

TYMOTEUZ HORBIŃSKI, JAKUB WOŹNIAK, CYPRIAN ŚWIECH
Adam Mickiewicz University
Department of Landscape Ecology
Poznań, Poland
0000-0002-9681-6762; tymoteusz.horbinski@amu.edu.pl
0009-0001-1132-5594; jakwoz10@st.amu.edu.pl
0009-0007-3899-7351; cypswi@st.amu.edu.pl

Use of game engines in cartographic research: an introductory overview

Abstract. Technological progress plays a key role in the development of cartography, influencing the ways spatial information is produced, analysed, and communicated. In recent years, game engines have gained particular significance, benefiting from increasing computational performance, broad accessibility, and advancements in 3D visualization and Extended Reality (XR) technologies. These factors have contributed to their growing adoption beyond the entertainment industry, including in cartography. The aim of this article is to provide an introductory overview and discussion of existing research on the use of game engines in cartography, with particular emphasis on 3D visualizations, XR and user studies. The article highlights that the greatest advantages stem from reusing native functionalities of game engines and consciously integrating their technological capacities with principles of cartographic design. The conclusions indicate that game engines constitute a promising direction for the development of cartography, requiring further methodological studies, standardisation of procedures, and in-depth analyses involving users.

Keywords: game engine, cartographic research, introductory overview, Extended Reality (XR), 3D visualizations

1. Introduction

Cartography and Geographic Information Science (GIScience) have long benefited from the dynamic development of information technologies (Keil et al., 2021). The widespread availability of personal computers equipped with increasingly powerful graphics cards has enabled the creation of pseudo-3D renderings and full 3D models, providing more realistic and immersive representations of geographic space compared to classical two-dimensional depictions (Buchroithner & Knust, 2013). In parallel, the computer games market expanded rapidly, driving continuous improvements in both software and hardware and resulting in increasingly advanced tools for real-time rendering. A key outcome of this trend has

been the emergence of game engines – complex software structures originally designed for the development of interactive video games (Walmsley & Kersten, 2019). Over time, however, these engines have evolved beyond their original purpose, becoming universal platforms for rendering and simulating complex virtual environments (Janovský, 2024).

Game engines may be seen as sets of formulas, principles, and algorithms (Thorn, 2011) comprising core components that enable the creation of a wide range of interactive applications, such as platformers, role-playing games (RPGs), or first-person shooters (FPS) (Thorn, 2011). As early as Trenholme and Smith (2008), researchers observed that game technologies allow for fast and relatively low-cost development of advanced 3D virtual environments that

can be efficiently adapted to experimental needs without extensive programming.

The interdisciplinary nature of these technologies has opened new opportunities for cartographers. Nearly every contemporary video game incorporates a spatial component, meaning that it also includes some form of cartographic product (Ash, 2016; Chądzyńska & Gotlib, 2015; Troups Dugas et al., 2019). Owing to the integral role of spatial representations in the structure of video games, game engines facilitate the creation of such products while simultaneously accounting for principles of cartographic design. This creates new avenues of application for cartographers, who can adopt tools originally built for the gaming industry to conduct cartographic research (Olberding & Vetter, 2023).

The term game engine was introduced with the shift of games to the PC platform around 1990 (Mat et al., 2014). Since then, the number of available engines has grown rapidly. Already in the early 2000s, Lewis and Jacobson (2002) identified more than 600 commercial game engines. Modern engines are characterised by broad accessibility, often offering free versions for non-commercial use (Walmsley & Kersten, 2019). Tools such as Unity, Unreal Engine, and Godot Engine allow users to create interactive virtual environments without licensing fees, which supports their increasing popularity in science, engineering, and education.

In contrast to traditional 2D visualization methods and pre-rendered pseudo-3D visualizations, environments built using game engines allow exploration from an almost unlimited number of perspectives (Indraprastha & Shinzaki, 2009). The purpose of this article is to provide an introductory overview of the current state of knowledge regarding applications of game engines in cartographic research. By summarizing recent achievements and identifying emerging trends, this article aims to outline the future directions of cartography in the context of the growing role of game-engine-based technologies.

2. Literature overview

2.1. Methodology of source retrieval and scope of analysis

To structure the literature exploration, a set of keywords was developed based on selected

methodological recommendations of Creswell and Creswell (2018), Reitman et al. (2020), and Horbiński and Zagata (2022). The keywords used to support the structured literature search were: game engine cartography, game engine, cartography, Unity Engine, Unity Engine cartography, Unreal Engine, and Unreal Engine cartography. The procedure was intended to support a structured and transparent literature overview, rather than a fully systematic review following formal protocols. The primary controlled term was game engine cartography, whereas the remaining phrases served as thematic extensions enabling the identification of broader conceptual links in the literature. Searches were conducted in Google Scholar, Scopus, and Web of Science, limited to peer-reviewed journal articles, conference proceedings, and monographs or book chapters (June 2025). The analysis included matches found in article titles, abstracts, keywords, and in the case of Google Scholar full texts. The search strategy was intentionally focused on publications explicitly linking game engines with cartography. Therefore, the review did not aim to exhaustively capture all adjacent strands of research indexed under broader descriptors such as map, visualization, spatial data, virtual reality, or simulation. This approach increased thematic precision, but at the cost of reduced comprehensiveness.

Only English-language publications were included (Table 1). The results confirm that the phrase game engine cartography considerably narrows the scope of the search, while previous studies (Horbiński & Zagata, 2022) have shown that the inclusion of the term cartography can likewise reduce the number of matches by focusing results more tightly on cartographic research topics. Table 1 presents an exploratory mapping of search-term visibility rather than a closed screening corpus.

Given the relatively small number of works directly linking the phrase game engine cartography, the review was expanded to include two widely used and industry-leading engines: Unity and Unreal Engine (Keil et al., 2021). At the same time, the review was not limited exclusively to these engines – additional works available to the authors and publications relevant to the development of cartography in the context of game-engine technologies were included. Accordingly, this paper should be

Table 1. Summary of keywords used in the analysis (as of June 2025)

Keyword	Scopus	Web of Science	Google Scholar	
			Title*	Anywhere**
game engine cartography	16	3	0	826
game engine	8,020	4,444	8	58,400
cartography	23,876	15,646	325	15,100
Unity Engine	2,737	1,551	1	16,000
Unity Engine cartography	6	2	0	272
Unreal Engine	1,278	666	1	1,880
Unreal Engine cartography	3	0	0	65

Explanation: * matches in titles; ** matches anywhere in the article (Google Scholar)

understood as a focused literature review of explicitly cartographic uses of game-engine technologies rather than a fully exhaustive systematic review of all related geovisualization and XR research.

2.2. Game engines as research tools in cartography

Game engines, defined as collections of formulas, principles, and algorithms (Thorn, 2011), have evolved from tools dedicated to developing video games into universal platforms for rendering and simulating complex virtual environments (Janovský, 2024; Walmsley & Kersten, 2019). Their strengths include the integration of real-time rendering, physics, sound, interaction, and modularity, collectively reducing the entry threshold compared with many GIS/VRI tools (Trenholme & Smith, 2008). Modern engines (e.g., Unity, Unreal Engine) feature broad accessibility, including free versions for non-commercial use, supporting their adoption in science, engineering, and education (Carbonell-Carrera et al., 2021; Walmsley & Kersten, 2019).

The authors acknowledge that individual game engines differ in their technical architecture, rendering pipelines, and production-oriented capabilities. However, from the perspective of cartographic research, these differences are less important than the practical ability to integrate, process, and communicate geospatial data within interactive 3D environments. In this context, both Unity and

Unreal Engine offer viable development ecosystems, while the choice between them depends primarily on project goals, available expertise, preferred workflows, and the required balance between visual realism, flexibility, and performance. For cartographers, the key issue is therefore not a general ranking of engines, but the extent to which a given environment supports the meaningful implementation of spatial data and cartographic design principles.

The criteria listed in Table 2 indicate that the selection of a game engine for cartographic research should not be reduced to a general comparison of software popularity or rendering quality. From a cartographic perspective, the most important issue is the relationship between technological capacity and research purpose. For example, highly realistic rendering may be crucial in immersive landscape reconstruction, whereas controlled interaction, logging functions, and repeatability may be more important in user studies. Similarly, large-scale 3D geovisualization requires particular attention to geospatial data integration, coordinate handling, level-of-detail management, and real-time performance. Therefore, the choice of a game engine should be treated as a methodological decision that affects not only implementation efficiency, but also the clarity, reliability, and interpretability of the resulting cartographic representation.

In the reviewed literature, Unity appears relatively often in educational applications and user studies, whereas Unreal Engine is more frequently associated with highly realistic virtual environments; however, these tenden-

Table 2. Practical criteria for selecting game engines in cartographic research

Selection criterion	Relevance for cartographic research	Practical implication
Geospatial data integration	Determines how easily spatial datasets can be transferred into the game-engine environment, including terrain models, vector data, 3D city models, point clouds, BIM data, and tiled 3D datasets.	Engines should be assessed in terms of supported import formats, availability of GIS-oriented plugins or SDKs, and compatibility with common geospatial workflows.
Coordinate-reference and scale handling	Cartographic applications often require spatial consistency, real-world scale, georeferencing, and transformation between coordinate systems.	The selected engine should allow reliable management of real-world coordinates, large extents, object positioning, and scale-dependent representation.
Rendering quality and visual realism	Visual realism is important in landscape visualization, heritage reconstruction, immersive environments, and communicative 3D cartography.	Engines with advanced rendering pipelines may be preferable for highly realistic 3D scenes, but visual fidelity should be balanced against cartographic clarity and analytical usefulness.
Real-time performance	Interactive 3D and XR applications require stable performance, especially when working with large terrain models, dense urban scenes, or VR headsets.	The engine should support optimisation techniques such as level of detail, occlusion culling, asset streaming, mesh simplification, and efficient texture management.
XR support	Many cartographic applications involve Virtual Reality, Augmented Reality, Mixed Reality environments.	The selected platform should support target devices, interaction methods, tracking systems, and deployment workflows required for the planned XR application.
Interaction and user-study functionality	Game engines are useful as experimental environments for studying spatial cognition, navigation, perception, and map interaction.	Researchers should consider whether the engine enables logging of user behaviour, control of experimental stimuli, integration of questionnaires or sensors, and repeatable experimental scenarios.
Prototyping speed and development flexibility	Cartographic research often requires iterative testing of visualization methods, symbols, interfaces, and interaction techniques.	Engines with accessible scripting, visual programming, reusable assets, and strong documentation may reduce implementation time and support experimental design.
Availability of plugins and external ecosystems	Many cartographic workflows depend on external tools for GIS data processing, 3D Tiles streaming, BIM import, point-cloud management, or web deployment.	The practical value of an engine depends not only on its native functions but also on the maturity of its plugin ecosystem and compatibility with existing geospatial tools.
Licensing and long-term accessibility	Research projects may require reproducibility, open dissemination, educational use, or long-term maintenance.	Licensing conditions, costs, version stability, export restrictions, and institutional access should be considered before selecting an engine.
Team expertise and learning curve	The effectiveness of a game engine depends strongly on the skills of the research team.	A technically advanced engine may not be optimal if the team lacks experience with its programming language, editor workflow, optimisation methods, or deployment pipeline.
Cartographic design control	Cartographic applications require more than realistic visualization: they need symbolisation, hierarchy, generalisation, uncertainty representation, and legibility.	The engine should allow sufficient control over visual variables, labels, symbols, scale-dependent display, thematic layers, and interaction design.
Reproducibility and methodological transparency	User studies and experimental cartography require repeatable procedures and clearly documented technical settings.	Researchers should document engine version, plugins, data conversion steps, rendering settings, interaction scripts, hardware configuration, and performance constraints.

cies should not be treated as strict functional boundaries.

Due to the breadth of the field, the article focuses on three development directions that appear particularly well represented in the reviewed literature and especially relevant to contemporary cartographic research: 3D visualization, XR, and user studies. This selection does not exhaust all possible application domains of game-engine technologies in cartography.

2.3. Development directions: 3D visualization

One of the most fundamental and frequently discussed applications of game engines in cartography is the creation of virtual environments, particularly in the form of 3D visualizations (Che Mat & Mahayudin, 2018). 3D representations of real-world environments are now widely used on personal computers and mobile devices, forming an essential element of modern spatial information communication. Their growing popularity results from the ability to intuitively represent complex spatial structures, enhance realism and visual engagement, and thanks to game engines allow real-time free exploration (Oleggini et al., 2010).

The entertainment industry, particularly the video game sector, has had a significant impact on the development of 3D visualization technologies, becoming a driving force behind innovations in landscape and virtual-environment rendering (Herwig & Paar, 2002). This rapid development has increased the value of virtual environments as both research and applied tools (Clay et al., 2019). Initially, 3D representations of Earth in games primarily served to produce visually realistic scenes; however, as game engines evolved, they became multi-platform environments capable of creating interactive spatial visualizations (Trenholme & Smith, 2008).

A significant contribution to this research direction is the concept of geogames proposed by Ahlqvist and Schlieder (2018). The authors introduced the term *geocontent*, defined as real spatial information that provides games a unique character. Geogames use *geocontent* and geographic information technologies to represent a specific genre inspired by both GIS and video games. Examples include virtual

landscapes used as educational and research tools in fields such as archaeology or history. These environments enable user interaction with data and knowledge that are otherwise difficult to present in traditional educational contexts, and they support narrative approaches, enhancing engagement and comprehension. At the same time, the authors note that technical issues can lead to user frustration and achieving high-quality immersive environments often entails significant costs.

To address these limitations, Ahlqvist and Schlieder (2018) proposed the use of photogrammetry as a method for creating 3D models, for example from UAV imagery, and subsequently exporting the resulting models into a game engine, specifically Unreal Engine. Advantages include free non-commercial licensing, user-friendly learning processes, and VR (Virtual Reality) support (e.g., Oculus Rift). However, drawbacks include constraints on maximum resolution of heightmaps and textures (8,192 × 8,192), which can affect terrain accuracy over large areas.

The relationship between GIS technologies and video games was analysed by Shepherd and Bleasdale-Shepherd (2008), who observed increasing convergence between tools used in both fields. These include the use of digital elevation models, vector data, and aerial or satellite imagery texturing. Similarities also extend to hierarchical data structures, integration of spatial information, and performance-optimization mechanisms such as Levels of Detail (LoD, Biljecki et al., 2016). The authors highlight that video games possess user-interface advantages and sophisticated dynamic-modelling capabilities that could benefit GIS specialists.

Empirical examples of large-area 3D visualization using game engines include Janovský (2024) and Laksono and Aditya (2019). Janovský examined the potential of Unreal Engine for visualizing a 1,670 km² section of the Vltava River valley (Figure 1), noting issues such as data import complexities, project-dependent constraints, and dependence on proprietary resources and plugins. Laksono and Aditya (2019) used Unity and Mapbox Unity SDK to visualize topographic data from TLS (Terrestrial Laser Scanning), topographic maps, and OpenStreetMap. They observed that varying levels of accuracy across data sources can negatively impact spatial-relationship analysis.



Figure 1. Fragment of 3D visualization created in Unreal Engine 5 (Janovský, 2024)

Game engines also support the development of interactive 3D maps based on publicly available spatial datasets. Komadina and Mihajlović (2022) showed that Unity was crucial for harmonising varying levels of detail in models of urban areas derived from different sources and techniques. Schnürer et al. (2020) employed Vuforia and Unity to create partially animated 3D models enhancing printed school atlases through AR (Augmented Reality). Shin et al. (2015) demonstrated that Unity-based 3D terrain visualization for navigation simulations is more time- and cost-effective than traditional 3D modelling, while maintaining high performance even with many object types.

2.4. Development directions: Extended Reality (XR)

One of the most dynamically expanding directions in the use of game engines within cartography is Extended Reality (XR). Game engines form powerful platforms for presenting 3D terrain data in Virtual Reality (VR) environments, as they provide a comprehensive set of functionalities necessary to achieve immersion and a sense of presence within virtual worlds (Walmsley & Kersten, 2019). These functionalities include real-time graphics rendering, interaction handling, physics simulation, and integration with input-output devices such as VR headsets or motion-tracking controllers.

Integrating VR technologies with 3D virtual environments significantly enhances users' sense of immersion and presence in the represented space (Kersten et al., 2018; Lütjens et al., 2019; Mütterlein, 2018; Noor, 2016; Olberding

& Vetter, 2023). Immersion is understood as the process of becoming absorbed within a virtual environment, driven primarily by visual and auditory sensations (Baños et al., 2004; Waterworth & Riva, 2014). Presence, in turn, is one of the key factors influencing the effectiveness of spatial-information communication. In this context, VR-based cartography enables users to explore environments in ways more closely aligned with real-world experience, which can lead to improved understanding of spatial relations and geographic processes (Hruby et al., 2020; Keil et al., 2021).

Although VR applications are not limited exclusively to game engines, VR technologies remain strongly integrated with them, and most contemporary immersive applications rely on game-engine platforms (Pavelka & Landa, 2024). Game engines enable rapid prototyping, multi-platform deployment, and the integration of advanced interaction mechanisms, making them a natural choice for XR-based cartographic projects. Realistic virtual environments created with game engines offer user-friendly interfaces and the ability to simulate real-world phenomena such as motion, lighting, and atmospheric conditions (Trenholme & Smith, 2008).

Advances in hardware performance, increasing graphics-processing capabilities, and declining costs of VR technologies, 3D modelling tools, and game engines have made the creation of highly immersive visualizations more accessible. Notable examples include reconstructions of historical cities and landscapes that serve as advanced forms of cartographic storytelling. Walmsley and Kersten (2019)

demonstrated the use of Unreal Engine 4 to develop a virtual model of the historic town of Stade (Germany) as it appeared in 1620, later implemented within a VR environment. The authors highlighted the potential value of such presentations for museums and cultural institutions by enabling immersive exploration of past spatial structures.

Beyond visualization, virtual environments serve as interactive communication systems for presenting spatial information (Indraprastha & Shinozaki, 2009). Their usefulness in cartography depends strongly on the realism of physical behaviour and consistency of simulated processes, as only physically coherent environments can effectively support spatial analysis and data exploration (Bermudez & King, 2000).

Game engines can also support the development and refinement of cartographic presentation methods tailored to XR environments, enabling higher-level spatial cognition, particularly spatial perception. Olberding and Vetter (2023) note that video games have long incorporated cartographic symbols in various forms, which grants cartographers an opportunity to create interactive 3D maps compatible with VR. Owing to higher levels of immersion and presence, additional graphic effects beyond classic visual variables proposed by Bertin (1983) such as non-photorealistic rendering (NPR) techniques or animations may enhance both quantitative and qualitative representations of spatial data.

The integration of geospatial data with VR technologies has also been examined by Keil et al. (2021), who demonstrated how public spatial datasets (Open.NRW and OpenStreet-Map) can be used to create immersive virtual environments in Unity. The authors found that immersive spatial representations significantly strengthen geographic-information communication but simultaneously identified critical technical limitations. Many common GIS file formats are not natively supported by game engines, requiring data conversion and simplification workflows. Their proposed solutions illustrate how public and volunteered geographic information (VGI) can be transformed into formats compatible with modern game engines – an important step toward broader XR adoption in cartography. Recent years have also seen increasing integration between GIS software

and game engines, exemplified by the glTF/GLB format, which enables efficient transfer of data from GIS applications into game-engine environments.

When developing XR applications using game engines, performance constraints of VR hardware must also be considered. Kersten et al. (2021) emphasize that although 3D models implemented via game engines can play an important role in heritage-conservation visualization, VR developers must carefully balance data volume with hardware limitations. According to the authors, real-time VR visualization requires maintaining a frame rate of approximately 90 frames per second.

2.5. Development directions: user studies

Game engines play an increasingly significant role in user-based research, including studies conducted within cartography and geo-visualization. Historically, the video-game industry served as the primary and occasionally the only market for advanced graphic techniques, demonstrating the extent to which high levels of visual realism could be achieved even on relatively constrained hardware by skilfully combining texture-mapping methods and artistic design strategies. Rising production costs associated with highly realistic simulations contributed to the emergence of game engines as modular structures of simulation code, originally built for individual games but sufficiently generalised to be applied across families of similar applications. This separation of “function” from “content”, characteristic of game-engine architecture, facilitated the reuse of these technologies in scientific research, including investigations of spatial cognition, particularly orientation and perception (Lewis & Jacobson, 2002).

One of the key advantages of game engines in user studies is the high level of control they provide over visual and auditory stimuli presented within virtual environments. Compared with real-world studies, environments created with game engines allow researchers to eliminate extraneous stimuli and precisely manipulate experimental conditions such as lighting, perspective, object movement, and the spatial configuration of elements (Minderer & Harvey, 2016). This enables the design of repeatable

and highly controlled experiments, which is of particular importance in research on cartographic perception, spatial orientation, and user interaction with maps and 3D environments.

The use of game engines is also well justified in the context of cartographic and geographic education. Carbonell-Carrera et al. (2020) demonstrated that practical exercises based on the Unity3D engine can lead to significant improvements in spatial-orientation skills and spatial thinking. Within a cartography course, participants were tasked with creating 3D visualizations of five basic landforms (mountain, depression, ridge, valley, and col) in the study area of 1×1 km. After building the models, students completed a virtual field trip from a first-person perspective view (FPV), during which they identified spatial relationships between landforms, determining their locations using cues such as constant sun position and geographic directions. Results from the Spatial Thinking Ability Test (STAT, Caduff & Timpf, 2008) and the Perspective Taking–Spatial Orientation Test (PTSOT, Hegarty & Waller, 2004), performed before and after the course, confirmed statistically significant improvement, validating the authors' hypothesis regarding the positive influence of Unity on the development of spatial skills.

In another study, Carbonell-Carrera et al. (2021) focused on analysing user experience and motivation in a low-immersion VR environment displayed on desktop and laptop screens. Using a 3D geovisualization of a landscape created in Unity (Figure 2), the authors designed tasks involving exploration and navigation within the virtual environment. Findings

revealed high perceived quality of the 3D environment and positive user experiences. Furthermore, the educational approach based on a game engine was assessed as motivating, suggesting that these technologies can effectively support learning processes in cartography.

Schnürer et al. (2020) conducted a study focused on assessing technological feasibility in extending printed school atlases with digital content displayed in AR. Using the Vuforia and Unity engines, the authors created partially animated 3D visualizations. A usability experiment demonstrated that this approach, constructing 3D models of geographic features and subsequently implementing them in AR applications, resulted in comparable task performance, engagement, and balance in solving geographic problems relative to printed maps.

In summary, the literature indicates that game engines constitute a valuable tool in user studies, facilitating controlled experiments on perception, spatial orientation, and interaction with geovisualizations. Their use in educational and experimental contexts opens new perspectives for cartography, particularly with regard to the development of interactive, 3D, and immersive methods of spatial-information communication.

Other relevant directions, not discussed here in detail, include digital twins and smart-city applications, real-time spatial-data integration, simulation-oriented environments, procedural modelling, indoor cartography and BIM-based visualization, accessibility-oriented design, and serious games. These areas remain important for future, more specialised reviews.



Figure 2. Example of 3D geovisualization of a landscape created in Unity (Carbonell-Carrera et al., 2021)

3. Discussion

The conducted literature review confirms that game engines are becoming an increasingly important tool in the development of contemporary cartography, particularly in the context of 3D visualizations and immersive environments. As noted by Hruby et al. (2020), the implementation of VR technologies in 3D representations significantly enhances immersion, which directly contributes to a stronger sense of presence within virtual space (Keil et al., 2021). Consequently, game-engine-based cartography provides users with an experience of spatial exploration that more closely resembles real-world perception.

The relationship between games and spatial representation is not new. Since early civilizations, games have relied on landscape elements, symbols, and map like figures, as seen in traditional games such as Go or chess, as well as in sports games where the landscape serves as the arena of action (Herwig & Paar, 2002). Modern game engines may therefore be viewed as a continuation of this tradition, enhanced by advanced digital technologies that enable dynamic, interactive, and realistic representations of geographic space. A significant manifestation of this relationship, as highlighted by Ahlqvist and Schlieder (2018), is the concept of geogames. Their use of real spatial information and geographic information technologies underpins the uniqueness of such applications. This relationship may be mutually beneficial: advancements in video-game technology can positively influence the technical quality of GIS products, whereas developments in theories of spatial-information communication can support spatial design practices within the video-game industry, as seen in functionalities such as mini-maps.

However, the literature also identifies substantial technical challenges associated with integrating geospatial data into game-engine environments. Working with real-world data remains complex because most game engines provide limited or non-native support for standard GIS formats (Laksono & Aditya, 2019; Petridis et al., 2012). Nevertheless, support for numerous 3D data formats enables the integration of diverse topographic datasets, offering potential for constructing interactive environments based on multi-source spatial data

(Laksono & Aditya, 2019). Such potential may be applied to analytical reasoning and spatial-information communication in fields such as crisis management (Tully et al., 2015) or interactive geodesign (Rafiee et al., 2018; Trubka et al., 2016). Another concern is the difference in performance between VR hardware and desktop computers: VR devices typically offer considerably lower computational capacity. As a result, cartographers must carefully balance the level of complexity in 3D visualizations with the need to maintain real-time performance in VR environments (Kersten et al., 2021).

From a cognitive perspective, numerous studies confirm the advantages of 3D visualizations over traditional 2D maps. Mat et al. (2014) demonstrated that 3D terrain is perceived more intuitively than 2D maps, which require specialised interpretative skills. Furthermore, tasks carried out in 3D environments created with game engines can effectively support the development of spatial-orientation skills and spatial thinking, as confirmed by educational research conducted by Carbonell-Carrera et al. (2020, 2021).

Game engines introduce into cartography a set of functionalities unavailable in classical 2D and pseudo-3D methods, such as advanced interactivity, animation, simulation of dynamic processes, and freedom of movement and exploration within virtual environments (Ferworn et al., 2013; Shin et al., 2015; Vetter, 2019). Importantly, they enable relatively fast and low-cost creation of 3D representations of real areas, which is advantageous for simulation-based applications such as the analysis of navigation strategies (Shin et al., 2015). At the same time, the tradition of striving for visual realism, which often exceeds the constraints of the physical world, continues to distinguish game simulations from classical scientific models (Lewis & Jacobson, 2002).

It should be noted, however, that increasing realism and immersion requires trade-offs. Keil et al. (2021) found that insufficient terrain detail reduces the immersiveness of visualizations, as overly smoothed surfaces are perceived as unnatural, especially in areas with varied topography. Likewise, Ahlqvist and Schlieder (2018) observed that technical difficulties may diminish users' sense of presence in virtual environments. Walmsley and Kersten

(2019) further emphasize that pursuing increasingly detailed representations significantly extends the time required for modelling and texturing and may be limited by technological constraints that cannot be overcome at a given moment. As a result, the design of cartographic environments based on game engines requires conscious balancing among visual realism, development costs, and the clarity and functionality of spatial-information communication.

Based on the reviewed literature, game engines can be conceptualised as four complementary instruments in cartographic research: visualization platforms for interactive 3D representations, XR delivery environments, experimental laboratories for controlled user studies, and narrative or simulation media combining spatial data with interaction and storytelling. These roles define the main opportunities of game-engine-based cartography, including immersive communication, educational applications, controlled perception experiments, and interactive spatial narratives. At the same time, they expose key challenges related to geospatial data integration, coordinate-reference handling, level-of-detail management, real-time performance, methodological standardisation, and the preservation of cartographic clarity and credibility.

In summary, game engines offer cartography new possibilities in immersive visualization, interaction, and user-based research. However, their effective use requires further efforts in geospatial-data integration, standardisation of workflows, and critical reflection on the role of realism within cartographic communication.

4. Limitations

This overview has several limitations. First, the search strategy was intentionally focused on publications explicitly linking game engines with cartography and on selected engine names, which increased thematic precision but may have excluded relevant studies framed through broader descriptors such as map, visualization, spatial data, virtual reality, simulation, or 3D mapping. Second, the paper discusses in detail only selected development directions, namely 3D visualization, XR, and user studies, while other relevant areas such as digital twins, smart cities, real-time data integration, procedural modelling, indoor cartography, BIM,

accessibility, and serious games were not analysed in depth. Third, some older publications were retained primarily where they provide important definitional, historical, or conceptual background. Consequently, the article should be understood as a focused review of selected directions rather than an exhaustive or fully synthetic account of the field.

5. Conclusion

The dynamic development of information technologies has for decades been one of the primary forces shaping the evolution of cartography. As a focused introductory overview, this study seeks to synthesise selected directions in the use of game engines in cartography rather than to provide an exhaustive or fully systematic review of the literature. The history of the discipline demonstrates that cartographers have repeatedly leveraged technological progress to transform the ways in which spatial information is produced and communicated from the widespread adoption of affordable computers and displays, which enabled dynamic and interactive digital maps (Brainerd & Pang, 2001), to the implementation of GPS and the substantial increase in its accuracy following the removal of selective availability in 2000, which catalysed the development of modern navigation systems and location-based mapping (Zumberge & Gendt, 2001).

Today, game engines play an analogous role, with their accessibility and performance increasing alongside advancements in computer hardware. As noted by Janovský (2024), even standard desktop computers now offer performance levels sufficient to support game engines and technologies such as virtual reality, which facilitates the creation of smaller, independent projects, both within and beyond entertainment contexts. This trend is reflected in cartography, where game engines are emerging as alternative platforms for visualization, simulation, and communication of geospatial data.

The literature review conducted for this article indicates that the greatest potential of game engines lies in their capacity to support 3D and immersive spatial representations, including XR environments. These environments enable more intuitive perception of spatial relationships, enhance users' sense of presence and immersion, and strengthen the communication

of geographic information. User studies further confirm that interactive 3D environments created with game engines can support spatial cognitive processes, including spatial thinking and spatial orientation, while also increasing motivation in educational contexts. However, despite these advantages, researchers often continue to favour low-immersion environments displayed on desktop or laptop screens when conducting cartographic studies using XR technologies (Duan et al., 2015; Huang & Hu, 2025; Kuil et al., 2018; Swetnam & Korenko, 2019).

Narrative cartography also constitutes an important field of game-engine applications. As highlighted by Thöny et al. (2018), map-makers can now deliver 3D geospatial visualizations to broad audiences in more engaging and intuitive ways, using interactive narrative forms. Game engines support the placement of stories within real locations ("placing stories in real places"; Caquard & Cartwright, 2014) and facilitate the mapping of "real-life" stories, integrating spatial data with social, cultural, and temporal contexts. Existing geospatial and game-engine ecosystems already reduce part of the integration burden through SDKs, plugins, and data-streaming workflows. Therefore, future work should not be framed primarily as the creation of a generic integration tool from scratch. A more relevant direction for cartographic research is the development of car-

tography-oriented workflows and methodological guidelines that build on existing ecosystems while addressing specifically cartographic requirements: symbolisation, multiscale representation, level-of-detail management, coordinate-reference handling, uncertainty communication, metadata, and the preservation of visual hierarchy and analytical credibility in interactive 3D and XR environments.

In conclusion, game engines may be viewed as the next stage in the technological evolution of cartography, analogous to earlier breakthroughs associated with the digitisation of maps and the rise of navigation systems. Their adoption opens new possibilities for 3D visualization, immersion, narrative cartography, and user-based research, but it also requires deeper methodological integration between cartographic principles and technologies originating from the game-development domain. The future development of game-engine-based cartography will depend on the discipline's ability not only to combine technological potential with the principles of clarity, credibility, and functionality that underpin effective cartographic communication, but also to better integrate existing geospatial and game-engine workflows in ways that respond to specifically cartographic needs.

References

- Ahlqvist, O., & Schlieder, C. (2018). *Geogames and geoplay*. Springer International Publishing. <https://doi.org/10.1007/978-3-319-22774-0>
- Ash, J. (2016). Video games. In P. C. Adams, J. Craine, & J. Dittmer (Eds.), *The Routledge research companion to media geography* (pp. 119–135). Routledge.
- Baños, R. M., Botella, C., Alcañiz, M., Liaño, V., Guerrero, B., & Rey, B. (2004). Immersion and emotion: Their impact on the sense of presence. *Cyber-Psychology & Behavior*, 7(6), 734–741. <https://doi.org/10.1089/cpb.2004.7.734>
- Bermudez, J., & King, K. (2000). Media interaction and design process: Establishing a knowledge base. *Automation in Construction*, 9(1), 37–56. [https://doi.org/10.1016/S0926-5805\(99\)00051-5](https://doi.org/10.1016/S0926-5805(99)00051-5)
- Bertin, J. (1983). *Semiology of graphics: Diagrams, networks, maps* (W. J. Berg, Trans.). University of Wisconsin Press.
- Biljecki, F., Ledoux, H., & Stoter, J. (2016). An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*, 59, 25–37. <https://doi.org/10.1016/j.compenvurbsys.2016.04.005>
- Brainerd, J., & Pang, A. (2001). Interactive map projections and distortion. *Computers & Geosciences*, 27(3), 299–314. [https://doi.org/10.1016/S0098-3004\(00\)00108-4](https://doi.org/10.1016/S0098-3004(00)00108-4)
- Buchroithner, M. F., & Knust, C. (2013). The third dimension in cartography: Recent and future developments. *KN – Journal of Cartography and Geographic Information*, 63(3), 127–132. <https://doi.org/10.1007/BF03546123>
- Caduff, D., & Timpf, S. (2008). On the assessment of landmark salience for human navigation. *Cognitive Processing*, 9, 249–267. <https://doi.org/10.1007/s10339-007-0199-2>
- Carbonell-Carrera, C., Gunalp, P., Saorin, J. L., & Hess-Medler, S. (2020). Think spatially with game engine. *ISPRS International Journal of Geo-Information*,

- 9(3), 159. <https://doi.org/10.3390/ijgi9030159>
- Carbonell-Carrera, C., Saorin, J. L., & Melián Díaz, D. (2021). User VR experience and motivation study in an immersive 3D geovisualization environment using a game engine for landscape design teaching. *Land*, 10(5), Article 492. <https://doi.org/10.3390/land10050492>
- Caquard, S., & Cartwright, W. (2014). Narrative cartography: From mapping stories to the narrative of maps and mapping. *The Cartographic Journal*, 51(2), 101–106. <https://doi.org/10.1179/0008704114Z.000000000130>
- Chądzyńska, D., & Gotlib, D. (2015). Maps in video games—Range of applications. *Polish Cartographical Review*, 47. <https://doi.org/10.1515/pcr-2015-0011>
- Che Mat, R., & Mahayudin, M. H. (2018). Using game engine for online 3D terrain visualization with oil palm tree data. *Journal of Telecommunication, Electronic and Computer Engineering*, 10(1–10), 93–97. <https://jtec.utem.edu.my/jtec/article/view/3797>
- Clay, V., König, P., & König, S. U. (2019). Eye tracking in virtual reality. *Journal of Eye Movement Research*, 12(1). <https://doi.org/10.16910/jemr.12.1.3>
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage.
- Duan, Q., Gong, J., Li, W., Shen, S., & Li, R. (2015). Improved Cubemap model for 3D navigation in geo-virtual reality. *International Journal of Digital Earth*, 8(11), 877–900. <https://doi.org/10.1080/17538947.2014.947339>
- Ferworn, A., Herman, S., Tran, J., Ufkes, A., & McDonald, R. (2013). Disaster scene reconstruction: Modeling and simulating urban building collapse rubble within a game engine. In *Proceedings of the 2013 Summer Computer Simulation Conference (SCSC '13)*. Society for Modeling & Simulation International.
- Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, 32(2), 175–191. <https://doi.org/10.1016/j.intell.2003.12.001>
- Herwig, A., & Paar, P. (2002). Game engines: Tools for landscape visualization and planning? In E. Buhmann, U. Nothelfer, & M. Pietsch (Eds.), *Trends in GIS and virtualization in environmental planning and design* (pp. 161–172). Wichmann. https://www.researchgate.net/publication/240013413_Game_Engines_Tools_for_Landscape_Visualization_and_Planning
- Hruby, F., Sánchez, L. F. Á., Ressler, R., & Escobar-Briones, E. G. (2020). An empirical study on spatial presence in immersive geo-environments. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88(2), 155–163. <https://doi.org/10.1007/s41064-020-00107-y>
- Horbiński, T., & Zagata, K. (2022). Cartography in video games: Literature review and examples of specific solutions. *KN – Journal of Cartography and Geographic Information*, 72, 117–128. <https://doi.org/10.1007/s42489-022-00104-8>
- Huang, J., & Hu, Y. (2025). A systematic review of immersive virtual reality applications in geography higher education. *Journal of Geography in Higher Education*, 49, 295–312. <https://doi.org/10.1080/03098265.2025.2449883>
- Indraprastha, A., & Shinozaki, M. (2009). The investigation on using Unity 3D game engine in urban design study. *ITB Journal of Information and Communication Technology*, 3(1), 1–18. <https://doi.org/10.5614/itbj.ict.2009.3.1.1>
- Janovský, M. (2024). Pre-dam Vltava River Valley—A case study of 3D visualization of large-scale GIS datasets in Unreal Engine. *ISPRS International Journal of Geo-Information*, 13(10), Article 344. <https://doi.org/10.3390/ijgi13100344>
- Keil, J., Edler, D., Schmitt, T., & Dickmann, F. (2021). Creating immersive virtual environments based on open geospatial data and game engines. *KN – Journal of Cartography and Geographic Information*, 71, 53–65. <https://doi.org/10.1007/s42489-020-00069-6>
- Kersten, T. P., Deggim, S., Tschirschwitz, F., Lindstaedt, M., & Hinrichsen, N. (2018). Segeberg 1600—Eine Stadtrekonstruktion in virtual reality. *KN – Journal of Cartography and Geographic Information*, 68(4), 183–191. <https://doi.org/10.1007/BF03545360>
- Kersten, T. P., Drenkhan, D., & Deggim, S. (2021). Virtual reality application of the Fortress Al Zubarah in Qatar including performance analysis of real-time visualisation. *KN – Journal of Cartography and Geographic Information*, 71(4), 241–251. <https://doi.org/10.1007/s42489-021-00092-1>
- Komadina, A., & Mihajlović, Ž. (2022). Automated 3D urban landscapes visualization using open data sources on the example of the city of Zagreb. *KN – Journal of Cartography and Geographic Information*, 72, 139–152. <https://doi.org/10.1007/s42489-022-00102-w>
- Kuil, M. N. V. D., Visser-Meily, J. M., Evers, A. W., & Ham, I. J. V. D. (2018). A usability study of a serious game in cognitive rehabilitation: a compensatory navigation training in acquired brain injury patients. *Frontiers in Psychology*, 9, Article 846. <https://doi.org/10.3389/fpsyg.2018.00846>
- Laksono, D., & Aditya, T. (2019). Utilizing a game engine for interactive 3D topographic data visualization. *ISPRS International Journal of Geo-Information*, 8(8), 361. <https://doi.org/10.3390/ijgi8080361>
- Lewis, M., & Jacobson, J. (2002). Introduction. *Communications of the ACM*, 45(1), 27–31. <https://doi.org/10.1145/502269.502288>
- Lütjens, M., Kersten, T. P., Dorschel, B., & Tschirschwitz, F. (2019). Virtual reality in cartography:

- Immersive 3D visualization of the Arctic Clyde Inlet (Canada) using digital elevation models and bathymetric data. *Multimodal Technologies and Interaction*, 3(1), 9. <https://doi.org/10.3390/mti3010009>
- Mat, R. C., Shariff, A. R. M., Zulkifli, A. N., Rahim, M. S. M., & Mahayudin, M. H. (2014). Using game engine for 3D terrain visualisation of GIS data: A review. *IOP Conference Series: Earth and Environmental Science*, 20, Article 012037. <https://doi.org/10.1088/1755-1315/20/1/012037>
- Minderer, M., & Harvey, C. D. (2016). Virtual reality explored. *Nature*, 533(7603), 324–325. <https://doi.org/10.1038/nature17899>
- Mütterlein, J. (2018). The three pillars of virtual reality? Investigating the roles of immersion, presence, and interactivity. In T. Bui (Ed.), *Proceedings of the 51st Hawaii International Conference on System Sciences*. <https://doi.org/10.24251/HICSS.2018.174>
- Noor, A. K. (2016). The HoloLens revolution. *Mechanical Engineering*, 138(10), 30–35. <https://doi.org/10.1115/1.2016-Oct-1>
- Olberding, H., & Vetter, M. (2023). Dynamic 3D-cartographic symbols for VR geovisualizations. *KN – Journal of Cartography and Geographic Information*, 73, 265–275. <https://doi.org/10.1007/s42489-023-00153-7>
- Oleggini, L., Nova, S., Orvieto, I., & Hurni, L. (2010). Smooth transition between 2D and 3D digital atlas visualization using computer game technology. In M. Madden & E. L. Usery (Eds.), *Geospatial data and geovisualization: Environment, security, and society* (ISPRS Archives, Vol. XXXVIII, Part 4). ISPRS. <https://doi.org/10.3929/ethz-b-000026718>
- Pavelka, K., Jr., & Landa, M. (2024). Using virtual and augmented reality with GIS data. *ISPRS International Journal of Geo-Information*, 13(7), Article 241. <https://doi.org/10.3390/ijgi13070241>
- Petridis, P., Dunwell, I., Panzoli, D., Arnab, S., Protopsaltis, A., Hendrix, M., & de Freitas, S. (2012). Game engines selection framework for high-fidelity serious applications. *International Journal of Interactive Worlds*, 2012, Article 418638. <https://doi.org/10.5171/2012.418638>
- Rafiee, A., Van der Male, P., Dias, E., & Scholten, H. (2018). Interactive 3D geodesign tool for multidisciplinary wind turbine planning. *Journal of Environmental Management*, 205, 107–124. <https://doi.org/10.1016/j.jenvman.2017.09.042>
- Reitman, J. G., Andersin-Coto, M. J., Wu, M., & Lee, J. S. (2020). Esports research: A literature review. *Games and Culture*, 15(1), 32–50. <https://doi.org/10.1177/1555412019840892>
- Schnürer, R., Dind, C., Schalcher, S., Tschudi, P., & Hurni, L. (2020). Augmenting printed school atlases with thematic 3D maps. *Multimodal Technologies and Interaction*, 4(2), 23. <https://doi.org/10.3390/mti4020023>
- Shepherd, I. D., & Bleasdale-Shepherd, I. D. (2008). Towards effective interaction in 3D data visualizations: What can we learn from videogames technology? In *International Conference on Virtual Geographic Worlds* (pp. 7–8). https://www.researchgate.net/publication/251433901_Towards_Effective_Interaction_in_3D_Data_Visualizations_What_can_we_learn_from_videogames_technology
- Shin, I. S., Beirami, M., Cho, S. J., & Yu, Y. H. (2015). Development of 3D terrain visualization for navigation simulation using a Unity 3D development tool. *Journal of the Korean Society of Marine Engineering*, 39(5), 570–576. <https://doi.org/10.5916/jkosme.2015.39.5.570>
- Swetnam, R. D., & Korenko, J. (2019). Can computer game landscapes target new audiences for landscape quality assessment? *Applied Geography*, 113, Article 102102. <https://doi.org/10.1016/j.apgeog.2019.102102>
- Thorn, A. (2011). *Game engine design and implementation*. Jones & Bartlett Publishers.
- Thöny, M., Schnürer, R., Sieber, R., Hurni, L., & Pajarola, R. (2018). Storytelling in interactive 3D geographic visualization systems. *ISPRS International Journal of Geo-Information*, 7(3), Article 123. <https://doi.org/10.3390/ijgi7030123>
- Toups Dugas, P. O., Lalone, N., Alharthi, S. A., Sharma, H. N., & Webb, A. M. (2019). Making maps available for play: Analyzing the design of game cartography interfaces. *ACM Transactions on Computer-Human Interaction*, 26(5), 1–43. <https://doi.org/10.1145/3336144>
- Trenholme, D., & Smith, S. P. (2008). Computer game engines for developing first-person virtual environments. *Virtual Reality*, 12, 181–187. <https://doi.org/10.1007/s10055-008-0092-z>
- Trubka, R., Glackin, S., Lade, O., & Pettit, C. (2016). A web-based 3D visualisation and assessment system for urban precinct scenario modelling. *ISPRS Journal of Photogrammetry and Remote Sensing*, 117, 175–186. <https://doi.org/10.1016/j.isprsjprs.2015.12.003>
- Tully, D., El Rhalibi, A., Carter, C., Sudirman, S., & Rhalibi, A. (2015). Hybrid 3D rendering of large map data for crisis management. *ISPRS International Journal of Geo-Information*, 4, 1033–1054. <https://doi.org/10.3390/ijgi4031033>
- Vetter, M. (2019). 3D-Visualisierung von Landschaft—Ein Ausblick auf zukünftige Entwicklungen. In O. Kühne, F. Weber, K. Berr, & C. Jenal (Eds.), *Landschaft* (pp. 559–573). Springer Fachmedien Wiesbaden.
- Walmsley, A., & Kersten, T. P. (2019). Low-cost development of an interactive, immersive virtual reality experience of the historic city model Stade 1620. *The International Archives of the Photo-*

- grammetry, *Remote Sensing and Spatial Information Sciences*, XLII-2/W17, 405–411. <https://doi.org/10.5194/isprs-archives-XLII-2-W17-405-2019>
- Waterworth, J., & Riva, G. (2014). *Feeling present in the physical world and in computer-mediated environments*. Palgrave Macmillan. <https://doi.org/10.1057/9781137431677>
- Zumberge, J. F., & Gendt, G. (2001). The demise of selective availability and implications for the International GPS Service. *Physics and Chemistry of the Earth, Part A*, 26(6–8), 637–644. [https://doi.org/10.1016/S1464-1895\(01\)00113-2](https://doi.org/10.1016/S1464-1895(01)00113-2)