Serious Digital Geogames and Their Implementations Enhanced by Artificial Intelligence, Mixed- and Augmented-Reality

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Abstract. This paper concentrates on technological advancements of serious digital geogames. Geogames are games that are placed in a spatial context and often aim at realistic visualization of real-world situations. Novel technologies such as mixed-reality and augmented-reality represent opportunities for more advanced geogame design. Artificial intelligence (AI) tools can expand geogame concepts implemented with technologies that aim to immerse users into the game world. This paper overviews virtualized geometry, procedural content generation, and biometric feedback as novel AI expansion. Virtualized geometry can contribute to a more realistic visualization of geogame environments. Procedural content generation may automatically generate new content, game levels, characters, and unpredictable events to increase conflict in geogames that can make them more appealing to the players. Biometric feedback may be used to model the game based on the state and condition of the player. This paper summarizes the potential for expansion of serious digital geogames and discusses the opportunities AI offers as a novel contribution to this field.

Keywords: serious geogames · mixed- and augmented-reality · artificial intelligence · procedural content generation

1 Introduction

Serious games are games that are developed for more than just fun (Abt 1970, Ritter-feld, Cody and Vorderer 2009). They concentrate on solving real-world problems, dealing with real-world situations, and may provide learning and training opportunities. Geogames are a novel research area with a focus on games that include spatial component; geo originating from an ancient Greek word gaia meaning "and" or "earth". Research on geogames goes back to the first papers published in 2005 and 2006 by Schlieder and his group at the University of Barmbek in Germany (Schlieder et al. 2005, Schlieder et al. 2006). At that time, a geogame was defined as a location-based game that makes use of positioning technology (e.g. GPS) and integrates the player's position into the logic of a game. A few years later, Ahlqvist and his collaborators (Ahlqvist et al. 2012) expanded this definition of geogames to mean "all games that use real-world spatial information and are mediated by geographic information technology (GIS)". A fundamental idea

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underlying the approach taken by geogames is their focus on creating an online world that mirrors authentic real-world geography. This world may be realized by a full range of GIS supported mapping and processing services. Since these beginnings of geogames, the idea has been expanded into many fields of study, from implementations and development in urban planning (Poplin 2012, 2014), geography (de Sena et al. 2021) and cultural heritage (de Andrade et al. 2020), to mention just a few. Geogames can also be non-digital board games. The most recent edited book by Randal and Lasansky (2023) introduces a collection of articles and essays about place and space as the central element of the selected games and their specific take on the representation of place, architecture, urbanism, planning, history, heritage conservation and landscape history.

This article investigates the future of geogames, research of this specific area and the impact artificial intelligence (AI) developments may have on implementation of digital serious geogames. It attempts to answer the following questions: "What elements of AI can be the most beneficial for further development of serious digital geogames? How can mixed- and augmented-reality contribute to the enhancement of these games?" The term "game AI" is used to refer to a broad set of algorithms that also include techniques from control theory, robotics, computer graphics, computer science and agent-based modeling (Yannakakis et al. 2014, Togelius 2018). This article summarizes developments and advances that may expand and inspire further development of geogames and geoinformation science in general. Specifically virtualized geometry, procedural content generation, modeling player's behavior based on biometric feedback, and implementations of mixed- and augmented-reality are selected as potentially the most influential developments for the field of geogames. The article concludes with a discussion and further research directions.

2 Serious Digital Geogames and Their Implementations

2.1 Research on Serious Digital Geogames

Research on digital geogames is novel and its beginnings go back to the initial publications by Schlieder and his colleagues (Schlieder et al. 2005; Schlieder et al. 2006). These publications introduced the term geogame which was at the time defined as a location-based game (LBG) that is played outside in the environment with the help of mobile devices. Their research is followed by publications in urban planning and community engagement emerging, first at the Hafen City University Hamburg in Germany and later at Iowa State University (Krek 2008, Ben Hiba et al. 2009), University of Hasselt in Belgium (Devisch 2008), and Emerson College in the US (Gordon and Manosevitch 2010). At that time, these three hubs focused on the implementation and use of games in urban planning and community engagement as part of the planning for the future of neighborhoods in cities. The next breakthrough of the research on geogames can be marked with the publication by Ahlqvist and his colleagues (Ahlqvist et al. 2012). Their research is influential because of their expansion of the definition of geo- games and their test implementation and integration with a geographic information system (GIS) technology. They defined geogames to be "all games that use real-world spatial information and are mediated by geographic information technology (GIS)".

Researchers at the Federal University of Minas Gerais in Belo Horizonte, Brazil, joined the research on geogames, contributing with two PhD studies: the first one by de Andrade (2019) with the focus on cultural values in the village called Tirol in Brazil and the second one by de Sena (de Sena et al. 2021) who developed the game GeoMinasCraft which enabled players to explore mining areas of Ouro Preto in Brazil and learn about biodiversity. The next key milestone was the first edited book titled *Geo-games and Geoplay: Game-based Approaches to the Analysis of Geo-Information* published in 2018 and edited by Ahlqvist and Schlieder (2018). This book shows study cases of developed and implemented games as well as projects researchers were working on at that time. In 2020, Poplin and Schwartz (2020) edited the first journal published online titled *Gaming and Geoinformation* which features nine articles with a focus on games and geospatial information. Research in this field continues and offers value in a variety of application areas.

2.2 Application Areas of Serious Digital Geogames

Serious digital geogames application areas may include urban planning and community engagement, cultural heritage, geography, climate change, geodesign, architecture, disaster management, and well-being, to mention just a few.

Urban Planning and Community Engagement. Most of the literature on serious digital geogames concentrates on envisioning, designing, implementing and testing games that can be used in urban planning (Devisch 2008, Krek 2008, Poplin et al. 2017). These geogames can be implemented in various stages of the planning process, engaging residents to discuss visions and further developments of the cities and their neighborhoods (Gordon and Manosevitch 2010, Gordon et al. 2011, Gordon and Schirra 2012, Poplin 2011, 2012, 2014), contemplate proposed changes (Devisch at al. 2016), used as pop-up moving planning or playful gamified city engagement festivals (Poplin et al. 2023b), or implemented in a digital way as part of an online cloud-based participatory platform (Poplin 2022). Some of these games concentrate on a specific group, often on kids and ways to engage them to envision the future of places in which they live (Poplin et al. 2020b, de Andrade and de Sena 2020a, Poplin et al. 2023a).

Cultural Heritage. Preserving and understanding cultural heritage is another application area for geogames. Researchers such as de Andrade and Foroughi together with their collaborators explore how can geogames be utilized to study cultural values, explore them, and raise the awareness of their preservation (de Andrade et al. 2016, Foroughi et al. 2023).

Geography. Geo-diversity and learning about it in a particular geographic area is the goal of the geogame GeoMinasCraft developed by de Sena et al. (2021). Enabling players to explore characteristics of landscapes, their specifics, and qualities by enabling game non-playable characters (NPCs) to have an active role in the game while the player can communicate with them, ask questions, move through game landscapes and learn about the geographic areas. Such games may provide players with a new understanding of these landscapes and empower them with a deeper understanding of their role in creating livable environments for the residents.

Climate change and its consequences can be visualized in the form of scenarios or what-if futures enabled by geogame environments. Geogames offer creative possibilities to play with scenarios and visions for the future under specific conditions, explore their impacts and effects, and study possible consequences of climate change on people and environment (de Andrade 2019, 2020).

Geodesign is the process of designing for the future with the help of geospatial data (Steinitz 2012). Geogames can enhance this process with their playful ability to visualize the content discussed and engage residents in a playful way (de Andrade 2019, de Sena et al. 2021).

Architecture. Geogames can be implemented in architecture to display and study conditions of buildings, energy consumption, or even decision-making of the inhabitants and the choices they make regarding the upkeep of their buildings and homes or their efforts to reduce energy consumption (Poplin 2020, de Andrade et al. 2024).

Disaster Management and Well-Being. Geogames may serve as simulation tools presenting scenarios of evacuation, possible ways of reacting in emergency situations, or as a teaching tool for the rescue teams, medical personal or residents in a drill setting (Tomaszewski et al. 2018, 2020, Schwartz and Tomaszewski 2021).

3 Mixed-Reality Serious Digital Geogames

3.1 Mixed-Reality (MR)

Researchers of modern serious digital geogames may want to explore the use of mixed-reality. Mixed-reality (MR) encompasses all possible variations of the mixture between reality and virtuality in a composition of real and virtual objects and characters. It consists of both augmented-reality where the virtual augments the real, and augmented-virtuality, where the real augments the virtual. The physical and the digital worlds are blended and mixed. Digital imaginary elements and objects can interact with physical elements. The term mixed-reality (MR) was first introduced in a 1994 paper by Paul Milgram and Fumio Kishino titled *A Taxonomy of Mixed Reality Visual Displays* and is visualized in Fig. 1.

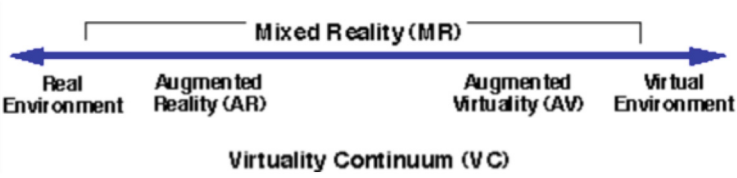


Fig. 1. Defining mixed reality by Milgram and Kishino (1994)

MR experience can be enabled by wearable mixed-reality devices such as MR glasses, cameras and sensors that place 3D digital objects in the real world. These digital objects appear as projected holographic images. The user can then interact with these

objects, move, and alter them. This effect is accomplished with the help of cameras, sensors, and AI technologies. It may also incorporate geographical mapping, hand tracking or vocal input. Implementation of MR systems may involve signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, information visualization, or the design of displays.

3.2 Developing Mixed-Reality Serious Geogames

Games and game environments have greatly benefited by the recent developments of mixed-reality that has the potential to build virtual communities, enhance interactions and expand players 'experience. Players can meet in a virtual community space, enjoy sharing and exploring it with other players and holographic avatars. MR games use virtual reality (VR) and augmented-reality (AR) combined with the real world. Objects and actions from the real world can affect simulated objects in a mixed-reality environment. The augmented reality glasses can create the illusion that virtual worlds are actually mixed with the real world in front of the user. According to Souza de Silva and Sutko (de Souza e Silva and Sutko 2009), the defining characteristic of such games is their "lack of primary play space; these games are played simultaneously in physical, digital or represented spaces (such as a game board)". Mixed-reality has been used in applications across fields including healthcare, entertainment, education, design, robotics and other application areas.

Mixed-reality applications require the use of a headset like for virtual-reality (VR). These headsets are also equipped with a camera which can scan users' surroundings. Virtual-reality games cannot be considered mixed-reality games, because they take place only in virtual reality. Figure 2 shows a demonstration of the use of the Microsoft augmented-reality glasses HoloLens, which include sensors, advanced optics and holographic processing to create holograms that appear as real objects for the player (Hughes 2015). In this way they can create an illusion of the virtual world. The implementation can be accomplished in Minecraft environments and projected on a table equipped with a map of the area. These environments can be designed in the form of buildings, urban furniture, or game characters. HoloLens also enables voice commands and supports gestures which contributes to an immersive experience for the player. Competitors such as Oculus Rift and HTC Vive Pro Eye enable higher quality visuals than HoloLens, but no voice commands or gestures. Possible technical challenges associated with mixed-reality implementations include tracking accuracy, latency, and processing power. They can impact the users 'experience and make it difficult for developers to create immersive MR applications.

3.3 Augmented-Reality Geogames

Augmented-reality (AR) adds a layer with digital elements over physical elements, often by using the camera on a smartphone. It superimposes a computer-generated image onto the view of the real world as seen through a headset or mobile device (N.A. 2016). In this way AR enhances the real world with computer-generated content. This interactive experience can be achieved by using software applications combined with hardware such as augmented-reality glasses. Microsoft's HoloLens technology enables multiple



Fig. 2. Mixex-reality game environments (Hughes 2015)

applications including gaming, collaborating on documents and analytics. The first AR technology was developed in 1968 at Harvard when computer scientist Ivan Sutherland, often named the "father of computer graphics", proposed an AR head- mounted display system.

Pokémon Go, an augmented-reality game, is one of the most successful examples of the implementation of AR technology (Fig. 3). It utilizes a geographic information system (GIS) to provide mapping with locations of Pokémon characters. A GIS is a system that enables storing, organizing, analyzing, and visualizing geospatial data. It also uses OpenGL for Embedded Systems (OpenGL ES) for rendering the graphics of Pokémon characters in 3D created with the help of Maya. Pokémon GO implemented a real-time AR, which is a live direct or indirect view of a physical, real-world environment whose elements are augmented by a computer-generated sensory input such as sound, video, graphics, or GPS data. A player first navigates to a location using GIS and hovers



Fig. 3. Pokémon Go using augmented reality in a smart phone (Pokémon Go 2024)

the camera in the selected area. The virtual and playful characters are then extracted from the game library and rendered on video frame as a superimposed model using OpenGL ES.

4 Artificial Intelligence for Digital Serious Geogames

Artificial intelligence (AI) is developing very fast. This section looks only into three selected AI areas that may greatly benefit serious digital geogames. These three areas include virtualized geometry, procedural content generation, and modeling player's behavior.

4.1 Virtualized Geometry

Virtualized geometry represents an exciting opportunity for geogames due to its ability to enable very realistic visualizations of landscapes. For example, Unreal Engine 5 developed by Epic Games brings innovations in visualizations that are very relevant for the implementations in geogames. Its virtualized geometry system Nanite "uses a new internal mesh format and rendering technology to render pixel scale detail and high object counts. It intelligently does work on only the detail that can be perceived and no more. Nanite's data format is also highly compressed and supports fine-grained streaming with automatic level of detail," (Nanite 2024). It can produce highly realistic visualizations of landscapes, cities and other game environments as Fig. 4 demonstrates. The benefits that Nanite brings to the geogames field are mostly related to its visualization capabilities. It is now possible to directly import photogrammetry scans into Nanite/Unreal Engine 5.3 which is of incredible value for geogames and urban AI enabled visualizations. Geoinformation science sector and industry possess many of such scans and they could be effectively used to create dynamic and interactive geogame environments. Applications relevant for STEM learning, urban planning, community engagement and planning for smart and sustainable cities with the help of technologies may greatly benefit from this new technological advancement. Additionally, film-quality source arts, such as ZBrush sculpts, can also be imported for the benefits of realistic visualizations of the selected environments.

4.2 Procedural Content Generation (PCG)

Procedural generation (proc-gen) in computing is a method of creating data with the help of computer algorithms. The term "procedural" refers to the ability of a computer to process a particular function. In video games it can be used to automatically create large amounts of content. PCG is typically considered a feature of digital games and refers to the use of a formal algorithm to generate game content that would typically be produced by a human (Smith 2015). Research on PCG has approached the subject of game artificial intelligence framed as an AI problem of how to replicate human creativity in a computer-based system, how to enable AI to reason about the quality of the created content, and how to build an AI system that can interact with players (Liapis, Yannakakis and Togelius 2013, Smelik et al. 2010, Smith, Whitehead and Mateas 2011).



Fig. 4. Nanite's visualizations of city scenes (Nanite 2023)

Game content created by AI in an automatic way may include in-game generation of 3D models, landscapes, fractals, interactive stories, changing and enhancing environmental conditions, creating game levels, quests, characters, items, game rules, or even changing music depending on the player's playstyle.

An example could be an AI generated conditions in the e-*footprints* energy game (Poplin 2020), a game that invites players to immerse themselves in a city, neighborhood, and finally in their own home (Fig 5). The players can manipulate conditions related to energy in a simulated room environment. They may be surprised by some extreme conditions such as, for example, extreme heat or extreme cold. These new situations are generated on the spot in real-time. The *e-footprints* energy game gives players a variety of options on how to react to those newly generated conditions. The data registering players 'choices is then stored in the back end and can be further analyzed with various data mining and machine learning algorithms. In this way, researchers can study human behavior related to energy consumption.

The newly generated content can also lead to new versions of the game and may result in a high replay value of the game making it interesting and exciting to play. "Moreover, if new content can be generated with sufficient variety, quality, and quantity, then it may become possible to create truly endless games with ultimate replay value. Finally, when content generation is associated with aspects of play, we can expect personalized and adaptive play to emerge via the modification of content" (Yannakakis and Togelius 2018), p. 24). An additional advantage is that it may enable game designers to create unpredictable and therefore very immersive and engaging games based on the concept of conflict, tension, unexpected turns and challenges in AI enhanced games (Togelius et al. 2011, Shaker et al. 2016).

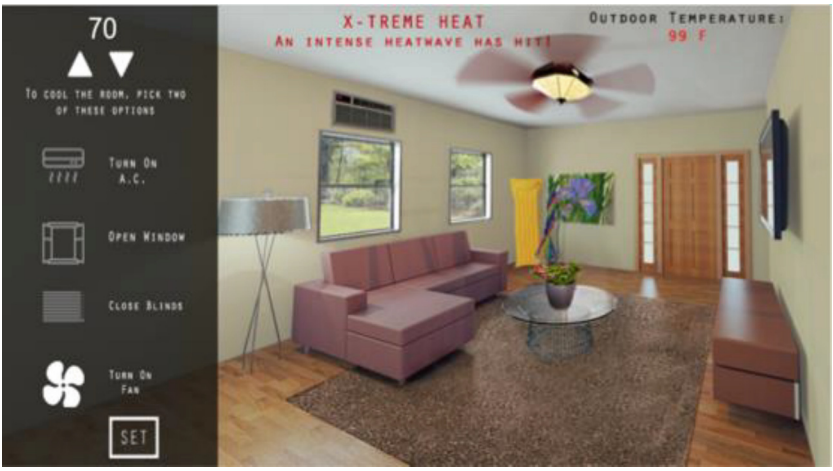


Fig. 5. Extreme heat condition in *e-footprints* energy game (Poplin 2020)

4.3 Games Adapting to the Players' Behavior

Adapting games to the players 'behavior can be accomplished in several ways; by devices measuring biometric feedback and giving feedback directly into the game; data about the gameplay can be stored in the back-end of the game registering decisions made by the players; statistics and analytical functions of the game may be implemented regularly monitoring the players actions in the game. Registering players 'behavior enables the new game content to be adapted to their needs, skills and playstyle and to create player-adaptive games. It can be used to increase the conflict in the game, enjoyment of players, or to maximize learning in a serious game. In the case of a game in which the created content is adaptive, personalized player-centric games refer to experience-driven content. S games may be referred to as player-adaptive games. The opposite of this, in which content generation does not take player's experience into account, is referred to as experience-agnostic.

New developments in hardware and software are fundamental for the inclusion of biofeedback in the concept of modern games. It can include the use of special cameras such as Intel RealSense, which enables depth and tracking capabilities. Nevermind game (2015) is an example of a player-adaptive game. The player is an expert in healing repressed mental trauma. The game was designed to be played with biometric feedback, although it is optional. As the player gets more stressed playing the game, the game gets more difficult, harder to play, the screen may get foggy and unsteady and the navigation in the game may become more difficult for the player.

5 AI Opportunities for Serious Digital Geogames

Artificial Intelligence with its novel tools and capabilities offers a series of opportunities for further development of serious digital geogames. Table 1 summarizes some of these opportunities in the three potential areas of further development including virtualized geometry, procedural content generation, and modeling player's behavior. The first

column summarizes implementations that are relevant for Serious Digital Geo-games. The following columns include the implications for these implementations in the recent developments in AI and the novel capabilities these systems bring with them.

Table 1. Opportunities for Serious Digital Games provided by AI capabilities

Implementations relevant for Serious Geogames	Virtualized geometry	Procedural content generation	Modeling player's behavior
Visualizations of different perspectives	Very realistic visualizations	The content can start with simple concepts and be gradually added to present more complex situations	Visualizations created specifically for the needs of the user or based on the user's experience
Immersive content	Future projections can be added in visualizations What-if scenarios can be visualized	Game elements can be added	Based on the pre-knowledge of the player the content can be presented Biometric feedback can be taken into consideration to engage the users on an emotional level
Responding to the state of the user/player	Simple visualizations can be gradually expanding to more complex	Generated content adjusts to the needs and skills of the user/player	Biometric feedback can be taken into consideration to engage the users on an emotional level
Experiments and new views: future projections and scenarios	Creation of visions, future projections, developments, opportunities, scenarios	The content gets gradually more complex	Depending on the user's biometric feedback new landscapes and projections for the future are created
Learning about the specific topic	Visualizations enable exploring, interacting, asking questions, retrieving data	The more the users learn, the more difficult the content gets	The content is adjusted to the knowledge base of the user
Community engagement and discussions	Create spaces for discussions, topics of discussions	Add role-playing and other game-based concepts and principles	

6 Conclusions and Further Research

Artificial intelligence tools are developing at an incredible speed. They offer new possibilities for further development of serious digital geogames. Their value mostly lies in enabling serious digital geogames to be more immersive and creating engaging and playful content that can be adapted to the players 'behavior and players 'interaction with the computer-based system.

This article suggests studying mixed-reality, including augmented-reality, as one of the most promising technological advancements that can significantly change design, implementation ideas, and principles for serious digital geogames. Mixed-reality concepts can expand the possibilities of digital geogame implementations, inspire their design and improve game mechanics. Especially interesting may be realistic visualizations of cities or neighborhoods in the context of community engagement and discussions about the future of these places.

Artificial intelligence offers some very inspiring possibilities. This article summarizes ideas in virtualized geometry, procedural content generation, and modeling players 'behavior. Virtualized geometry as developed within Unreal Engine enables very realistic visualizations of landscapes which is often an advantage for serious digital geogames. Their environments often take the player to a particular place or real-world situation. Such realistic visualizations can simulate environments and enable the player to imagine real-world situations. Procedural content generation (PCG) adds additional possibilities in the mechanics of serious digital geogames and in ways that they entice and immerse players to keep on coming back to the game and play more. PCG can automatically create new levels, add surprising and unexpected events, start competitions, provide awards, and add characters or music to the existing content. It is the magic of the game and artificial intelligence that play with possibilities in the design and mechanics that keeps the player engaged. Mechanisms can be implemented that invite and stimulate players to return to the game and keep on playing and exploring. Modern games may also explore the connection with the player and register and track their situation and status based on the received biometric feedback. Such geogames and their mechanics can be based on the data received from the biometric measurements of the players and can respond to their emotional and physical states.

It is a beginning of this new era, a revolution in possibilities offered by novel technologies, especially artificial intelligence. Serious digital geogames have yet to make these advancements reality. Geogames usually take years to design and develop and a whole team is needed for their implementation. AI developments are fast and at times unpredictable. The research field of geogames and geoinformation science can greatly benefit from these developments.

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