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AUGMENTED REALITY IN CARTOGRAPHY: ENHANCING ANALOG MAPS WITH GIS-BASED VISUALIZATION

Abstract:

Modern cartography and geoinformatics are increasingly embracing immersive technologies, which require specific adaptations for application in these fields. Augmented reality (AR) is one such technology that can provide a high degree of adaptability in order to support the transfer of information and knowledge through maps. This paper analyzes trends in the application of technologies and methods used in the development of various systems for displaying augmented reality in cartography. A method for expanding the content and functionality of analog maps using augmented reality technology is described, enabling the display of additional information while simultaneously providing new interactive capabilities.

Keywords: augmented reality, cartography, GIS, geospatial visualization, interactive mapping.

ПРОШИРЕНА СТВАРНОСТ У КАРТОГРАФИЈИ: УНАПРЕЂИВАЊЕ АНАЛОГНИХ КАРАТА ВИЗУЕЛИЗАЦИЈОМ ЗАСНОВАНОМ НА ГИС-У LINES

Сажетак:

Модерна картографија и геоинформатика прихватају имерзивне технологије, захтевајући специфичне адаптације за употребу у овим областима. Проширена стварност (AR) је једна таква технологија која може да пружи висок степен прилагодљивости како би подржала пренос информација и знања на картама. У раду се анализирају трендови примена технологија и метода које се користе у развоју различитих система за приказивање проширене стварности у картографији. Описан је метод за проширивање садржаја и функционалности аналогних мапа коришћењем технологије проширене стварности, омогућавајући приказ додатних информација уз истовремено пружање нових интерактивних могућности.

Кључне ријечи: проширена стварност, картографија, ГИС, геопросторна визуелизација, интерактивно мапирање.

1. INTRODUCTION

Augmented Reality (AR) is a technology that enhances a person's sensory perception by overlaying virtual objects onto the user's immediate environment. Until recently, AR was considered an advanced technology used primarily within scientific research institutions; however, due to its rapid development, it has become increasingly accessible and transparent to the global community. The proliferation and diversification of sensors, along with improvements in hardware performance, have enabled these software solutions to be operationalized across a wide range of systems. Advances in image analysis software, improved algorithmic performance, and new methods for integrating data from multiple sensors have allowed this technology to meet growing expectations. Systems for storing and sharing data via the internet have made access to necessary information available anytime and anywhere.

The benefit of integrating Geographic Information Systems (GIS) with AR technologies lies in the usefulness of geospatial information within these systems. Location information is extremely important for AR systems, and technological development now enables not only the positioning of data but also increasingly precise positioning of users in time and space. Consequently, the integration of GIS and AR technologies represents a logical direction in the further development of AR systems.

This paper explores a new and promising field in cartography and geoinformatics, augmented reality, which combines analog maps with virtual objects. The use of augmented reality in cartography and geoinformatics is analyzed as an approach to improving visualization and increasing geographic awareness. The research is motivated by different perspectives on cartography, both in terms of its practical applications and the scientific disciplines it encompasses. Modern cartography is the result of careful observation and analysis, applying established methods and principles, and presenting information in an attractive way for long-term relevance while utilizing the latest technologies and focusing on the needs of users.

2. AUGMENTED REALITY, CARTOGRAPHY AND MAPS

Globalization has changed not only the way the world functions, but also the way we, as both participants in and subjects of globalization processes, perceive the planet Earth. Graphic displays have a long history of translating the complexity of our environment into understandable visual representations, with various types of maps being the most fundamental images we have in mind when thinking about the spaces in which we live. In modern society, the essence of cartography has changed. From a science focused on the creation and use of maps, it has gradually transformed into a fundamental science dealing with methods of representation, modeling, exploration, and understanding of the surrounding space. As the science of cartography has evolved, the subject of cartography has also changed, including the forms of interaction with users. Cartography focuses on the presentation and visual perception of the surrounding space through cartographic works in the form of figurative-symbolic metric models. The metric model of a figurative symbol is the map itself, which represents an informational product possessing numerous useful properties and functions [1].

Cartography is the science, technology, and art of studying and creating maps. All types of drawings, diagrams, and 3D models that represent the Earth at any scale are considered cartographic representations. New technologies that emerged in the twentieth century, such as geoinformatics, remote sensing, 3D modeling, multimedia, and the internet, have transformed the cartographic process and reshaped the definition of cartography.

Modern cartography continuously implements advanced digital technologies, improving both the quality and the demand for cartographic products. One such innovative approach is augmented reality, which can be used to extend map content through the use of mobile devices. The widespread use of smartphones and high-speed mobile internet, not only in large cities but also in rural areas, as well as the decreasing cost of electronic devices and services, has accelerated the expansion of augmented reality. Depending on the application of augmented reality in cartography, the approach to selecting software and hardware may vary.

In digital cartography, the choice of software largely determines the list and content of processing steps, as well as the overall organization of production. It is necessary to consider software characteristics such as the quality of spatial object visualization, functionality, performance, ease of use, cost, technical support, and others. This aspect has not yet been sufficiently studied in relation to augmented reality technology in cartography [2].

One of the key aspects of augmented reality is that it enables the overlay of digital information onto the physical world. Digital information may be synthetic (computer simulations) or digitized copies of the real world. In addition to the most common visual and auditory information, there may also be information related to smell, taste, or touch. These elements may be static or based on evolving computer simulations with data that change in real time [3].

The technological approach to implementing augmented reality functions involves the use of a specialized AR application, a software product that implements augmented reality technologies for various purposes (education, navigation, entertainment, tourism, etc.). The implementation of a specific AR project consists of hardware, software, and a scenario plan. Working with augmented reality on maps requires the use of a smartphone, tablet, or smart glasses equipped with a video camera and appropriate software.

The sequence of reproducing content with augmented reality elements varies depending on the method used to define the object (reference point). The workflow of augmented reality can be presented in the form of scenario plans for three areas of AR application in cartography.

Cartography and geoinformatics, as components of the geospatial industry, require the application of immersive technologies, particularly augmented reality (AR). It is a rapidly advancing technology that enhances users' perception of the real world by overlaying virtual elements. The geospatial field is gradually focusing on AR due to its ability to create immersive spatial experiences and facilitate spatial learning. However, designing effective AR interfaces presents several challenges, including managing information overload, providing intuitive user interaction, and optimizing system performance. Augmented reality is a system that bridges the gap between the virtual and the real world, most commonly using images captured by a camera-equipped device. Real-time images are enhanced or supplemented by adding digital elements, including sounds and images, which appear to the user as part of the real environment. The broadest definition of virtual reality is: "a new interface paradigm that uses computers and computer interfaces to create the effect of a three-dimensional world in which users directly interact with virtual objects." The virtual world is an interactive, computer-generated, three-dimensional environment [3].

The application of virtual reality (VR) and augmented reality (AR) technologies in cartography provides users with a more immersive experience. These technologies can transform two-dimensional maps into interactive three-dimensional scenes, adding more contextual information to various scenarios (such as tourism, education, urban planning, and emergency response). Virtual reality (VR) creates a fully virtual environment that users can explore. In cartography, VR is used to generate detailed simulations of the real world and allows users to explore it virtually, significantly improving user experience and environmental awareness.

Today, augmented reality represents one of the most promising technologies in cartography, enabling, for example, the expansion of analog map content through the use of smartphones, tablets, and other electronic devices. This significantly increases the value of cartographic products, which gain new functionalities and begin to interact with the user [4]. Cartography and geoinformatics, as components of the geospatial industry, require the application of immersive technologies, particularly augmented reality. The ability to visualize abstract information enables computer technology to become a powerful tool for studying many concepts in cartography and geoinformatics by creating and constructing dynamic, animated, and realistic augmented reality models. This technology can be used to create physical representations of phenomena and processes. AR integrates virtual objects (graphics, sounds, video recordings, 3D models, etc.) with the view of the real world [5]. It is characterized by three key features: 1) the combination of real and virtual elements, 2) real-time interactivity, and 3) registration in three-dimensional space.

Maps are spatial representations of the reality that surrounds us and have been closely connected with the processes of civilizational development since the earliest times. The problem of the ontogenesis of maps concerns the relationship between humans and their environment. An optimal solution to this issue lies in the integration of human structures (somatic, psychological, and cognitive) which are expressed through human interaction with the environment, including the creative and practical role of map visualization. Thus, a map is an oriented informational entity based on the unity of three concepts: system (purpose), model (information), and image (transmission), *tria iuncta in uno* (Latin) [6]. Given the close relationship between maps and human activity, the definition of a map, according to A. Makowski, is as follows: "A geographic map is a systemic informational entity of model and image that represents spatio-temporal situations in the context of purposeful human activity within an adopted georeferenced coordinate system" [7]. Most modern maps are instances derived from geospatial databases (Fig 1). Visualization through maps serves as an intermediary tool between humans and information systems, supporting targeted data analysis and the presentation of analytical results [8].

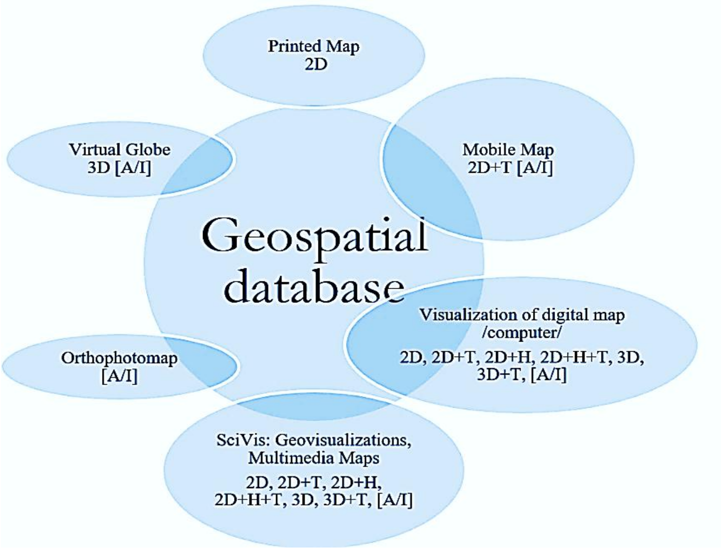

Figure 1. Map instances derived from geospatial database. Legend of symbols: 2D, 3D – spatial dimensions, T–time, H–height/depth, A–animation, I–interaction, SciVis–scientific visualization [8].

Map clarity improves when the shapes, sizes, and positions of spatial features can be clearly perceived. Three-dimensionality is particularly important in this context. Users can easily explore and interact with the surrounding environment through a virtual map based on a real-world coordinate system. The relevance of a map increases when it reflects the current state of the represented features. A paper map can be “updated” with current digital information [9]. However, map clutter increases as the map becomes filled with symbols and labels.

3. GEOGRAPHIC INFORMATION SYSTEMS AND THEIR APPLICATION IN CARTOGRAPHY

Geographic Information Science (GIScience) is an interdisciplinary field that plays a central role in our increasingly interconnected world. GIScience is commonly defined as the scientific foundation of Geographic Information Systems (GIS), serving as the driving force behind the development and advancement of these systems. This holistic approach encompasses a wide range of disciplines and methodologies. GIS is a computer-based technological system designed for the collection, storage, manipulation, management, analysis, modeling, and presentation of geographic and non-geographic data. Its primary focus is on data related to the Earth’s surface, encompassing either the entire planet or specific regions.

In an era of rapid development in information technologies (IT), GIS has become seamlessly integrated into many aspects of everyday life, gaining significant importance in fields such as remote sensing data analysis, urban planning, disaster risk management, and 3D modeling. Furthermore, as technology continues to evolve, the integration of GIS with emerging technologies such as big data, cloud services, and artificial intelligence has ushered in a new era of GIS development, opening innovative directions for its future growth [10].

There are various definitions of Geographic Information Systems, each developed from different perspectives or disciplinary backgrounds. Some emphasize the relationship with maps, others focus on databases or software tools, while some highlight applications such as decision-support systems. Defining GIS can be approached either by explaining what it can do (its functions) or by examining its components. Both perspectives are important for a comprehensive understanding and effective use of GIS.

An analysis of the three letters of the GIS acronym provides a clear understanding of its meaning:

G – Geographic: Refers to the spatial identity or location of specific entities on, above, or below the Earth’s surface.

I – Information: Refers to the need for information in order to support decision-making. Data, or raw facts, are interpreted and processed to create meaningful information useful for making decisions.

S – System: Refers to the combination of personnel, computer hardware, and procedures required to produce the information necessary for decision-making, including the collection, processing, and presentation of data.

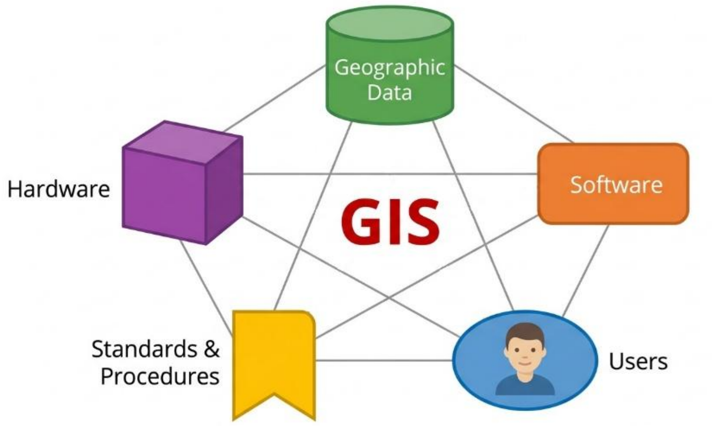

Figure 2. Graphical representation of a Geographic Information System [11].

Several original definitions of GIS are also recognized: 1) GIS provides the ability to view the world around us in a new way; 2) GIS is a tool for understanding the world through its interrelated components; and 3) GIS is a powerful tool for integrating and organizing information.

In the era of the Internet, an important direction for the development of GIS is the application of high-performance computing systems within the GIS domain to solve complex problems. The development of GIS is closely connected with advanced spatial computing. This progress promotes the evolution of GIS architecture, enabling more efficient processing of large volumes of data, models, and algorithms, as well as more accurate and faster spatial analysis, more efficient spatial modeling, and more intelligent spatial prediction [12].

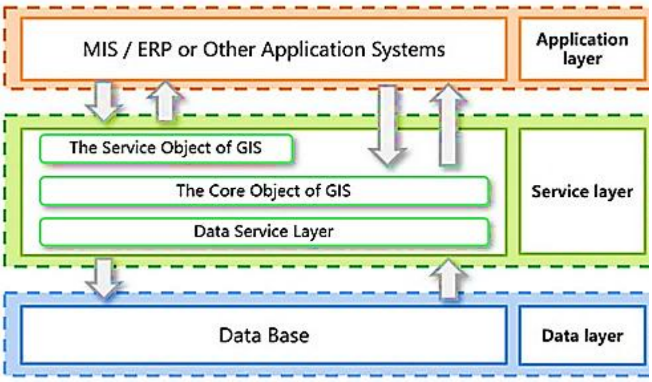

Figure 3. Architecture of Components GIS system [12].

The integration of cloud computing technology has improved resource management and data maintenance capabilities, enabling GIS to efficiently process large-scale datasets and support real-time analysis. At the same time, the application of artificial intelligence and deep learning has made GIS systems more intelligent, enhancing spatial and temporal analysis as well as visualization capabilities. This trend of technological integration will continue to shape the future development of GIS, providing powerful tools for solving a wide range of complex geographic problems.

Cartography has provided essential support for many aspects of communication and information exchange related to the geographic world, while automated cartography has created numerous concepts and procedures that form the foundation of modern GIS technology. One of the most important origins of GIS lies in the automation of cartographic workflows, with the additional goal of integrating and analyzing geospatial information. This has led to the evolution of fundamental methods of spatial data processing, including the storage and representation of various spatio-temporal data in digital databases and the efficient production of maps that can be used for decision-making and for understanding spatial relationships through spatial analysis [13].

The growing involvement of GIS in human activities, together with the transition of AR from traditional experimental applications to industrial use, makes the integration of GIS and AR technologies particularly suitable for simultaneously leveraging the advantages of both systems. The simultaneous visualization of real and virtual geospatial information enables an interactive approach. By allowing concurrent visualization and eliminating the need for data exchange between different systems, potential errors can be significantly reduced.

4. INTEGRATION OF AUGMENTED REALITY AND 3D GEOGRAPHIC INFORMATION

Augmented reality technology enables access to digital-world data through the camera of a mobile device. This feature is only beginning to gain popularity in cartographic products, and its use is currently limited by the capabilities of most devices and standard software solutions. However, products based on the combination of GIS and AR technology are increasingly appearing on the market. AR can be described as an environment perceived through human senses in which visual, auditory, tactile, gustatory, or olfactory information from physical objects and phenomena is supplemented with related digital data generated by a computer in real time. Most commonly, AR is understood as an environment in which physical objects in a person's field of view are overlaid with computer graphics in the form of two-dimensional and three-dimensional models, object highlighting using various graphical methods, or alphanumeric labels [14].

The transition from the real world to maps represents the abstraction process of mapping. This process involves making decisions about how spatial features should be represented. In the context of GIS it is essential to be explicit, consistent, and precise when defining and describing geographic features of interest. A lack of explicitness, consistency, and precision may result in inaccurate and inconsistent maps, as well as analyses and decisions based on such maps and GIS systems.

In order to successfully develop an AR application based on 3D features, several key tasks must be fully addressed. When using AR technology, it is essential to have both hardware devices and software interfaces capable of displaying AR content and enabling user interaction with the system. It is also important to ensure that the presentation of AR information is accurately aligned with the correct geographic position. This requires precise determination of geospatial information, user device location, and the phenomena being represented. To continuously provide personalized information in real time as users move through space, a feature-based 3D GIS, a backend server, and a service mechanism are required [15].

AR can be used to represent geospatial data as a digital layer within the real environment. Although this functionality offers several advantages, such as providing immediate feedback, enabling data collection, and facilitating data manipulation, it also presents significant challenges that must be addressed. Depth perception is a major issue in AR visualization, as it involves determining the true distance between objects. Depth distortions and object ordering problems can lead to incorrect recognition of spatial relationships and consequently to inaccurate interpretations [16]. Potential solutions include improved control of lighting and shading. Another challenge in AR visualization is visual information overload, which can interfere with the user's interpretation of the environment. Data filtering, dimensionality reduction, and variable-resolution approaches may represent possible solutions.

A flexible data management approach has also been proposed to address challenges in presenting geospatial data within AR systems. This approach ensures data consistency between the GIS database level and the AR 3D geometry level, thereby improving the interactivity of data visualization. Specifically, a bidirectional layer called transcoding is designed to convert GIS data into a specific, interpretable 3D geometry. Furthermore, to support system interactivity, this layer enables users to modify geospatial data through selection, manipulation, and navigation [17].

The augmented map represents a further step in interaction with digital cartographic data. Analog maps are combined with digital models, enabling an immersive mode of operation for each user of the system simultaneously. Furthermore, through the internet, the user's physical location becomes irrelevant. Multiple users can manipulate their own thematic layers and place them within a shared virtual environment.

5. DEVELOPMENT AND USE OF AR MAPS

Cartographic visualizations are typically presented either as printed maps or as digital, screen-based maps. Printed maps allow users to interact with spatial information in a direct, natural, and familiar manner, much like they would with other physical objects in their environment. In contrast, advances in computer vision make it possible to extend maps beyond two dimensions, enabling the visualization of three-dimensional landscapes and dynamic animations. The usability of such systems depends largely on the user's experience as well as on the capabilities of the underlying software. AR integrates the advantages of both approaches by preserving intuitive and familiar modes of interaction while simultaneously exploiting the full potential of modern computing technologies [18].

Markers are used as reference points for the georeferencing of the physical map and virtual objects. In this way, real and virtual information can be integrated. The layout of an augmented map is shown in Fig 4. The physical map is bordered by four markers, allowing the viewer to observe the map while always maintaining at least one reference point relative to the virtual environment. To ensure reliable marker recognition, it is necessary to maintain sufficient distance from other graphical elements (Fig 4A). Additional information can be obtained using an augmented pointer (Fig 4B). In this case, virtual objects (visible or invisible) intersect with the virtual end of the pointer. Depending on the object and the pointer's position, further actions can be triggered [18].

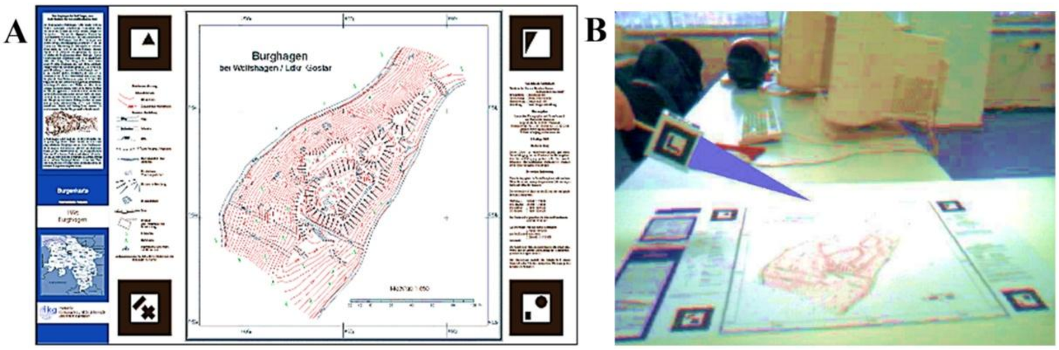

Figure 4. Layout of augmented map (A). Augmented pointer (B).

An important aspect of the effective implementation of VR and AR in cartography is the development of user interfaces that enable practical and intuitive interaction with cartographic data in virtual and augmented environments. This involves the development of gesture-based controls, virtual controls, and other interface elements adapted to the specific characteristics of VR and AR, thereby opening new possibilities for practical interaction with geographic objects and spatial data. Interaction with information in augmented or virtual space, in turn, facilitates a clearer and more intuitive understanding of the data.

AR enables the direct superimposition of additional information onto the three-dimensional space perceived by the user in real time. This capability is particularly important in map-based spatial interaction, as well as in navigation and planning tasks. It can help address common challenges in cartographic interpretation, such as the geometrically accurate alignment of spatial objects represented on maps with their corresponding positions in real-world space (georeferencing). This is especially valuable for spatial orientation, as AR can present essential route indicators directly within the user's field of view [19]. One of the most common and widespread applications of AR integration with GIS is the enhancement of map comprehension. By generating maps in GIS environments and visualizing them through AR systems, even users without specialized spatial, geographic, or cartographic knowledge can more easily interpret and use map content. As a result, this approach can improve the overall user experience and make map use more intuitive, accessible, and reliable (Fig 5) [20].

Figure 5. Example of a three-dimensional AR map visualization displayed on a table.

Traditional maps provide users with essential information for spatial orientation and route selection to their destination. They have retained their value even in today's digital age. With the development of AR systems, with or without markers, digital annotations can be added as an additional layer on maps. Whether in printed or digital format, maps can be enhanced and "augmented" using computer vision. Useful information can be presented in real time through AR, providing detailed statistics without requiring users to thoroughly analyze map data, thereby making maps easier to use for a broader range of users [21].

Using AR tools and head-mounted devices, paper maps can be digitally enhanced in the field and equipped with a certain level of interactivity. To achieve better performance, dynamic information about the area of interest can be preloaded before going into the field instead of loading data for the entire region. AR maps can provide real-time visualization of geographic information [22].

There are two possibilities for the collaborative exploration of geographic data using AR maps. The first involves an interface that combines AR with user motion tracking through image analysis. Users can view a physical geographic map on paper and observe a 3D model aligned with that map. The second approach offers different interaction techniques (zooming, moving, annotations, etc.), for example by using a zoom tool metaphor that allows users to explore data in greater detail (Fig 6) [23].

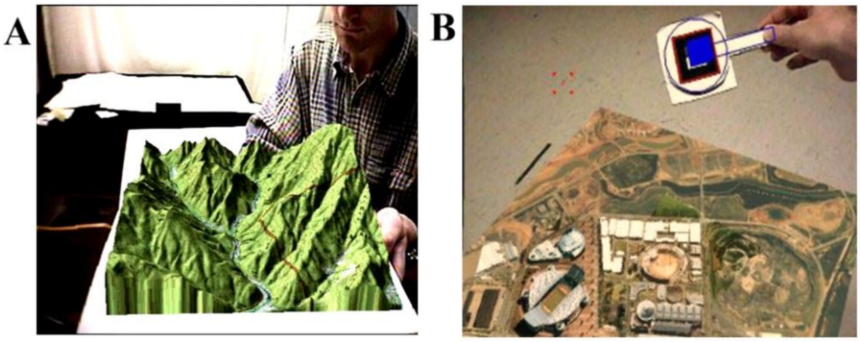

Figure 6. Visualization of a 3D model of an AR map (A). Interactive AR map (B) [23].

The visualization provided by an AR sandbox in geoscience education is not only useful for simulating real-world events but can also improve students' spatial reasoning skills. For this reason, experts suggest incorporating this system into topography lessons. The importance of geo-factors in collaborative decision-making is significant, and the use of an AR sandbox can contribute to the efficiency of collaborative geo-design processes. It can also be used to create educational environments for learning and design in active transportation and tourism systems [24].

A visualization of spatial models placed on a table using environment tracking is presented in Fig 7A. The software is designed to be hardware-agnostic, supporting marker-based tracking on lower-end devices and environment tracking on higher-end devices. Fig 7B illustrates a cartographic visualization of an augmented reality map with various base maps, including satellite imagery, shaded relief, slope maps, and hillshade maps. In addition, any custom texture can be applied, provided that it conforms to the shape of the underlying terrain model. Similar to tracing-paper and base-map tools, terrain enhancements remain consistent across different base maps. In a multi-user environment, changes to the base map can be controlled either individually by each user or centrally by a group leader, thereby facilitating instructor-led activities [24].

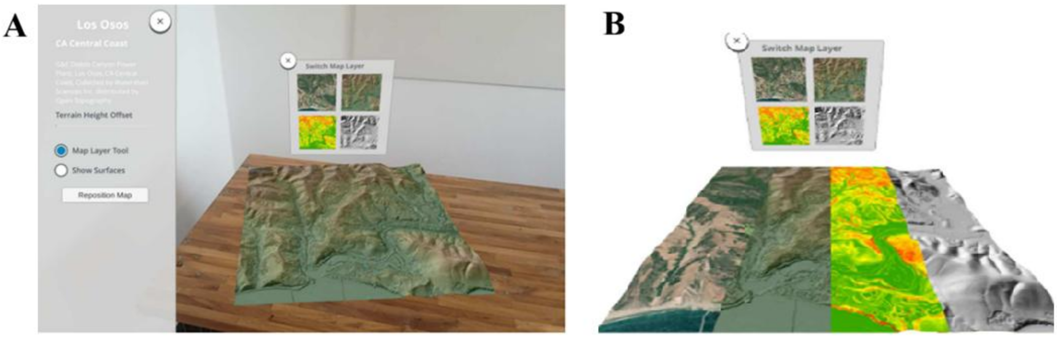

Figure 7. 3D terrain covered with a colored relief map anchored to the table using environment tracking (A) and a close-up of the map layer tool showing the ability to instantly visualize and select from a range of base map styles (B).

Although the nature of printed maps will not be replaced by innovative technologies, they can be complemented by new technological capabilities. Augmented reality offers a range of unique improvements compared to other digital media, such as touch-sensitive displays, with the ability to support both global and personal perspectives on the presented data within a shared space. However, the high barrier to entry for software development may limit its wider adoption. The use of open-source software can encourage broader adoption in both research and practical applications.

6. FUTURE DIRECTIONS IN THE DEVELOPMENT OF CARTOGRAPHIC TECHNOLOGY

Over the past 40 years, map production technology has undergone fundamental changes. Today, paper maps are produced exclusively using digital technologies. However, they are increasingly being replaced by multimedia or electronic maps. Global cartographic services provide potential applications that were unimaginable until recently.

With continuous technological advancement, the future development of cartography will focus more on intelligence and precision in order to meet the growing complexity and dynamic demands for geospatial information. Future cartographic technologies may develop in the following directions [25]:

- Intelligence: Artificial intelligence and machine learning will be increasingly applied to the automated extraction of geographic features, classification, and map updates in order to improve map accuracy and production efficiency (Fig 8).
- Personalized services: Analysis of location-based data and user behavior will provide more personalized cartographic services and navigation experiences.
- Cloud computing and big data: Cloud computing will enable efficient management and processing of massive geospatial datasets, while its combination with big data technologies will provide deeper insights for map analysis.

Furthermore, drones and autonomous vehicles may improve the ability to collect ground-level data, providing real-time information for high-precision mapping.

Fig 8 illustrates the relationships among the geographical referent (a), the physical referent (b, c), and the physical representation (d). The term geographical indirection denotes the distance between the geographical referent and the physical referent. These two may coincide directly, or may be linked through a scaled intermediary, such as a map. Spatial indirection denotes the distance between the physical referent and the physical representation.

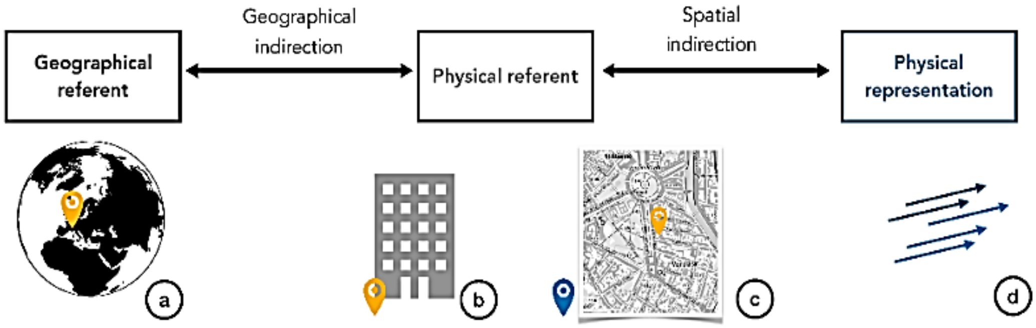

Figure 8. Relationship between the geographical referent (a), physical referent (b, c), and physical representation (d), illustrating geographical and spatial indirection.

7. CONCLUSION

The visualization of paper maps retains significant value even in today's "all-digital" world due to their high information density and ease of use in remote or mobile environments, particularly in military contexts. The complete elimination of paper maps may create a sense of discomfort for military users. Augmented reality techniques are used to digitally enhance paper maps, resulting in three-dimensional spatial visualization with certain interactive capabilities. Dynamic terrain information, the placement of virtual objects, and user interaction are features of the digital environment that can be superimposed onto paper maps.

AR has proven to be an important and widely applied innovation whose full potential will continue to unfold with further technological development. It enables interaction with digital data through visual and spatial interfaces that integrate naturally into the human environment and everyday life. AR is not a simple technology but rather a complex medium composed of multiple technological innovations. Nevertheless, combining GIS with AR-based visualization techniques presents several challenges, both in terms of technological development and application methods. However, through continued research and technological advancement, these challenges can be overcome. This paper examines the integration of GIS and augmented reality in order to bridge the gap between real and digital data. Specifically, it explores how the combination of real-world and digital information enabled by AR can enhance GIS visualization capabilities.

In conclusion, the integration of virtual and augmented reality into cartographic production represents an important development in modern cartography, enabling the creation of more informative, interactive, and efficient maps for various purposes and applications. It also contributes to improving the accessibility of cartographic information for a wide range of users, including individuals with disabilities or special needs. By enabling the visualization of data in virtual and augmented environments, maps become more accessible and easier to understand, facilitating improved situational awareness, enhanced navigation, and greater user safety in various contexts such as tourism, expeditions, and emergency situations. Therefore, the integration of virtual and augmented reality into cartography opens new perspectives for the development of cartographic products and promotes improved visualization and interaction with geographic information in the digital world.

From digital maps and dashboards to satellite imagery, 3D models, and real-time data, GIS brings data to life, helping us understand complex problems and develop effective solutions. This encompasses not only the core of spatial thinking, research, and problem-based learning, but also education that encourages active engagement and the ability to make a difference in our rapidly changing world.

Considering the trends identified in this study, cartography is well positioned to assume a more significant role in education and society. The question remains whether cartographers will seize the opportunity presented to this discipline and propel it onto the global stage.

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