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Title
The Virtual Reality of GIScience

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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 GIScience represents an interdisciplinary approach, incorporating 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, accessible to anyone anywhere in virtual reality.

1 Introduction

Virtual reality is an increasingly accessible tool with applications to many scientific and technological disciplines, including GIScience [15, 19]. It provides a truly three-dimensional experience, rather than the common two-dimensional or 2.5-dimensional faux-3D view [20]. 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 [23]. GIScience can incorporate virtual reality through existing geospatial methods and those from other fields.

2 Review of Foundations

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 types are both widely supported and used. Many of

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

Couclelis' desiderata describe the ability for GIScientists to use the system and data format that best suits their study purpose. Virtual reality addresses this through the combination of vector and raster datasets, depending on the program [28]. Couclelis suggests 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 raster projected onto a sphere, used to show the more distant areas of the game world [28].

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 individual houses on platforms such as *Google Street View* or in *Microsoft Flight Simulator* (2020) [22] shows how detailed and accessible geographic information has become in the decades since Couclelis' writing.

Many of Couclelis' desiderata for GIScience are addressed with the introduction of virtual reality technology. 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, Faust stresses that the depiction of the three dimensions of real geographic places must be realistic [10]. Released in the same year as Faust's writing, the Nintendo Virtual Boy was the first publicly available stereoscopic video game console [29]. The display resolution was 384×224 pixels in monochromatic red, using mirror-directed LED light [29]. 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 over time, Faust's vision of a highly realistic virtual environment will be achieved to a greater standard.

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. It 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 effectively zero degrees of freedom [29]. 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

Virtual reality GIScience also has roots in Al Gore's *Digital Earth* speech [11]. Gore, like Couclelis [7], outlines necessary developments in technology to create a near-complete virtual Earth. The complexity of nature requires computational power to codify, and large amounts of digital storage to record [11]. Physical frameworks, such as data storage and high-speed Internet [11], and software frameworks such as *Virtual Reality Modelling Language* (VRML) allow for realistic representations of the real world. 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 [16]. Virtual reality presents a next step in this intuitive GIScience approach, moving from a three-dimensional model displayed on a flat screen to a truly three-dimensional environment 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 such as 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 [17].

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. 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 can effectively model complex natural structures such as tree crowns [18] or rocky outcrops [4], especially when combined with high-resolution 360° imagery [19]. LiDAR, an established GIScience technology, has applications in virtual reality environment generation, enabling highly realistic renditions of real places.

Photogrammetry is another GIScience method applicable to virtual reality [24]. 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 [15]. 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 [17], however its uptake remains limited. SFM could provide virtual 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. The modelling and animation software *Blender* is being used to generate three-dimensional models based on geospatial data, for example [25]. A key source of digital infrastructure being used in virtual reality development, including within GIScience, is video game engines. Unity and Unreal Engine are the most commonly used engines for video games and scientific programs [27].

Video game engines provide tools for the development of virtual reality programs, with

support for devices from multiple manufacturers. Unity, launched in 2005 [27], uses the C#
scripting language and is known for its user-friendliness [26]. Unreal Engine was originally
released in 1998 [26], with Unreal Engine 5 releasing 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 [26].

Video game engines also fill a niche for environmental scientists. Unity's physics engine
has been used to simulate rockfall at various sites globally [12]. These 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-focused 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 with Unity for
Oculus hardware, integrating 360° video and audio with GPS location data to generate
spatial information.

The environment in Locative Reality is presently created using recordings created with the
Insta360 Pro 2 camera. Locative Reality uses 360° video in 8K resolution, with accompanying
spatial audio and GPS data [14]. This is well suited for current studies involving forest
environments, which contain fine details such as tree leaves, requiring a high resolution to
capture. 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.

(a) The basic interface.   (b) The expanded controls.   (c) During an annotation.
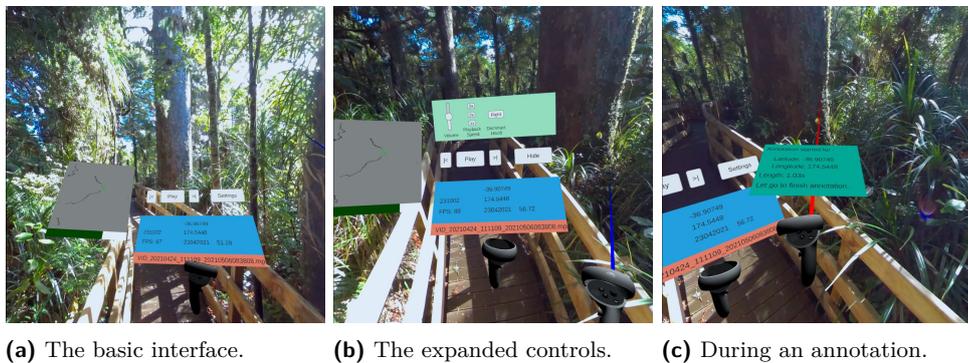
Figure 1 Screenshots of the user interface of Locative Reality while the user is in a video
experience.

The critical part of Locative Reality is the ability to create audio annotations to the virtual experience using the built-in microphone of the headset, shown in Figure 1c. Where the user was looking and their position in real-world space is also recorded in GeoJSON format. This spatial information is markedly more detailed than that generated from in-person go-along interviews, for example [5], with the added benefits of accessibility that virtual reality provides [21].

Locative Reality combines GIScience and virtual reality to create a medium for generating geospatial information from virtual environments. Its current use is for research interviews, both for studying the technology itself and for studying experiences within the virtual environment. The virtual reality aspect increases accessibility, reducing factors such as disability or environmental restrictions. The future of GIScience using virtual reality is being created today with applications such as 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, as in Locative Reality, 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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