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# GIS using Virtual Reality (VR) and Augmented Reality (AR) instead of computer screens – an opportunity to present geographical information in cognitively more approachable ways?

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# 1 Introduction

Since the early development of the first Geographic Information Systems (GIS) in the 1960s, great advancements have been made. Today, these systems are used by a great variety of users ranging from private companies over administrations and authorities to scientific researchers. This has been achieved through continuous improvements of user experience and software capabilities as well as advancements in computational performance and availability of geodata (Bill, 2010, p. 15).

What has remained essentially unchanged since the emergence of the first GIS are the computer interface and the navigation tools used to access these systems. While these devices have been proven to be effective tools, key limitations persist. One way to overcome these limitations is to change the way how users communicate with computers.

Recent progress in the technologies and concepts of virtual reality (VR) and augmented reality (AR) has revived the excitement within sciences and industry to realise the potential of VR/AR. This is primarily due to the fact that the technological development in the last years have led to cheaper and lighter devices and improved software experiences compared to previous generations. These recent developments promise a possible breakthrough of the technology and mass adoption by consumers (Çöltekin et al., 2020, p. 1).

The aim of this paper is to provide an overview of potential opportunities as well as risks and challenges of VR/AR technologies for the field of GIScience. This has been done by conducting a qualitative analysis, screening published scientific literature of the last years and summarizing the main arguments for and against the technologies as well as thoughts about future developments. Publications were selected from the scientific search engines “Scopus” and “Web of Science”. The focus was set to literature that had high impact (many citations) as well as recent publication dates, as the technology is rapidly evolving. As the field of VR/AR research as a whole is too large for the scope of this work, the search results were further limited to literature containing the keywords “GIS” or “GIScience” and “VR” or “virtual reality” or “AR” or “augmented reality”.

The paper is structured in three parts. In the beginning the key terminologies VR and AR are defined. This is followed by a description of two important concepts of the VR/AR discourse, “immersion” and “presence” as well as a short overview about current AR/VR technologies. Then, the connection to GIScience is drawn. The main part contains the description of the potential of VR/AR technology to GIScience, followed by risks and challenges. Then, selected examples of implementation are given before the final conclusion is made.

## 1.1 Definition of VR/AR

The terms virtual reality (VR) and augmented reality (AR) are commonly used in scientific literature to describe "technologies and conceptual propositions of spatial interfaces studied by engineering, computer science, and human-computer-interaction (HCI) researchers over several decades" (Çöltekin et al., 2020, p. 1).

The classification of the terms can be done by arranging them along an axis between reality and virtuality (see Figure 1). This was proposed by Milgram and Kishino (1994) which ordered these terms based on their position in a theoretic reality-virtuality continuum where real worlds and virtual ones are overlapping. In this concept VR is understood as contrary to the real world, standing at the opposite site in the reality-virtuality continuum where users are fully surrounded by a virtual environment (Milgram & Kishino, 1994, pp. 1-2). The exact demarcation of other terms in the space between reality and virtuality is more difficult. Milgram and Kishino used the term Mixed Reality (MR) as an umbrella term for concepts and technologies that incorporate both reality and virtuality environments. Augmented Reality was understood as a subset of MR where virtual objects are superimposed onto the real environment, adding virtuality to the user's field of view and "augmenting" his vision (Milgram & Kishino, 1994, p. 4). Although Milgram and Kishino tried to create a uniform terminology early on, the use of the terms in science remains somewhat inconsistent. This is highlighted by Çöltekin et al. (2020) where they note that no uniform concensus on the definition of MR has been met, with researchers using different terminologies or variations. Today, AR is still the dominant term when regarding to concepts and technologies bridging the real and the virtual world (Çöltekin et al., 2020, p. 3f.), subsequently this paper will only refer VR and AR.

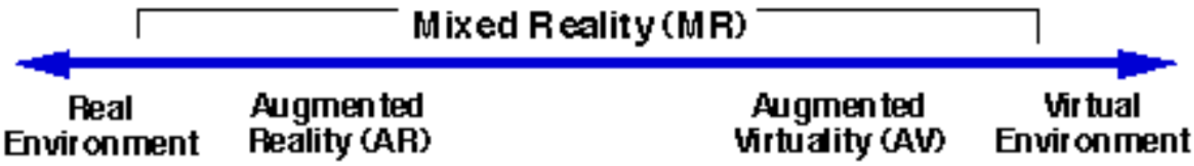


*Figure 1: Virtuality continuum (Milgram & Kishino, 1994).*

## 1.2 Concepts of immersion and presence

On the part of the scientific community, a handful of terms and underlying concepts have been established in the VR/AR discourse to better describe the unique characteristics of these technologies. Most notably the concepts of "immersion" and "presence".

### 1.2.1 Immersion

These terms were first defined in the influential paper of Slater and Wilbur (1997) where they assess immersion as a fundamental characteristic of the VR technology. They define the term immersion as a "description of a technology" that "describes the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997, p. 3). In this context, the effectiveness of the technology is defined by its grade of immersiveness where the user is fully submerged into a virtual environment. They also argued that the grade of immersion can be increased by matching the users body movements with the feedback generated in the virtual world for example by using head and body tracking devices (Slater & Wilbur, 1997, p. 3).

### 1.2.2 Presence

In addition to the term immersion as an objective description of what the technology provides, "presence" was introduced to define the "state of consciousness, the (psychological) sense of being in the virtual environment" (Slater & Wilbur, 1997, p. 4). Contrary to information transmission via images, virtual environments should be experienced as a more engaging and more natural way of conveying information (Slater & Wilbur, 1997, p. 4). By this, they mean that users are feeling that they are not merely looking at an image but are in the scene itself. While Slater and Wilbur focused on visual information transmission, other researchers have since stated, that VR/AR involves all human senses (mainly adding auditory senses to the concept in an attempt to further increase the immersiveness of VR technologies) (Çöltekin et al., 2020, p. 4).

### 1.2.3 Influence on the VR/AR experience

The role which the terms immersion and presence play in contributing to the experience of VR/AR technologies is not trivial and difficult to assess. In a study taken by Cummings and Bailenson (2016) on effects of immersive technology on users experience of presence found out that different features of VR have different effects. They highlight tracking level, stereoscopy, and field of view as most contributing to immersion and presence compared to other features such as image quality, resolution, and sound (Cummings & Bailenson, 2016, p. 297). In their interpretation, presence is a "two-dimensional construct construed in terms of perceived self-location and perceived possibilities to act within the environment at hand" (Cummings & Bailenson, 2016, p. 297), which adds interaction as a factor contributing to increased presence. The implication in their study's results is also that functioning VR/AR devices and developed technologies are crucial to a good VR/AR experience more so than detail and realism of the virtual models (Cummings & Bailenson, 2016, p. 298).

## 1.3 Technology

Current advancements in VR/AR research are based on recent technological breakthroughs. Especially, in the domain of fully immersive displays, significant improvements can be recognized. New VR products offer better visual quality, easier to set-up hardware, provide more realistic virtual experiences, while being more affordable. In the VR domain, head-mounted devices (HMDs) are the dominant device type with multiple competitors, such as Valve with the Valve Index (VALVE, 2022), Meta with the Oculus Quest 2 (Meta, 2022), and HTC with the VIVE Pro 2 (HTC, 2022), trying to gain traction in the consumer market. In the current state, HMDs provide the highest level of immersion to users (Hayek, Waltisberg, Philipp, & Grêt-Regamey, 2016, p. 101).

While VR devices have gained much popularity in recent years, AR is still more experimental (Çöltekin, Oprean, Wallgrün, & Klippel, 2019, p. 119). On the AR market, only Microsoft offers high-end AR devices. They are mostly targeted at companies and professionals (Microsoft, 2022).

# 2 VR/AR in GIScience

While much of the VR/AR development has been coming from the field of HCI, their technologies contain inherent geographic concepts and questions, creating links to GIScience. This is one of the reasons why many scientists in the field of GIScience attribute great potential to VR/AR technologies. The potential of VR/AR to GIScience is, that it can provide new experiences that change the way how users consume and produce geospatial data. For example, in comparison to the current static and predetermined content often found in GIScience, the focus changes to more experimental and interactive forms of visualizations that can be visualized, perceived, and interacted with in situ (Çöltekin et al., 2020, p. 5).

The concept of VR/AR in GIScience is not new. A paradigm shift in interaction with geodata was already envisioned in Al Gore's much acclaimed speech "The digital earth - Understanding our planet in the 21st century" in 1998, where he described a potential future where interactions with geodata are carried out by using head-mounted displays and data gloves. In this future, people are fully immersed, and interactions are so intuitive that everyone can use and interact with spatial data. This was illustrated by an example of a young child interacting with a virtual globe in a museum. (Gore, 1998, p. 89). Since then, almost 24 years later the realisation of the vision is closer than ever before. Therefore, it is important to assess the progress made and discuss the risks and opportunities can come with this new technology.

# 3 Potential

As described in the previous chapters, VR/AR technology has many connections to the field of GIScience. Because of its multidisciplinary nature, areas of applications are manyfold. VR/AR technologies are starting to get used in a variety of domains not limited to research institutions, such as civil defence, aviation, emergency preparedness and evacuation planning, education and many more (Çöltekin et al., 2020, p. 2). For GIScientists the potential primarily lies in the changed perspective and increased interactivity, that can potentially overcome a number of cartographic limitations of traditional maps. During the screening of the related literature three main areas with particular improvements have become visible, improvements in user-friendliness, improvements in the transmission of information and enhanced spatial analysis.

## 3.1 Accessibility and user-friendliness

In current GIS, maps and images are used to represent the real world, but they are limited in their way to convey all information of reality to the user. To increase the attractiveness and accessibility of geographic information in GIS, one obvious way is to make it more humanoriented (Lu et al., 2019, p. 350). With VR/AR technologies, users can perceive environments from the ego-perspective instead of less immersive cartographic views (Edler et al., 2019, p. 270). Thereby they can experience 3D landscapes in more detail compared to other geographical media. This has the potential to reduce the amount of abstraction necessary in traditional geovisualizations and subsequently less required cognitive processing, making geospatial information more accessible for the average user (Çöltekin et al., 2020, p. 5).

## 3.2 Enhancing transfer of information

Besides improvements in accessibility, VR/AR has the potential to enhance the way how people interact with geographic data. Integrating VR/AR technologies into geographic software could enrich our environment with additional spatial information, in previously unimaginable ways. This is especially true for AR. By implementing AR interfaces, certain environmental features could be highlighted which helps to recognize relevant information and assist navigation in space. Context could be added to spatial features. By using AR to highlight certain features, AR could be used similar to cartographic generalization which has been applied by cartographers to improve readability of maps and filter out unnecessary “noise” (Çöltekin et al., 2020, p. 2).

Besides highlighting, AR could also add additional information to the scene otherwise not visible which would improve decision making. Possible examples in the domain of infrastructure management could be information about costs of elements or maintenance history. IoT solutions could add displaying and updating information in real time (Carneiro, Rossetti, Silva, & Oliveira, 2019, p. 4). Not only artificial information could be integrated into the environment, but historic data as well (Arnaldi , Guitton , & Moreau 2018, p. 303). In the context of landscape planning, changing and manipulating the environment could “lead to new impressions on an area and create a different assessment of a multifaceted landscape” (Edler et al., 2019, p. 272).

Unlike traditional cartographic concepts, VR enables researchers and developers to include additional senses to assist the visual impressions, such as specific audio inputs. The auditory element can have the function to communicate specific semantic information or just increase the impression of immersion in the environment (Edler et al., 2019, p. 274). This is also stated by Çöltekin et al. (2019) which emphasize the possible inclusion of additional senses in the future (Çöltekin et al., 2019, p. 119).

## 3.3 Spatial analysis

For spatial analysts VR/AR creates the opportunities to improve spatial analysis by changing the dimensionality from a planar 2D perspective of current GIS to an immersive environment where data can be experienced, perceived and interpreted multidimensionally (Çöltekin et al., 2020, p. 20). It also has the potential to improve interactions with virtual data by enabling on-site accessibility to geodata (Carneiro et al., 2019, p. 7), closing the gap between field space and lab space and "allowing for situated GIScience that supports the cognitive connection between data and space" (Çöltekin et al., 2020, p. 20).

### 3.4 Areas of application

Within GIScience, different researchers have started to explore and realise the potential of VR/AR on a wide range of topics.

Arnaldi et al. (2018) have stated potential benefits for spatial exploration by enabling augmented site visits for industries or tourists (Arnaldi et al., 2018, p. 304). Linked to this is the integration of VR/AR technology in history teaching and heritage conservation. VR makes the virtual exploration of selected locations possible without having the limitations of many heritage sites and museums, thereby improving the accessibility (Scianna, Gaglio, La Guardia, & Nuccio, 2021, p. 179). VR could also function as a tool for reconstruction, preservation, and safeguarding of artistic works (Scianna et al., 2021, p. 181).

Boulos et al. (2017) have summarized the potential of VR/AR in emergency training and education. Disasters could be simulated in the virtual world and different reactions and adaptive measurements could then be compared in a controlled scenario. This is supported by the increasing availability of GIS data and virtual city models which can be used as a basis for simulation scenarios and remove the need large-scale conventional drills in the real world (Boulos, Lu, Guerrero, Jennett, & Steed, 2017, p. 3).

Besides emergency scenarios, education is an area that could benefit from the potential of VR/AR as well. Several studies have been conducted whether AR could be used as an educational digital technology. Advocates have been pointing out that AR could provide immersive and interactive learning experiences that make it easier to bring data and information to people (George, Howitt, & Oakley, 2020, p. 209). Especially geoscientists have pointed out that AR could improve spatial thinking by improving on the two key components, spatial orientation and spatial visualization, where spatial orientation refers to the understanding of alternative perspectives and navigational abilities, while spatial visualization refers to the ability to imagine objects within the mind (George et al., 2020, p. 210).

In the healthcare sector, AR applications could improve personal health and well-being. Boulos et al. (2017) describe the potential based on mobile games such as Pokémon Go. Such games work on enriching real-world locations with virtual items and challenges and tracking the players position via GPS. The player is then encouraged to visit the sites to collect items and play against other players and virtual non-player characters. They argue, that these types of geosocial games could help preventing physical and mental health issues by reconnecting players to the real world (Boulos et al., 2017, pp. 3-4).

In surveying, AR can help workers to immediately visualize geometries and to bring them into the context of their surroundings, giving them the possibility for correction (Zollmann, Schall, Junghanns, & Reitmayr, 2012, p. 684).

The last big domain of VR/AR research is urban (participatory) planning. Among others, Hayek et al. (2016) have expressed the capabilities of VR to involve citizens in the planning process. By providing a virtual environment of proposed projects, citizens could better assess the impact of certain developments such as tall buildings and wind turbines (Hayek et al., 2016, p. 107).

# 4 Risks and Challenges

Despite all the praise and attention that VR technology has received in recent years, there are still significant risks and challenges to be addressed. Arnaldi et al. (2018) named four key reasons that have restricted the development of VR/AR in the past. Those were misinformation on the technologies and their potential power, cost and complexity of implementing existing technology which was limited to large companies, limited performance with small field of vision, precision, and reliability of position and localization sensors, and lastly, the limited number of applications which hindered further developments. (Arnaldi et al., 2018, p. 304). With recent progress in development, some of these challenges have been mitigated but some persist while others change in significance, transforming from theoretical to concrete problems. The following sections will point out the biggest current risks and challenges regarding VR/AR.

## 4.1 Technology

To achieve immersive virtual environments, capable hardware and software solutions are needed. In the past, immersion-breaking technical limitations of the VR implementation were image latency, low graphics resolution, missing sensory aspects (in the case of the study by Hayek et al., 2016 no perception of wind), and the missing possibility to interact with virtual objects. Criticised was also the lack of detail in the virtual environments making it appear “sterile and lifeless” (Hayek et al., 2016, p. 106). Most areas have seen significant improvements over the years, but some technological challenges persist.

### 4.1.1 Hardware

Interactivity in the virtual world requires real-time rendering, with high frame rates and low latency/ input-lag as prerequisites. Over the past decades continuous improvements through technological advancements and optimizations have been made in rendering technology, to a point where these goals are achievable while also offering high levels of detail (Boulos et al., 2017, p. 5).

Regarding the challenges in user tracking, differences between VR and AR exist. While VR tracking works in a fully controlled, spatially enclosed, environment, AR tracking is more complicated. Users expect to be able to move unhindered in the real world which requires more sophisticated spatial registration (Çöltekin et al., 2020, p. 8). Technical challenges of geographic AR solutions are therefore mainly centred around positioning errors of virtual objects in the real world. These inaccuracies lead to poor user experiences and limited applicability outside research labs (Carneiro et al., 2019, p. 5). This could prove to be a major hurdle for the further diffusion of AR in society.

In VR, body tracking also has its problems. While head tracking is already widely used, full-body interactions remain experimental. Currently, these issues are addressed by integrating eye tracking and hand tracking, but they haven't reached widespread adoption yet. Both concepts have the potential to further increase the feeling of presence in the VR/AR environment. Especially hand tracking is interesting, because it can overcome shortcomings currently experienced when navigating and interacting with mouse and keyboard input devices or other control devices (Çöltekin et al., 2020, p. 8).

Concluding the technological issues, more improvements are necessary in the areas of user tracking and localization, which are still insufficient for many advanced tasks (Carneiro et al., 2019, p. 6f.).

#### 4.1.2 Software

Authentic complex environments need detailed models and textures. While improvements are made, software issues continue to be a challenge. Today, a variety of data sources exist to create virtual worlds with matured software programs for manual and procedural modelling, with additional possibilities to rely on data created by individuals through Volunteered Geographical Information (Boulos et al., 2017, p. 5). While current developments push to realise high levels of visual realism which is aspired for getting the immersion Slater and Wilbur (1997) described, there is persistent need to keep the virtual reality computationally performant. The immersion and the illusion of reality is only possible when visual artifacts are not overly noticeable and delays in rendering not frequent. This requires high performance hardware to keep up with the refresh rates and screen resolutions required for a good experience and visual fidelity (Çöltekin et al., 2020, p. 9)

### 4.2 Lack of content

Many risks of VR/AR are shared with other innovative technologies of the past that have failed to meet expectations of investors and the public, such as 3D TVs. The main reasons of failure were the lack of content at release and the problem of acceptability by the user. This could be an obstacle for the development of VR/AR as well, as these technologies currently only cover a relatively small number of applications areas (Arnaldi et al., 2018, p. 305).

### 4.3 Conceptual limitations

In addition to obvious technological challenges, there are also conceptual ones regarding key cartographic issues. In the VR/AR development fundamentally opposing concepts become discernible. On the one hand, there is the attempt to present the virtual environments as realistically as possible in order to achieve the desired immersion. Abstractions in the representation of the environment have so far only been justified as necessary measures to maintain the performance of the devices, not as a design decision. On the other hand, there are the principles of cartographic generalisation, in which it is assumed that reductions of details are necessary for effective information transmission (Çöltekin et al., 2020, p. 12).

In regard to AR, challenges are information clutter, depth perception issues or wrong interpretations of information (Zollmann et al., 2012, p. 676). Adaptions in visualization design between GIS and AR are necessary. While GIS symbology is standardized, there are still missing standards for AR visualizations, an issue that needs to be addressed for further development in AR research (Zollmann et al., 2012, p. 676).

### 4.4 Ethics and Privacy

Besides the technological and conceptual issues that VR/AR still has, ethics and privacy are growing concerns. Ethical considerations are in parts related to the increased tracking and logging of the VR/AR users' movements. Extended tracking and collection of user data enables the modelling and prediction of private information with possible with unforeseeable consequences. Based on the early stage of development, investigation is needed (Çöltekin et al., 2020, p. 18). Other ethical considerations regard the extended use of VR/AR technology. As we let someone else manage our (virtual) geographic nature, a potential threat to human autonomy arises "that may influence our cognitive system at a fundamental level" (Çöltekin et al., 2020, p. 2). In the future the problem may come, where we cannot longer tell virtual objects from real ones (Çöltekin et al., 2020, p. 2). This is closely connected with another concern. When the responsibility to manage our perceived environment is handed over to other people, possibilities for exploitations are given (Çöltekin et al., 2020, p. 16).

### 4.5 Health concerns

Lastly, questions remain about the impacts on individual health by prolonged use of VR/AR devices. Little research has been done in this regard, especially for children whose physical and mental development is not yet complete. This issue is mentioned by multiple researchers, among others Arnaldi et al. (2018) and Çöltekin et al. (2020).

## 5 Examples of Implementation

To better assess the opportunities and possible risks of AR/VR, selected application examples that could demonstrate the possible future use of VR/AR technology are presented in the following section. Examples are given for the domains of pipeline management, emergency management, and urban planning.

## 5.1 Pipeline Management

First attempts have been made to use AR technology in pipeline management. The LARA project described by Stylianidis et al. (2020) aimed at combining AR methods with technologies for geodata acquisition to develop a user-friendly mobile system for field workers in the underground network utilities sector (Stylianidis et al., 2020, p. 175). The result can be seen in Figure 2. Similar to other AR projects, the project sought to take advantage of AR capabilities to incorporate virtual otherwise invisible objects ("x-ray vision") into the field of view of users. (Stylianidis et al., 2020, p. 174). Key innovations compared to previous projects were the combination of GNSS technology and AR technology, the use of GIS technology to integrate geodata, the use of rendering approaches to change GIS data into virtual 3D objects, and finally the visualization of the integrated data in AR (Stylianidis et al., 2020, p. 176). Major challenges named in the paper were positional inaccuracy and insufficiency between objects in reality and the stored values in the database, which was a problem unrelated to the AR technology itself, but commonly experienced when using GIS data (Stylianidis et al., 2020, p. 181).


*Figure 2: Result of the project. GIS line features are superimposed onto the field of view. Selected features can be interacted with, showing additional information (Stylianidis et al., 2020, p. 183).*

## 5.2 Emergency Management

AR has been successfully used in the field of emergency management. In a study by Lochead and Hedley (2019) virtual 3D emergency evacuation simulations were combined with mixed reality technologies in an attempt to improve the level of visual reasoning for planners and to overcome current limitations of GIS to represent the complexity of 3D spaces and pathways of movement (see Figure 3) (Lochhead & Hedley, 2019, p. 191). They argue, that in current spatial analytical methods in GIS, "evolving scenarios, human decision-making, and unexpected circumstances in three-dimensional built environments are not well served" (Lochhead & Hedley, 2019, p. 192) and thereby more multi-dimensional approaches are to be developed. Even though the authors considered the study results to be successful, some limitations of the approach remain. Main issues were related to occlusion of objects, a problem related to current AR implementations (Lochhead & Hedley, 2019, p. 203), as well as positional accuracy (Lochhead & Hedley, 2019, p. 204). Both of which are expected to be solved with ongoing improvements of technology (Lochhead & Hedley, 2019, p. 205).


*Figure 3: Result of the AR emergency simulation. Simulated agents are superimposed onto the screen of the device when the camera recognizes the surrounding (Lochhead & Hedley, 2019, p. 200).*

## 5.3 Urban planning

Urban planners have implemented VR/AR in population management, traffic prediction and mitigation, urban resource allocation, water resources monitoring, environmental protection, disaster prevention etc. (Boulos et al., 2017, p. 7). The GIS software producer ESRI has started to integrate VR capabilities to its software products. The CityEngine VR Experience for Unreal Engine is offering planners, designers, and other stakeholders to explore virtual 3D city environments based on GIS data to discuss and modify possible development scenarios. The software allows to export GIS data and 3D modelling assets to be exported into the Epic Games Unreal Engine where the complex environment is rendered in real time. Simple spatial analysis is also supported by changing the time of day und the incidence angle of the sun (see GUI in Figure 4) (ESRI, 2018).

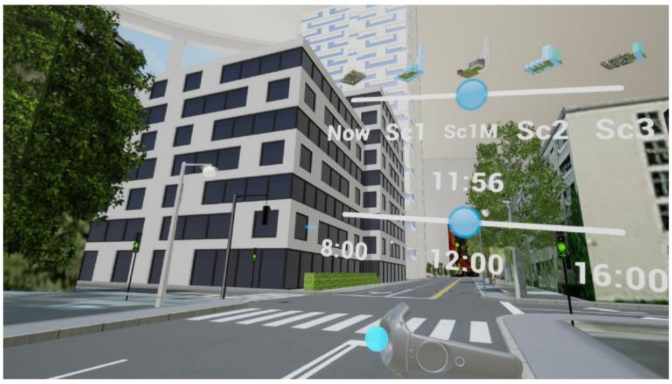


*Figure 4: CityEngine VR in the ego perspective. GIS Building structures can be explored (ESRI, 2018).*

Potential use of AR technologies in smart city contexts have been discussed by Yagol et al. (2018). They tried to evaluate the use of AR as a potential substitute to web mapping services for finding places and additional information about landmarks (Yagol, Ramos, Trilles, Torres-Sospedra, & Perales, 2018, p. 7). The result was a multiplatform mobile app which connected AR with GIS services which, in an attempt to evaluate its use, could in specific tasks show a better performance compared to traditional mapping apps (Yagol et al., 2018, p. 18).

# 6 Conclusion and Outlook

VR and AR have the potential to revolutionize the interaction with geodata by closing the gap between reality and virtuality. Immersion and presence experienced with VR/AR technologies promise to change the way people interact with geographic data. This is made true by significant recent advancements in the development of user interfaces (namely HMDs) and navigation tools. With the hopes of a technological breakthrough, global companies invest into the new technologies and are thereby also creating new opportunities for GIScientists. Based on the literature, the biggest potentials of current VR/AR technologies lie in the increased immersion and interactivity, the increased user-friendliness in presenting geodata, the possibility of adding virtual information to the scene, the possible integration of past or future, and the option to include additional senses to the experience. This potential is supported by increasing numbers of experimental applications in various domains.

While almost all authors of the screened literature had an optimistic view of the developing technology, the vision Al Gore had almost 24 years ago has not yet been fulfilled. Challenges remain, such as tracking issues and inaccuracies, especially for AR devices, ethics and privacy, as well as unsolvable dilemmas, such as the balancing between maximum quality and maximum performance, and the balancing between realism and generalisation in the design of virtual environments. Some other aspects also remain heavily underexplored, such as the impact on health, where both, possible opportunities and risks have been mentioned.

Regarding GIS, VR/AR has the potential to overcome limitations of current software, but a complete replacement seems to be unlikely, also because not all analyses benefit from a change in perspective. Whilst the development continues and VR/AR technologies start to mature, GIScientists should continue to address current challenges so that more analytical capabilities are available when the market penetration of these devices has increased.

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