The Virtual Reality of GIScience: Short Paper

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Abstract

Virtual reality technology has the potential to be a revolutionary addition to the field of Geographic Information Science. The application of virtual reality to GIScience has been discussed for decades, however adoption has been limited until recently. Virtual reality implements established GIScience methods and those from other fields such as video game development. In this paper, we introduce Locative Reality, a virtual reality software that presents users with immersive 360° video experiences of forest environments. It incorporates spatial information into the virtual environment so that data generated by virtual research can be directly linked to real-world locations. The implications for the field of GIScience include virtual research tools and educational experiences, all accessible to anyone anywhere in virtual reality.

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1 Introduction

Virtual reality is an increasingly accessible tool with applications to many scientific and technological disciplines, including GIScience [15, 18]. It provides a truly three-dimensional experience, rather than the common two-dimensional or 2.5-dimensional faux-3D view [19]. Virtual reality is also highly interactive – three-dimensional programs can be explored much like real-world space. This is an immersive form of GIScience, with the potential to enhance techniques such as participatory GIS using this immersivity [22]. GIScience can incorporate virtual reality through existing geospatial methods and those from other fields.

2 Review of Foundations

The place of virtual reality within GIScience has been discussed for decades. In the 1990s Couclelis [7] and Faust [10] reviewed the then-current state of GIScience and the potential impacts of virtual reality technology on the field. Examining the past discourse on virtual reality GIScience from a modern perspective enables a situated understanding of the current state of this ever-developing discipline.

2.1 Couclelis, 1992: People manipulate objects (but cultivate fields)

Couclelis' [7] discussion on the vector-raster debate within traditional GIScience has implications today, even when the two data formats are both widely supported and used. Many of

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Couclelis' *desiderata* for the "next but one" generation of GIScience are addressed in the integration of virtual reality into the field.

Couclelis' desiderata describe the ability for GIScientists to be able to use the system and data format that best suits their study purpose. Virtual reality addresses these issues through the combination of vector and raster datasets depending on the program [27]. Couclelis stresses that vector data should be used for objects, while raster data should be used for fields, or areas. An example of this is the 'skybox', typically a 360° panoramic image projected onto a sphere, used to show the more distant areas of the game world [27].

Couclelis' final desideratum considers that "the most significant geographic spaces may never make it into a computer". The coverage of locations ranging from the Grand Canyon to individuals' houses on services such as *Google Street View* or in *Microsoft Flight Simulator* (2020) [21] shows how detailed and accessible geographic information has become in the decades since Couclelis' writing.

Many of Couclelis' desiderata for GIScience are addressed in the introduction of virtual reality technology into the field. By Couclelis' criteria, this shows that virtual reality presents a step forward in the development of GIScience as a whole.

2.2 Faust, 1995: The virtual reality of GIS

Faust [10] examines the then-emerging field of virtual reality GIScience in the mid-1990s. Like Couclelis [7], Faust lists several criteria for the creation of a "truly interactive three-dimensional virtual reality GIS".

Firstly, the depiction of the three dimensions of real geographic places must be realistic, according to Faust [10]. Released in the same year as Faust's writing, the Nintendo Virtual Boy was the first publicly available stereoscopic video game console [28]. The Virtual Boy's graphics used oscillating mirrors to direct a red LED light into the user's eyes [28]. The display resolution was 384×224 pixels in monochromatic red [28]. In contrast, the Oculus Quest 2, a current consumer virtual reality headset, has a resolution of 1832×1920 RGB pixels for each eye [9]. As virtual reality technology improves, Faust's vision of a highly realistic virtual environment will be achieved to a greater standard over time.

Faust's [10] second criterion is the free movement of the user. Six degree-of-freedom (DOF) tracking is common among current virtual reality headsets. 6DOF tracking allows rotation on the x, y, and z axes (3DOF), as well as movement along all three axes (6DOF) [6]. The Nintendo Virtual Boy of Faust's time had no vision tracking, and was limited to a stationary stereoscopic display [28]. Modern virtual reality headsets, including the Oculus Quest 2 [9], use 6DOF head tracking, often combined with controller, hand, or body tracking to give an immersive virtual experience where the user has free movement as they would in real life.

Generally, Faust's [10] criteria have been addressed, or continue to be addressed, through technological developments in the decades following their writing.

2.2.1 Technology-Driven GIScience Milestones

Another discussion from the 1990s relevant to virtual reality GIScience is Al Gore's *Digital Earth* speech [11]. Gore, like Couclelis [7], outlines necessary developments in technology to create a near-complete virtual model of the world. Many of these developments have been addressed in the decades following Gore's speech. The complexity of nature requires computational power to codify, and large amounts of digital storage to record [11]. Both physical frameworks, such as data storage and high-speed Internet [11], as well as software frameworks allow for realistic representations of the real world. Software frameworks include *Virtual Reality Modelling Language* (VRML). VRML allows web browsers to display three-dimensional models [13]. Notably, this provides an easily-accessible platform for three-dimensional GIScience to be performed [13], where users can more intuitively understand the spatial phenomena they are viewing. Modern software such as ESRI's *ArcGIS 360 VR* is an example of this. Virtual reality presents a next step in this intuitive GIScience approach, moving from a three-dimensional model being displayed on a flat screen to a truly three-dimensional model that they can explore.

The aims put forward by Faust for virtual reality GIScience show the state of virtual reality technology in the 1990s, and how far the field has developed in the last 30 years. This technology development has facilitated high-fidelity representations of real space in virtual worlds, in manners following those outlined by Gore [11]. Many of both Faust's [10] and Couclelis' [7] desiderata have been addressed through the integration of virtual reality into GIScience, enabled by technological improvements including frameworks like VRML.

3 GIScience Methods

Virtual reality is currently being applied to GIScience in a number of ways. Remote sensing techniques, notably LiDAR, are being employed to generate three-dimensional models for virtual reality [3]. Additionally, structure-from-motion (SFM) methods, a form of stereo photogrammetry, can be used to create these environments [16].

LiDAR is an increasingly accessible technology. Consumer-grade electronics, such as the iPhone 12 Pro [2], have built-in LiDAR scanners that can produce three-dimensional models of objects. 3D models used in virtual reality are made of polygons, structured similarly to the triangular irregular networks (TINs) used in GIScience. The LiDAR technology often used to generate TIN digital elevation models [1] can be used to create other 3D models of real-world objects and places [3]. LiDAR has proven to be a useful technology for modelling complex natural structures such as tree crowns [17] or rocky outcrops [4], especially when combined with high-resolution 360° imagery [18]. LiDAR, an established GIScience technology, has applications in virtual reality environment generation, enabling highly realistic recreations of real places.

Photogrammetry is another GIScience method applicable to virtual reality [23]. Stereo photogrammetry can be utilised to construct three-dimensional models from multiple still images taken from different vantage points. This technology, used in 'structure-from-motion' (SFM) techniques, can be applied to 360° video that has corresponding location information. SFM can create highly detailed replications of real-world environments without the need to design models manually. Virtual reality using stereo photogrammetry has been demonstrated [16], however its use remains limited. SFM could provide virtual three-dimensional access to even the most inaccessible places around the world.

The combination of both LiDAR and SFM techniques presents a toolkit for highly accurate 3D modelling of natural areas. Each method is best suited for different scales and structures [15]. When combined they can be an effective three-dimensional terrain modelling system for use in virtual reality.

4 Non-GIScience Methods

The use of software not traditionally associated with GIScience in the field of GIScience is becoming ever more prevalent. Modelling and animation software *Blender* is being used to generate three-dimensional models based on geospatial data [24]. Another key source of digital infrastructure being used in virtual reality development, including within GIScience, is video game engines. Presently, Unity and Unreal Engine are the most commonly used engines for both video games and scientific programs [26].

Video game engines provide tools for the development of virtual reality programs, with support for devices from multiple manufacturers. Unity, launched in 2005 [26], uses the C# scripting language and is known for its user-friendliness [25]. Unreal Engine was originally released in 1998 [25], and Unreal Engine 5 is due to be released in 2022 [8]. It has state-of-the-art polygon rendering (known as Nanite) and dynamic lighting (Lumen). Both engines have real-time graphics rendering capabilities, however Unreal Engine is considered to have better-looking visuals and more support for complex structures such as foliage [25].

Video game engines also fill a niche for environmental scientists. Harrap, Hutchinson, Ondercin, and Difrancesco used Unity's physics engine to simulate rockfall at various sites globally [12]. They found that their simulations were able to predict real-world rockfall scenarios. The physics simulation capabilities of Unity add functionality to GIScience that is not provided in GIS programs. This added functionality is provided not through necessitating development of new software but through the embracing of technologies external to GIScience and acknowledging the importance of interdisciplinary approaches.

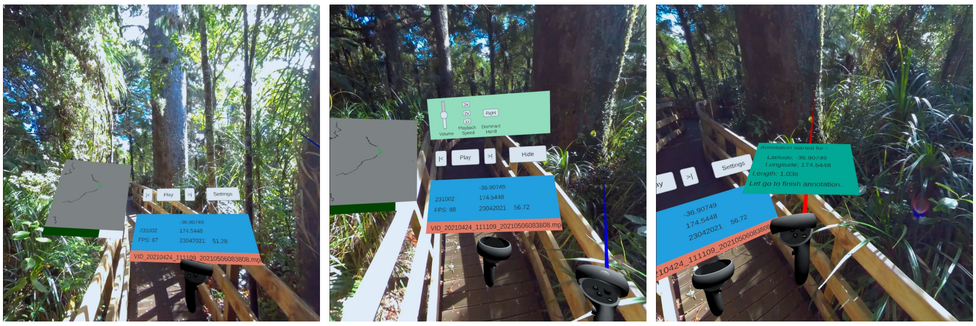
5 Locative Reality

Locative Reality is a virtual reality program developed by the Spatial Innovation Lab at the University of Auckland, New Zealand. It features an immersive virtual environment designed primarily for interview-based research. Locative Reality is built using the Unity game development engine for Oculus hardware, integrating 360° video and spatial audio with GPS location data to allow for spatial information to be generated.

The environment in Locative Reality is presently created using recordings created with the Insta360 Pro 2 camera. This camera captures 360° monoscopic video in 8K quality at 60 frames per second (fps), used in Locative Reality, or 360° stereoscopic 8K video at half the frame rate [14]. This is well suited for current studies involving forest environments, which contain fine details, such as tree leaves, that need a high resolution to capture. The Insta360 Pro 2 records spatial audio and GPS location information. The video is projected onto the inside of a sphere placed around the user's head, and the location data is used to ensure travel in the game space can be related back to the real world.

Locative Reality's user interface has several parts. Attached to the user's left hand is a map and graphical controls similar to a media player. The map shows the GPS tracks of each video segment, allowing the user to better understand where they are in real-world space. A progress bar shows the user how far along in each video they are and supports skipping back and forward in the video. There are additional point-and-click video player controls, shown in Figure 1.

The critical part of Locative Reality is the ability to create annotations to the virtual experience. The interface the user sees when annotating is shown in Figure 1c. What the user was looking at (and therefore what they were referring to) is recorded, and their position in space is recorded. These annotations are spatial data, with the real-world coordinates of the user being part of the data generated within the virtual world. The annotation information can then be exported from the program in GeoJSON format for analysis. Locative Reality is well-suited for many research methods, including go-along interviews [5] with the added benefits of accessibility that virtual reality provides [20].



(a) The basic interface. **(b)** The expanded controls. **(c)** During an annotation.

Figure 1 Screenshots of the user interface of Locative Reality while the user is in a video experience.

Locative Reality combines GIScience and virtual reality to create a medium for generating geospatial information from virtual environments. Its current use is for interview-based research, both for studying the technology itself and for studying experiences within the virtual environment. The virtual reality aspect enables accessibility for those who cannot go to some places, due to factors such as disability or environmental restrictions. The future of GIScience using virtual reality is being created today with applications like Locative Reality.

6 Conclusion

Virtual reality provides new ways of seeing and exploring the world in a highly accessible manner. As the technology is readily available in consumer markets, does not need expert knowledge to operate, and can display locations that would otherwise be inaccessible to the users, it is a thriving area. Applying virtual reality to GIScience represents an acknowledgement of interdisciplinary thinking, where users can take advantage of methods and technologies originating in other fields. Virtual reality provides resolutions to many of the desiderata presented by Couclelis [7] and Faust [10] in the 1990s, enabled by technological developments highlighted by Gore [11], a mere 30 years later.

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