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Recent Development in CartographyAn Analytical Review of Research for the Period 2015–2025: A Review Article

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التطورات الحديثة في الكارتوكرافيا : مراجعة تحليلية للأبحاث للمدة ٢٠١٥-٢٠٢٥ : مقال مراجعة

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Abstract

In the first decade of the third millennium, the science of cartography witnessed radical developments unprecedented in the history of mapping spanning thousands of years; the discipline has shifted from drawing maps on paper to the fields of artificial intelligence, augmented reality and machine learning. This article presents an analytical scientific review covering the most significant updates in cartography during the period 2015–2025, based on 33 peer-reviewed sources published in reputable international scientific journals. The article discusses six key themes, including: (1) emerging cartographic frameworks and their contemporary concepts, (2) interactive maps and user experience, (3) the interplay of artificial intelligence and machine learning in mapmaking, (4) Volunteered Geographic Information (VGI) and the state of collaborative mapping, (5) Immersive Cartography: Virtual Reality (VR) and Augmented Reality (AR), (6) Critical Cartography and the decolonization of maps. The review concluded that the field of cartography is undergoing a methodological renewal that requires updated educational and research plans.**Keywords: cartography, interactive maps, artificial intelligence, VGI, augmented reality, critical cartography, machine learning.**

ملخص:

في العقد الأول من الألفية الثالثة، شهد علم الخرائط تطورات جذرية لم يسبق لها مثيل في تاريخ رسم الخرائط الذي يمتد لآلاف السنين؛ فقد انتقل هذا التخصص من رسم الخرائط على الورق إلى مجالات الذكاء الاصطناعي والواقع المعزز والتعلم الآلي. يقدم هذا المقال مراجعة علمية تحليلية تغطي أهم المستجدات في مجال علم الخرائط خلال المدة ٢٠١٥-٢٠٢٥، استنادًا إلى ٣٣ مصدرًا خضع للمراجعة العلمية ونُشرت في مجلات علمية دولية مرموقة. تتناول المقالة ستة مواضيع رئيسية، منها: (١) الأطر الخرائطية الناشئة ومفاهيمها المعاصرة، (٢) الخرائط التفاعلية وتجربة المستخدم، (٣) التفاعل بين الذكاء الاصطناعي والتعلم الآلي في صناعة الخرائط، (٤) المعلومات الجغرافية التطوعية (VGI) وحالة رسم الخرائط التعاوني، (٥) الخرائط الغامرة: الواقع الافتراضي (VR) والواقع المعزز(AR) ، (6)الخرائط النقدية وتحرير الخرائط من الاستعمار. وخلصت الدراسة إلى أن مجال الخرائط يشهد تجديدًا منهجيًا يتطلب خططًا تعليمية وبحثية محدثة.

الكلمات المفتاحية: الخرائط، الخرائط التفاعلية، الذكاء الاصطناعي، المعلومات الجغرافية التطوعية، الواقع المعزز، الخرائط النقدية، التعلم الآلي.

1. Introduction:

Throughout history, cartography has been both a science and an art form, serving to represent spatial phenomena and condense them into two-dimensional maps on paper and screens[1]. In light of rapid technological developments, there is now a need to revisit this traditional definition. Basaraner (2016) argues that cartography in the field of computational geographic information is not limited to the era of final geographic visual representation, but is an integrative science that geographically models the natural and human environment, establishes the infrastructure for geographic data, and spatial citizenship[2]. In this context, the final report of the International Cartographic Association (ICA), published in the (International Journal of Cartography) in 2024, reviewed a decade of purposeful knowledge dissemination: " "Since 2015, we have contributed to the publication of more than twenty-eight issues, through which we have witnessed radical shifts in the fields of cartography and geographic information science." This growing academic engagement reflects the international attention being paid to the advancement of cartography, given that it is a dynamic and evolving field[3]. Several factors are also driving this field into new areas of application: the adaptability of cloud environments to workloads; the expanding use of smart devices equipped with GPS; the growing availability of crowd-sourced geospatial data; and a heightened critical awareness of the political function of maps. The general knowledge framework identified by a scientific review published by Elsevier in 2023 suggests that the interplay of big data, real-time information processing and machine learning has brought about a fundamental shift in the way maps are produced, used and disseminated[4].

٢. Study Population and Review Methods:

2.1 Definition of the study population:

This systematic review was based on a structured search of major scientific databases, including: Web of Science, Scopus, Google Scholar, and databases of specialist researchers who have published their research with Taylor & Francis, Springer, Elsevier and MDPI. The inclusion criteria for the study were defined as follows: (a) the study must have been published in a peer-reviewed scientific journal with an internationally recognized impact factor; (b) the publication must have taken place between 2015 and 2025; (c) the study must fall within the fields of cartography and geographic information science.The initial study population comprised all articles published in the following specialist journals: the International Journal of Cartography, published by the International Cartographic Association (ICA); The Cartographic Journal, published by the British Cartographic Association; Cartography and Geographic Information Science (CaGIS); Cartographica: The International Journal for Geographic Information and Geovisualisation, the International Journal of Geographical Information Science, the ISPRS International Journal of Geo-Information Geocarto International, and KN–Journal of Cartography and Geographic Information. The total number of studies subjected to the initial screening was 780 articles. Studies not directly related to developments in the field of cartography or lacking methodological rigour were excluded, leaving a final total of 33 peer-reviewed scientific studies.

2.2 Reasons for choosing the time period:

The period 2015–2025 was chosen because it represents a pivotal era of profound significance, during which a series of technological revolutions coincided: beginning with the emergence of deep machine learning in 2015–2016, through to the proliferation of geospatial big data, developments in virtual reality (VR) and augmented reality (AR) – i.e. immersive technology – and finally the emergence of generative artificial intelligence technologies in the years 2022–2025. This period thus covers the monitoring of an integrated and interconnected development trajectory, rather than a stratified sample.

3. Redefining Cartography – New Theoretical Foundations:

The intellectual work presented by Basaraner (2016) is considered one of the theoretical frameworks that best recognizes the complexity of modern cartography; It presents an integrated framework that redefines cartography not merely as a tool for map-making, but as a fundamental discipline that manages geographical information and builds active digital communities. The framework is based on three elements: spatial configuration, social interaction, and geographical location applications[5]. In the field of digital cartography within academia, Lin (2015) demonstrated how Web 2.0 has shifted map-making from the domain of official institutions to a broad audience of users. This represents a fundamental shift in the traditional relationship between the mapmaker and the recipient in the field of cartography. This view aligns with the conclusion reached by the International Journal of Cartography in its inaugural issue in 2015, namely that the map is no longer a tool for documentation, but has become an interactive medium for creating and negotiating spatial meaning[6]. This perspective is consistent with the conclusion reached by the (International Journal of Cartography) in its first issue of 2015, namely that 'the map has moved beyond being merely a tool for recording; it has become a participatory tool for producing geographical meaning and engaging in dialogue about it'. At the practical level of addressing global challenges, Ricker (2025) demonstrates that spatial data and cartography have become the primary technical foundation for international sustainable development plans—from climate change monitoring to natural resource management and urban planning—within the United Nations' 2030 Agenda for Sustainable Development[7].

4. Interactive maps and the user experience (UI/UX):

٤.1 The Concept of Interaction with Smart Maps:

Roth (2015) presented a review of relevant theories in which he defined cartographic interaction as 'the dialogue between the user and the map using a computer', and carried out a systematic comparison between the findings of theoretical studies and the practices of professionals in the field. Roth drew on detailed qualitative interviews with 21 experts in geographic information and concluded that interactivity is no longer an optional technical feature but a fundamental attribute that reconfigures the cognitive connection between the map and its user[8]. Within the same framework, a review (Roth et al., 2017) developed a research programme for studies of interactive map users, demonstrating how 'digital literacy for interaction requires a re-conceptualisation of the map user to be considered a user, taking into account the user's cognitive, knowledge-based, cultural and practical levels, which have a significant impact on their experience'. This context formed a fundamental basis for subsequent applied research[9].

4.2. User experience with digital maps:

Horbiński and Cybulski (2020) studied the visual behaviour of users of interactive online maps using eye-tracking technology. Their study found that users "systematically scan the corners of the screen for control buttons, without looking for the rest of the buttons", which suggests that map designers should group similar functions together to reduce cognitive load and improve the user experience[10]. A study (Song, Roth et al., 2022), which drew on a field experiment involving 125 participants, demonstrated that participants' performance was optimal when visual narrative designs utilised long-form content (scrollytelling) and guide line technology to highlight the content. The study also found that individual differences among participants in terms of experience level and prior motivations had a clear effect on their response to the map-based content[11].

2.3 Visual Narratives and the Narrative Map:

Roth's (2021) work represents a significant theoretical breakthrough, presenting the visual narrative as a hybrid framework that unites technology with practice, cartography with process, and authorship with criticism. Roth has also identified ten principles to distinguish the visual narrative from conventional cartography, thereby redefining the function of the map from a tool used to document information to a means of creating emotional impact and geographical persuasion[12].

5. Artificial Intelligence and Machine Learning in Cartography:

5.1 A comprehensive review of artificial intelligence applications:

Kang, Gao & Roth (2024) conducted a comprehensive review of artificial intelligence research in the field of cartography, which included an analysis of the methodologies, applications and ethical standards of dozens of studies. This review demonstrated that Artificial Intelligence used in the geographical field (Geo AI) has played an active role in two areas: firstly, accelerating complex cartographic tasks such as generalization and classification; and secondly, opening up new creative possibilities in mapmaking that did not previously exist with traditional tools[13]. The most technically intriguing application, however, lies in the deep neural networks used for map generalization, as demonstrated by Harrie et al. (2024) in their seminal paper on "machine learning in cartography". The researchers outline four main practical approaches, including: the identification of cartographic methods; the design of generalization algorithms; style transfer; and the labelling of digital maps[14].

5.2. Deep Neural Networks and Cartographic Generalization:

In this specialized applied field, a review (Fang et al., 2025) noted significant progress in deep neural network applications within the field of cartographic generalization over the past five years. The review concluded that models such as U-Net, Generative Adversarial Networks (GANs) and Graph Convolutional Networks (GCNs) have excelled in automating complex tasks such as building segmentation, road network extraction and object classification, although they remain at an exploratory stage and have limited potential to provide comprehensive solutions in all respects[15]. In the context of the theoretical debate surrounding interpretability, Fu, C. et al. (2024) demonstrated that integrating explainable artificial intelligence (XAI) with deep neural network models in cartographic generalisation allows for an accurate understanding of the cartographic information obtained from the model in specific cases, thereby transforming the model from a black box into an innovative, transparent tool that enables cartographers to respond to and develop it[16].

6. Volunteer-Generated Information (VGI):

٦.1 Theoretical Principles of VGI:

Goodchild (2007) coined the term 'VGI' in the academic discourse, but the period 2015–2025 saw a remarkable academic expansion in the study of this phenomenon[17].See et al. (2025) summaries the current situation by stating that "the concept of crowdsourced geospatial data has proven to be a cornerstone of geographic information science and geography, and has marked a paradigm shift in digital map production, moving away from traditional producers such as national surveying agencies towards the user". The (OpenStreetMap) platform has played a unique role in demonstrating this potential on a global scale[18]. However, the reliability of volunteer-generated data remains a persistent epistemological question. Yan et al. (2022) an organisational framework for assessing the reliability of Volunteer-Generated Information (VGI) in the context of field activities, based on five trust criteria derived from the fundamental characteristics of the data, and concluded that 'update frequency, number of contributors and label edits' are the most reliable indicators associated with the scientific accuracy of the data[19].

6.2. Governance and Geopolitical Context:

In her multi-sited ethnographic study of the OSM ecosystem in China, Lin (2018) highlighted an unusual situation in which legal, technical, political and social variables converge to reshape the architecture of collaborative geographic knowledge generation. The study concluded that VGI models are not objective, but rather construct their structure through complex interactions between technical platforms on the one hand and local systems and social movements on the other[20].

6.3. Accuracy and reliability of VGI data and editorial approach:

In the field of accuracy and subject-matter reliability, Foody et al. (2015) conducted an experimental study demonstrating that the accuracy of (VGI) data is closely linked to both the number of participants and their characteristics, and that 'a large number of participants does not necessarily compensate for their lack of specific expertise' This necessitates updating methods for classifying participants and assessing their capabilities, rather than relying solely on large volumes of data[21]. With regard to the editorial sustainability of VGI platforms, (Zhang et al., 2024), by tracking volunteer contributions to (OpenStreetMap), that "interaction mechanisms on VGI platforms are characterized by sharp disparities; a small number of dedicated editors account for the vast majority of map content". This finding calls for a reassessment of the assumption of an equitable distribution of collaborative mapping work[22].

7. Virtual Reality and Augmented Reality in Cartography

7.1. Immersive Cartography:

The study by Mietrik et al. (2019) is of great significance; it documented a comprehensive workflow for creating an interactive VR environment to visualise the Arctic fjord (Clyde Inlet) with real dimensions (160×80) kilometers and a spatial resolution of 5 meters, demonstrating the ability to display realistic terrain features in interactive virtual environments on mid-range computers[23]. Within a more rigorous methodological framework, Edler, D., & Kersten, T. P. (2021) the role of virtual reality and augmented reality in spatial perception, demonstrating that "the game development environment, head-mounted displays (HMDs) and mobile devices work together to create new possibilities for experiencing real-scale three-dimensional spatial environments with immediate personal perception"[24].

7.2. Elements of cartographic representation in augmented reality:

Kerker et al. (2021) established a theoretical basis for studying the effectiveness of augmented reality technology on cartographic design, demonstrating that "the integration of digital layers into the real-world environment results in a hybrid visual environment that requires cartographic design constraints fundamentally different from those known in conventional digital mapping". This study has served as a reference point for future applied research in this field[25]. (Qiu, Wang et al., 2023) presented a field study to identify cartographic representation elements in the spatial representation of augmented reality data in open-space areas. The study concluded that Bertan's theory of cartographic representation elements, which was designed for paper maps, cannot be directly transferred to the augmented reality (AR) domain without modification, as visual perception within an AR environment differs radically from classical two-dimensional flat representation, underscoring the need to develop a novel conceptual framework for the composition of cartographic symbols within the virtual digital environment[26]. Edler et al. (2023) found that animated 3D cartographic systems within VR environments demonstrated that "cartographic visualisation using a virtual reality headset creates a more immersive experience than desktop applications", and that interacting with the environment from a first-person perspective enables the user to grasp spatial details in a more vivid and tangible manner[27].

7.3. Immersive Cartography and Geospatial Science:

Cheng et al. (2022) conducted an evaluation of studies on the concept of "augmented maps" from a cartographic perspective, documenting how cartography addresses the challenges of integrating virtual elements into the real-world landscape, resolving visual interference, and achieving aesthetic harmony between the digital and physical layers. The study concluded that the field of enhanced mapping still has an urgent need for standardized design guidelines[28].

8. Critical Cartography and the End of Cartographic Imperialism:

8.1. Principles of Critical Cartography:

The tension between the concept of the map as an objective cognitive tool and the concept of the map as a form of authoritarian behavior has persisted, and this has become the basis for critical cartographic studies. Crampton (2009) previously documented this tension in the context of Cartography 2.0[29]. Subsequent reviews have served to reinforce this trend. Rose-Redwood (2015) outlines the framework of deconstructive cartographic analysis, noting that deconstructive analysis risks overlooking the potential for a future vision of constructive alternative cartographic behaviors that highlight the positive, creative aspect[30]. Rose-Redwood et al. (2020) proposed a conceptual framework for decolonizing cartography, based on three pillars: repositioning local knowledge, respecting the customs and traditions of indigenous peoples, and ensuring the active participation of these peoples in the mapping process itself. This goes beyond correcting cartographic content to renewing the entire logic of cartography[31].

8.2. Anti-colonial indigenous maps:

Araújo et al. (2022) have proposed an interpretation of indigenous cartographic representations from the Amazon (the Mbingokri and Owe peoples), re-centering these peoples as inhabitants possessing their own geographical cartographic knowledge and the capacity to produce it, rather than merely as subjects to be recorded[32]. This view is consistent with the point highlighted by (Álvarez & Santamarina-Campos, 2022) that government maps in Colombia reinforce colonial thinking, which is reflected in current urban planning practices, as the original black or uncolored maps based on field surveys were excluded from official cartographic representation[33]. In the same critical vein, Duggan & Gutiérrez-Ujaque (2025) examined the concept of 'counter-mapping' and developed a model that moves beyond the use of superficial participatory techniques to adopt techniques for renewing the representation of spaces, decolonisation, and radical cartography. The researchers acknowledge that counter-mapping faces a twofold challenge: firstly, the technical authority of state cartography; and secondly, superficial participation that does not bring about a fundamental change in spatial representation[34].

9. Discussion and analytical assessment:

A comprehensive review of the selected studies reveals three parallel pathways for the advancement of cartography during the period 2015–2025: The first pathway represents the technical aspect, evident in the integration of artificial intelligence, machine learning, augmented reality and user data to create maps with the highest levels of intelligence, interactivity and immersion. The second pathway, however, represents the social and epistemological aspect, focusing on redistributing the capacity to produce maps from government institutions to the public through VGI platforms and digital participation. The third approach represents the critical and political dimension, which redefines the concept of maps from being a government document and a tool for entrenching colonialism, and calls for a cartography that pays attention to marginalised voices and local knowledge systems. The current debate centres on a key question: does automation based on artificial intelligence tools threaten the human creative function of cartography, or does it liberate it from its focus on design, analysis and critique? The studies reviewed suggest that AI models have the potential to simulate the maps produced by a cartographic expert, but fail to grasp their line of reasoning, cognitive style, methodological judgement and artistic sensibility; this highlights both strengths and weaknesses simultaneously. The various studies reviewed also concur in emphasising that modern cartography requires cartographers who possess skills in programming, visual design, methodology and critical thinking simultaneously. One of the most prominent issues that repeatedly emerges in the studies reviewed is the problem of the accuracy, reliability and validation of VGI data, as well as the issue of disparities in the use of digital cartography among individuals; whilst there are areas where mapping participation is concentrated, particularly in wealthy nations, we find other marginalised regions, and the issue of data confidentiality in the era of interactive digital elevation models (DEMs) based on remote sensing, Finally, there is the issue of potential risks in artificial intelligence applications and the need for policies that serve as guidelines to regulate its behaviour and use transparently and responsibly, taking into account privacy and social impacts, particularly during map production and distribution.

10. Conclusion and Recommendations:

This scholarly review concludes that, during the period 2015–2025, the field of cartography underwent a radical methodological shift in its theoretical content, conceptual framework, technical tools and social objectives, such as community empowerment. The discipline has shifted from being a tool for spatial documentation to a field where technical, philosophical, political and creative elements converge. Among the most significant findings are:

1. Digital integration: The enhanced role of artificial intelligence and machine learning models in generalisation processes, classification and the production of visual representations; however, these cannot replace human cartographic expertise in making judgements.
2. User-centred approach: The shift from mapmaker-centred cartography to user-centred cartography, and the associated challenges in ensuring accuracy and reliability.
3. Digital immersion: Virtual and augmented reality open up unprecedented new cartographic horizons, requiring the creation of a theoretical framework and a restructuring of visual variables.
4. The critical approach: Cartography is no longer confined to a neutral technical sphere, but has become a field where conflicts over identity, power, equity and collective knowledge heritage converge.

This article recommends a number of promising research directions: (1) improving cartography curricula to combine technical and critical aspects, (2) establishing international standards for the accuracy and reliability of Volunteer-Generated Information (VGI) that take into account cultural diversity and regional variation, through two complementary practical stages: the first being the development of common standards to ensure data reliability and accuracy based on measurable geographical and temporal quality controls; the second being the improvement of participatory digital platforms that enable local residents to review and edit data relating to their areas in their native language; Third, establishing research collaboration between universities and national surveying authorities to implement quality management procedures throughout the chain of changes affecting VGI, from the data collection stage through to its publication on digital mapping platforms; (3) To explore the role of the Arabic language and geographical studies in the Middle East within the field of international cartography; (4) To establish cartographic studies in augmented or virtual reality within the fields of education, training and professional development in Arab countries.

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