A cure for the geologist’s curse?

As a geologist, you are always faced with one fundamental problem: the scales under which geology operates do not generally match well with those of humans. A geologist cannot dissect the Earth to watch the tectonic plates shift and slide across the mantle, they can’t peer inside a crystal as it forms and they can’t watch the full saga of climate change unfold within their lifetimes. They are cursed to always be out of sync with the scales of the features or processes they study, whether in space or time.

Professor Hans-Balder Havenith and his colleagues Philippe Cerfontaine and Anne-Sophie Mreyen at the Georisk and Environmental Research Unit at the University of Liège, aim to change this: they want to make immersive visualisation using virtual reality (VR) an accessible and widespread collaborative tool for both students and professionals in geosciences. Virtual reality provides a unique opportunity to step inside and take control of the spatial and temporal scales and visualise processes – all the way from the planetary scale down to the nano-scale and from multi-millenia to the millisecond.

First steps towards 3D visualisations

Most people who think about visualising geological or geographical data will think of a map – two dimensional and generally non-interactive. However, mapping has evolved. A good example of shifting a map from 2D to 3D is the so-called augmented reality sandbox (https://sandbox.ucdavis.edu), a favourite for the inner child in all of us, which allows users to manipulate sand and watch how changes in topography affect, for example, the flow of water within a catchment. The sandbox works by having the topography and contours projected onto the sand itself, adapting as the user shifts the sand. Users can simulate rainfall, watch how it interacts with and is affected by the topography and investigate slope stability under different conditions.

Geographical Information Systems (GIS) are the mainstay of geosciences using digital mapping. The power of GIS is immense, but it has its drawbacks in terms of looking beyond the surface and into the Earth. GIS data is generally restricted to 2D studies with limited temporal information.

Numerical modelling tools can handle 3D geo-data and can produce almost continuous time-dependent output, but this is both computationally intense and storage heavy. Such models require sophisticated – and expensive – computer facilities not readily available to the wider field.

Geomodelling software and 3D visualisation tools work to combine the outputs of both GIS and numerical modelling. They are designed to focus on ways of representing the data in a 3D space. They also include some pre-processing to reduce the computational intensity of the model and allow 3D volumes to be calculated – a key aspect for visualising 3D space. As a result, their potential for 3D visualisation is far greater than that of GIS or general numerical modelling tools.

However, 3D models are still rare and it’s only in recent years that technology has advanced to the stage of being able to explore geosciences using state-of-the-art coupled modelling, finally allowing us to actually look inside the processes and phenomena under study. These developing methods have actually come from a range of different areas, often geo-engineering or geotechnical fields, but their wider use is still hindered by the high cost and time investment needed. In their 2017 paper, Professor Havenith et al. discuss how effective Google Earth has been in partially bridging this gap despite its limitations in terms of analytical capabilities, its efficiency in representing data on a 3D globe, the ease of use for the user, and the free access, have made it widely accessible and very popular for the representation of surface and map data.

3D geomodelling and virtual reality

Many studies in recent years have begun to highlight the potential power of geomodelling with the extra impact of VR technology, including the use of Virtual Geographic Environments (VGE) and collaborative virtual environments (CVEs) (See Lin et al. 2013, for example).

However, the Georisk and Environment Research Unit and other laboratories such as the TESSIN VISlab are now striving to take this one step further and use VR to create a first visualisation experience where the user can step inside the models and be fully immersed in the 3D world presented to them. Some of the many uses for this technology are summarised in Bilke et al. (2014) and range from everything from climate change to town planning, hydrogeology to geothermal energy.

This new immersive visualisation takes advantage of the recent major advances in game development technology, much of which has been designed with ease-of-use in mind – very little coding or programming skills are necessary for the user to create a first visualisation which makes the technology easy to transfer between fields and between researchers.

But still, immersive visualisation is no easy feat – there are many things to be aware of as you create the VR environment. Movement within the environment must be smooth for the user in such a way as to not induce motion sickness. The brain and the inner ear can experience quite different stimuli and movement signals and any conflict between them needs to be kept to a minimum. The user creates what is known as a ‘mind map’ as they move across the virtual environment and this is very sensitive – any moments of instantaneous teleportation can completely destroy a user’s mind map and thus the success of their experience. The designers also need to be conscious of how the different scales of the subject affect movement within the VR environments – flying motions are best for large landscapes, for example, allowing the user to move rapidly and smoothly to different construction sites in Tajikistan.

Insight into a landslide in Belgium - 3D geomodel with Leapfrog Software.

Students attending lectures in the Department of Geology at the University of Liège are now treated to many different VR environments aimed at enhancing their learning.

Insight into a landslide in Belgium.
points of interest within the landscape, while at the smaller end of the scale, everything needs to be hugely scaled up to allow the data to fit inside the tracked space of the VR environment. All these movements and shifts in scale need to be directly controlled by the user, as naturally as possible.

Professor Havenith’s group uses a combination of different data sources to create their larger immersive VR landscapes. This usually involves geomoodels with a digital elevation model (DEM) for the surface, alongside subsurface information about the geology and seismic setting, including fault lines or earthquake hypocentres. Such information comes from seismic or electric tomography and other logging methods. The data then need to be georeferenced using the 3D modelling software before being imported into the VR environment. The user is generally equipped with a state of the art headset to allow them to move inside and direct the VR experience.

Students attending lectures in the Department of Geology at Liege University are now treated to many different VR environments aimed at enhancing their learning. These range from viewing a dinosaur in immersive 3D, to visiting a subduction zone down at the mantle boundary or getting inside a crystal and studying its form at a nanometre scale.

**THE MISSING DIMENSION**

Professor Havenith and his colleagues are currently working to improve one particular aspect of VR visualisation – the time component – to make a fully 4D experience possible. Most people within the VR community agree that time is often the forgotten component of the 4D space and there is much work that needs to be done to improve this.

The GeoRisk and Environment Research Unit are currently focusing on geological hazard and risk perception. In a 2017 paper, they discuss how, “geohazard assessment ([ii]) a prime target for VR applications as spatial and temporal components are equally important for related research […] other geoscience disciplines are typically either more ‘spatial’ or more ‘temporal’, for instance ‘time’ is the predominant element in the field of palaeontology whereas for structural geology spatial aspects are far more important.”

In this same paper, Havenith et al. discuss a number of their current projects. One example includes the study of a landslide site in the seismically active Hockai Fault Zone in East Belgium. Using high resolution light detection and ranging (LIDAR) data for the surface alongside subsurface geophysics such as seismic refraction and electrical resistivity tomography, they were able to map out the source of the fail and trace it within a conglomerate layer – all viewed by a 3D stereo-visualisation headset system.

They also work in the seismically active Tian Shan Mountains of Central Asia and have developed local and regional 3D models that support landslide and earthquake hazard analyses at various scales. Those include the areas of the Rogun Dam construction site in Tajikistan where they can simulate rock fall scenarios for a given earthquake size. Perhaps the team’s most exciting work to date is on earthquake risk assessment in Haiti. Here they plan to combine research and education activities with VR systems to create an innovative way of communicating risk, promote risk awareness and inform decision makers.

As the technology behind VR becomes ever more accessible it is beginning to take its place within research and education centres. The team are developing applications to allow better access to the technology and organise training for potential partners, NGO collaborators and teachers. The new Geosciences Master program at Haiti State University will also include the use of VR technology.

Geologists have always been cursed by their inability to experience processes or visit sites of interest, whether due to their scale – from the universal to the nanoscale, or due to the vast range of timescales involved which often don’t sit neatly within the human lifespan. On top of this, it is often the scientist’s job to explain these processes – either to students or policy makers. Humans tend to have very limited memories or powers of foresight when it comes to watching a process evolve over time. The work of Hans-Balder Havenith, Philippe Cerfontaine and Anne-Sophie Mreyen and their colleagues provides a way to change this.

It may not be a cure, but it is certainly an invaluable tool for the geologists of the future.