complex 3D environments and ensuring accessibility of 3D representations for users with different abilities is challenging. Research by Lokka & Çöltekin (2019) highlights the importance of user-centered design in 3D cartography to maximize usability and minimize cognitive load.

6 Discussion

The comparison between 2D and 3D spatial representations in cartography reveals that each approach has its own advantages and challenges. The choice between 2D and 3D representations should be based on the specific task or context rather than one being superior to the other (Çöltekin et al., 2017). Both 2D and 3D representations complement each other rather than competing. 2D maps are effective for providing clear overviews, efficient navigation, and thematic mapping, while 3D visualizations offer intuitive representations of complex terrain, urban environments, and multidimensional phenomena. The future of cartography may involve the intelligent integration of these approaches, as demonstrated in emerging hybrid representations. The study results further showed that cognitive aspects of map reading, and spatial understanding significantly influence the effectiveness of cartographic representations. 2D maps leverage human adaptation to abstracted spatial representations, while 3D visualizations tap into our innate ability to perceive depth and spatial relationships (Haeberling, 2008). When choosing between 2D and 3D, the nature of the data, cognitive load on the user, and specific spatial reasoning tasks should be considered. Advancements in technology, particularly in computer graphics, data processing, and display technologies, have been instrumental in the evolution of 3D cartography. As these technologies continue to improve, we can expect even more sophisticated and accessible 3D representations. However, technological capability should not be the sole determinant in choosing between 2D and 3D representations. The fundamental principles of cartographic design, including clarity, accuracy, and purpose-driven representation, remain crucial. Hence, the review of applications and use cases underscores the importance of context in choosing between 2D and 3D representations. Different fields have different needs, leading to varying degrees of acceptance of 3D visualizations across disciplines. This diversity reflects the importance of a flexible, multi-dimensional approach to cartography (Kraak, 2003).

Thus, addressing challenges such as data practices and processing for high-resolution 3D models, standardization of 3D cartographic practices, and ensuring accessibility and usability of complex 3D environments requires ongoing research and development. Additionally, the integration of AI and machine learning in cartographic processes offers possibilities for automated map generation and analysis, potentially revolutionizing how we create and interact with spatial representations (Li et al., 2020).

7 Conclusion and Recommendations

In summary, this comparison of 2D and 3D spatial representations in cartography shows that the field is evolving. Traditional 2D mapping techniques remain valuable, while 3D visualizations offer new possibilities for understanding and representing space. Both approaches have their strengths and limitations, indicating that the future of cartography depends on integrating them thoughtfully and applying them appropriately to the context. Based on our analysis, the paper offers the following recommendations for cartographers, GIS specialists, and spatial data scientists:

Choose between 2D and 3D representations based on the specific requirements of the task, the nature of the data, and the needs of the end-users. Consider cognitive load, spatial reasoning requirements, and the scale of the analysis when making this decision. Explore and develop hybrid 2D-3D representations that leverage the strengths of both approaches. This may include adaptive displays that switch between 2D and 3D views or layered visualizations that combine 2D and 3D elements. When developing 3D cartographic products, pay particular attention to user experience and interface design. Ensure that navigation in 3D environments is intuitive and that users can easily access the information they need. As 3D data becomes increasingly prevalent and detailed, invest in robust data management and processing solutions. This may include exploring cloud-based processing or developing more efficient data structures for 3D spatial data.

Keep abreast of emerging technologies such as augmented reality, artificial intelligence, and advanced rendering techniques. These technologies have the potential to significantly enhance both 2D and 3D cartographic representations. Actively participate in or follow standardization efforts for 3D cartography. Adopting common standards will be crucial for the interoperability and widespread adoption of 3D cartographic products. Regularly conduct user studies to assess the effectiveness of different cartographic representations for various tasks and user groups. Use these insights to inform the design and development of cartographic products. As cartographic techniques evolve, ensure that education and training programs are updated to cover both 2D and 3D approaches, as well as their integration.

By embracing these recommendations, the cartographic community can continue to advance the field, creating more effective, intuitive, and powerful spatial representations that meet the diverse needs of an increasingly data-driven and spatially aware world.

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