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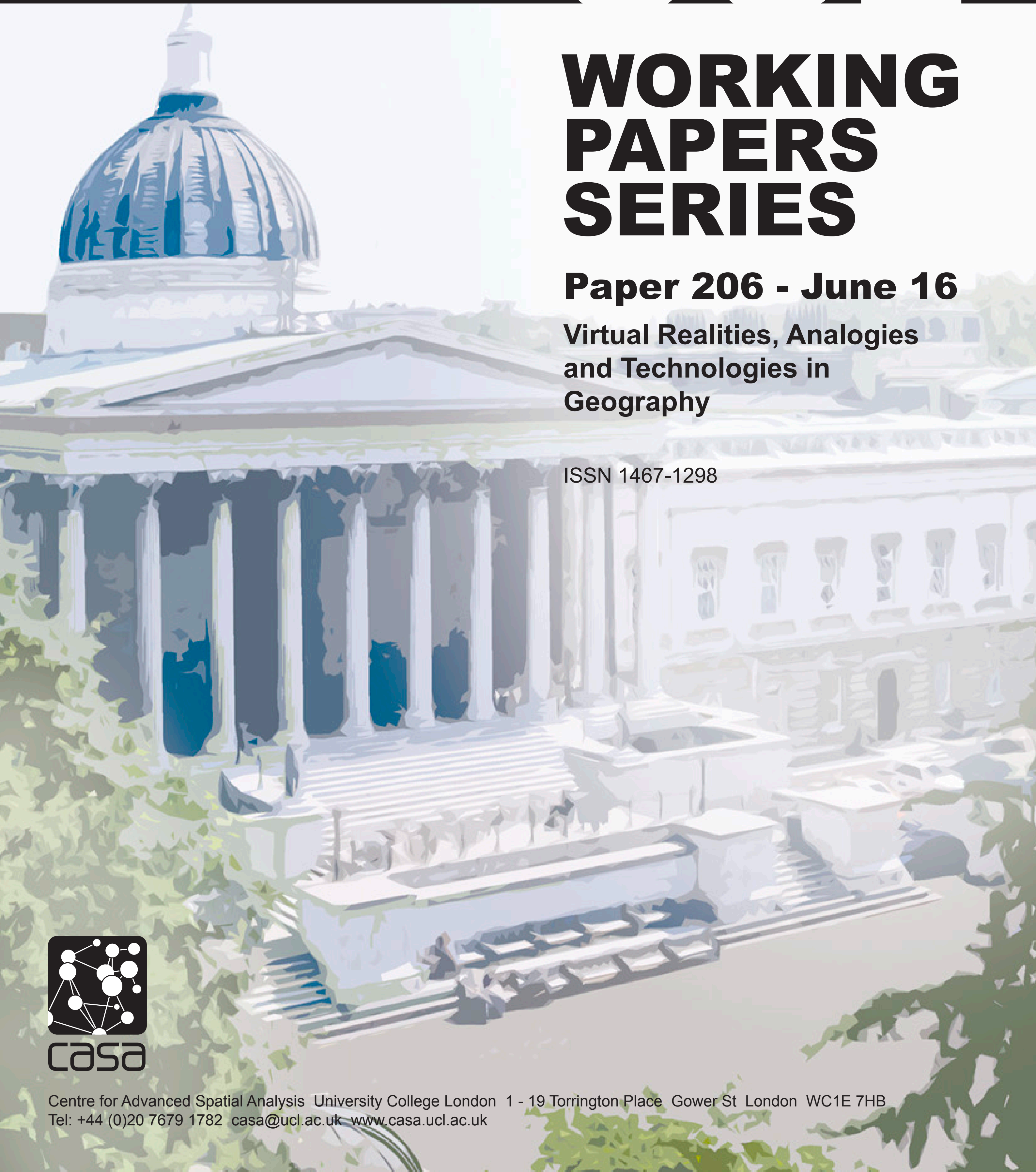

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Virtual Realities, Analogies and Technologies in Geography[1]

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Abstract

Virtual reality (VR) has entered geography in various guises over the last twenty years, building on the basic notion that when users of digital technology need to be immersed in the experience of computation, then special purpose technologies and environments must be built to make this possible. We review the brief history of this field and then focus on four distinct developments that mark contemporary technologies: 3D representations which are best seen in virtual city models, virtual worlds which mix humans, computable agents and geographic motion, virtual geographic environments (VGEs) which integrate model processes and users in integrated collaborative spaces, and augmented realities which mix the real and the virtual using analogies which incorporate mixed and blended virtual environments. We conclude by arguing that the use of VR in geography is by no means in a stable state and that we might expect quite profound developments in these technologies where users and computers are integrated in diverse and surprising ways in the not-too-distant future.

Key Words

virtual reality (VR); virtual worlds; 3D representations; augmented reality; material analogies

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[1] Barney Warf (Editor)(2016) **Handbook on Geographies of Technology**, Edward Elgar, Cheltenham, UK, forthcoming.

Introduction

From one perspective, all digital representation and simulation implies a virtual reality (VR) in which the world is abstracted and then manipulated using various kinds of computation. Indeed one could argue that any kind of abstraction, hence our ability to stand back from the real world and make sense of it, involves constructing a virtual reality although in terms of digital representation, the way we manipulate such a world is very different from anything prior to the introduction of computers in the middle of the last century. Digital computers are universal machines and hence the worlds that can be represented contain a generic mode of manipulation that involves producing changes to the virtual world that are impermanent and disappear (notwithstanding that such simulations can be captured digitally) once the devices are switched off. Strict virtual reality systems however are somewhat narrower than digital representation and simulation in general for the virtual worlds we will introduce here are characterised by an intrinsic link between the computable world itself and the way we as users of this world interact directly with it. Unlike the wider spectrum of computer models for example, virtual reality systems engage the user interactively in that the user changes the world with the world also changing the behaviour of the user. Virtual reality systems always involve this two-way traffic; they are thus said to be 'immersive' meaning that users interact directly with the world. But as we will see, there are many different kinds of immersion across a continuum from relatively passive interaction to complete immersion where there is little obvious difference between the user and the world itself.

Our implicit definition of VR is clearly illustrated in its short history. In the mid 1980s, Jaron Lanier who is the accredited populariser of the term, devised various artefacts that enabled users to directly interact with computable objects in which they could manipulate their own actions using devices such as the data glove and 3D goggles (Lewis, 1994). Right from the word go, this kind of interaction came to characterise VR with the user seeing, pointing at and touching the digital media in diverse ways, hence changing its form through literally 'hands-on' computation. Just as games were integral to driving the PC revolution forward, they were also instrumental in pushing VR. By the mid 1990s, gloves and related devices were followed by entire environments where the user could be immersed in a physical space such as a theatre or a room (sometimes called a CAVE) whose walls were controlled by computable media and in which users could interact with this media in 3D through various modes of touch.

Most VR systems until then were based on physically connecting users to machines but by the late 1990s, once computers had more or less converged with communications through the internet, VR came to be extended to networked environments. Online games emerged while virtual worlds were constructed using network software producing environments that although local, were controlled by users at remote locations. In particular, the emergence of virtual worlds represents a synthesis of networked communications, 3D virtual environments, and interactive gaming platforms where users might appear alongside each other as avatars. These avatars can interact with other computable objects, some controlled by other users acting autonomously with respect to other objects in the scene but with some objects simply acting as programmed by developers outside the immediate VR scene. Such worlds enable many different kinds of feedback between humans and computable objects which generate realities that are very different from the real world, that enrich the real world through such interactions as well as providing environments to explore future worlds as yet unrealised.

Currently we can distinguish between several types of VR environment that link users to computable representations and simulations in two-way fashion. First we have ***standalone personal environments*** which represent the lineage from Lanier's data glove to contemporary headsets such as Samsung's Galaxy **Gear VR** which are primarily used for gaming but which are now completely affordable and represent the wave of the future in personal VR. High end versions such as those produced by Oculus VR might also be networked and it now goes without saying that all the systems available can exist in networked desktop form. Second there are ***purpose-built environments*** such as VR Theatres and CAVEs which enable large numbers of users to participate in a virtual scene, where human-human as well as human-computer interaction is important. These systems are increasingly used for professional and scientific purposes although they can be used for gaming. Third there are ***virtual worlds*** that exist on the desktop of networked environments in which human users can appear as avatars alongside computable objects with whom they interact. The **Unity** platform provides such a virtual world with the focus on many uses from gaming to professional digital design. Fourth there are ***mixed environments*** which consist of a mixture of human interaction, global network access, gaming environments, and general purpose access to the digital world, often using various human-computer interactive tools such as those based on point and click, even sensory inputs. These are hard to classify but they do represent the most widely used of all VR environments, largely because they consist of stitching very different forms of human-computer interaction together. Last but not least, these are ***hybrid analogue environments*** where digital representation is projected back onto the real world and where human interactions are both with analogue and digital representations of the same phenomena. Sand tables, physical data tables, even touch tables and all kinds of surface access represent the contemporary realisation of these developments.

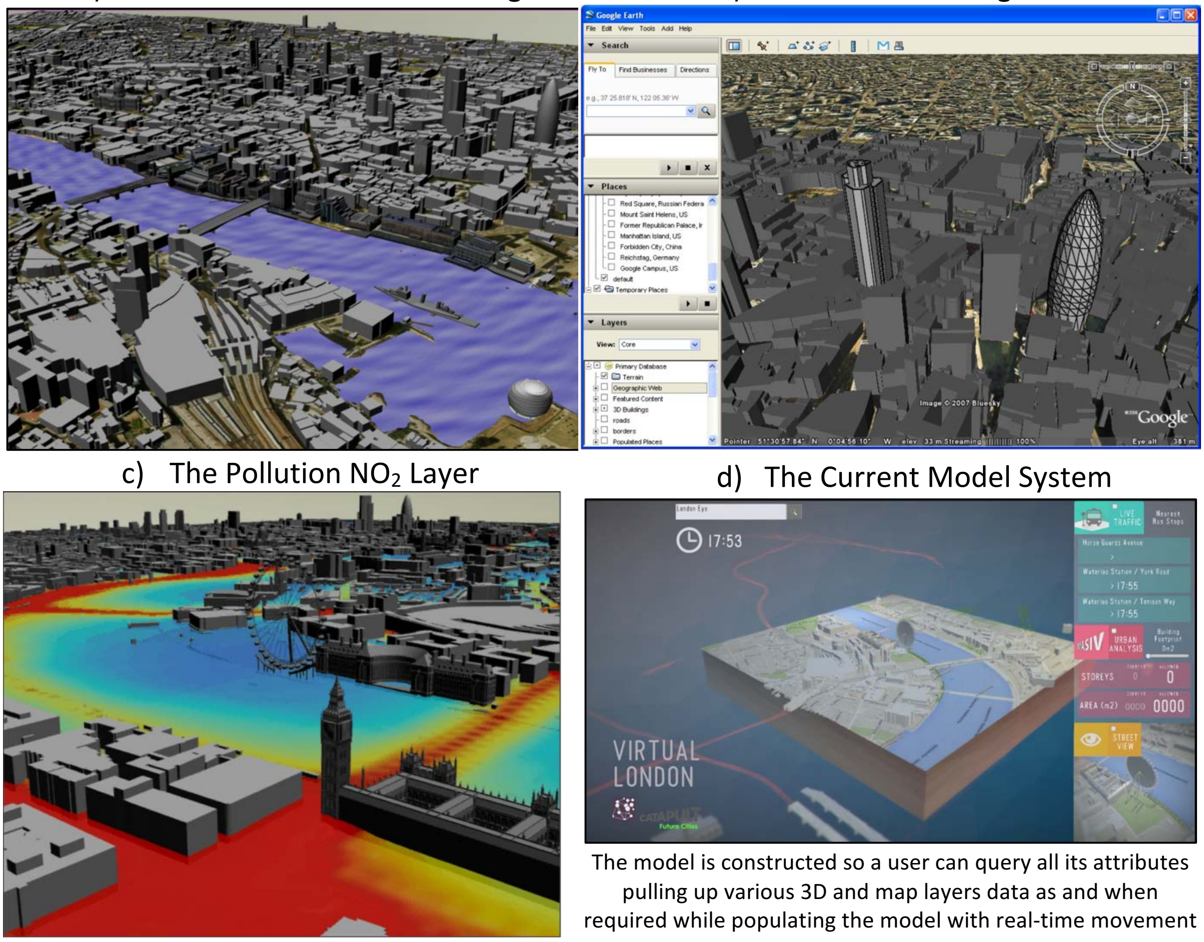
In our survey of VR technologies in geography, we cannot provide examples of all the many different types of system. We will thus avoid gaming software although a considerable body of such software does exist for both educational and professional purposes and this is relevant to our wider quest of grounding the role of VR in other technologies in geography. Our focus here will be on how VR technologies have developed in relation to other software technologies such as geographic information systems (GIS) which in turn embody spatial analytics, simulation modelling, and remote sensing amongst other developments in digital geography. We will also focus here on virtual environments that are integrated in some sense with GIS and Computer-Aided Design (CAD) methods and we will follow a line of development that embraces all these technologies under the banner of *Virtual Geographic Environments* or VGEs (Lin and Batty, 2011). We define these environments as "… computer-based digital spaces that we can observe, participate in, and experience in person" (Lin et al., 2015, p493). In particular, VGEs are something more than virtual realities *per se* for we argue that they deal with functions of the environment that are process-based. To an extent whenever we define complex topics such as VR, we encounter many new definitions that we must be specific about and by process-based, we mean that such VGEs embody geographic processes that evolve to forms of spatial organisation in space and time; in short they embody geographic models of various kinds and this will be our criterion for the selection of examples in the rest of this chapter.

We will begin with traditional standalone desktop environments which traditionally have been associated with single users but are rapidly being ported to the networked world. Our focus will be on 3D representations of cities which extend the idea of the digital map and immediately embrace the key idea in VR that the user moves through the scene. Motion is central to VR usually through the way users interact with the media but also in VGEs through the processes that are embodied in the scene. We will then move to networked environments which give equal importance to the user and the scene within virtual worlds, either on the desktop but increasingly across web-based portals that define the ways in which such worlds are configured. We will not spend very much time dealing with purpose-built hardware-software environments such as VR theatres for these have become commonplace. In many professional and now in retail environments, large screen displays with some multimedia are widely available and even TV technologies are embracing VR in the home. The cutting edge is now much more focussed on usage and the processes of engagement with the media than on the technology and in the examples we show we will focus on these features. We will then discuss mixed media realities which we call VGEs – virtual geographic environments – and illustrate how we can integrate different kinds of media in desktop and networked form. Last but not least we will move back from the virtual to the real world, illustrating how we might think of virtual realities as analogies, as analogues of the real world where we mix VR and ordinary human engagement. As we have implied, VR is now everywhere in contemporary life, accessible from the most common of our devices, our TVs and our smart phones. What we will provide here is a snapshot of this world as it pertains to geography, particularly but not exclusively to the geography of the city. To see how far we have come, look at Fisher and Unwin's (2001) edited collection of fifteen years ago entitled **Virtual Reality in Geography**. Read the progress report by Batty (2008) a little later but written ten years ago now and then consider this chapter and speculate on how this world will continue to change over the next fifteen years, to the year 2030.

3D Representations: Virtual City Models

When Ira Lowry (1965) wrote his seminal article "A Short Course in Model Design", there was a widely known distinction between iconic models and symbolic models. Symbolic were mathematical models whose functions could be formalised and thus programmed, hence implemented on digital computers for predictive purposes. They were regarded as an order more powerful and influential than iconic models which were essentially more superficial representations of systems with little or no predictive power. In the urban domain, such iconic models were essentially architectural constructions often of the building volumes at a much smaller scale than the real thing which could only be viewed from the outside. Interiors required separate iconic model representations. In the 1960s, there was barely any recognition that such icons could be made digital and it was only the rise of computer graphics where the graphic content was stored in the frame buffer of a computer – often as an add-on to computer memory – that led to digital representations. It was not until the 1980s when personal computers accelerated the rise of graphics and graphical user interfaces that such digital forms could be constructed routinely (Batty, 1987) and even then it would require the much more powerful miniaturisation that marked chip production in the 1990s to really reach the point where 3D iconic representations became truly digital.

The first 3D urban models were developed by large architectural firms such as Owings Skidmore and Merrill in the early 1980s. These were wire frame affairs where the buildings lacked solidity but right from the beginning the way to view these models was to interact within them: to fly through the scene and to navigate within the media. Thus 3D representation required more than simply passive map viewing which of course marked the development of computer cartography and GIS. The complexity of 3D was such that the models required direct interaction with the user and this still largely consists of navigation although more recently these models have been populated with many attributes which can be picked up and interrogated analytically as part of the navigation process. In fact by the early 2000s, another development had taken place. From the 1980s, first mini-computers, then workstations, and finally PCs embraced graphics algorithms which were hardwired into the machines themselves with 3D rendering, hidden-line elimination and all the transformations required to scale and rotate objects around being embodied within the geometry engines which became integral to the machines themselves. This enabled almost instantaneous rendering on-the-fly which is an obvious prerequisite to acceptable fly through and navigation.



a) The 2003 Model with Flooding

b) The Model in Google Earth

c) The Pollution NO_2 Layer

d) The Current Model System

The model is constructed so a user can query all its attributes pulling up various 3D and map layers data as and when required while populating the model with real-time movement

Figure 1: Various Renditions of a Traditional Virtual Reality: The 3D London Model

By the early 2000s, the relevant hardware and software made the construction of these 3D environments routine with systems ranging from ERSI's **ArcGIS** to Autodesk's **3ds Max**. Quite large scale 3D city models with thousands of blocks can be constructed in a matter of hours if terrain, building polygon and height data from LIDAR are readily available. We built our first models for London only a year or so before **Google Earth** released its 3D globe in 2004 and began populating this with 3D building blocks (Batty and Hudson-Smith, 2005). We illustrate such a 3D block model for the centre of London in Figure 1(a) where it is immediately obvious that there is little detailed rendering. Out of about 50,000 building blocks in this model, only some 1% are rendered in high detail for the purpose of this kind of virtual reality is to provide a 3D version of the 2D map – to populate the 3D content with attribute data pertaining to the building blocks while also enabling users to layer different surfaces across the scene associating the underlying geometry with other key geographic layers such as pollution, flooding and so on. In Figure 1(b) we show the same model in **Google Earth** which enables us to use all the functionality of that reality (such as **StreetView** and so on) to inform the user about the scene. In Figure 1(a) we also show how the River Thames begins to flood the south bank were it to rise by 1 metre (which is what the IPCC are forecasting for the North Sea off Eastern Britain by the year 2100) and in Figure 1(c) we show the layer of nitrogen dioxide, a particular pollutant associated with road traffic, in an area of central London adjacent to the Parliament.

The model in Figure 1(d) is our current model that is designed to provide considerably more flexibility to the user in that the move to using these block models as visual data bases is taken to an extreme. The long standing idea of using the model to visualize the aesthetics of the city is not within the mission of this kind of modelling for the interface is designed as a working link to the kinds of data the user can generate on-the-fly. Various analytics are accessible through this interface while the model can also be populated by importing movement streams generated from data and predictions from agent-based models of pedestrian and traffic flow. Another feature that has emerged from these kinds of 3D block model is to populate them with data that is not usually associated with 3D representations. In the development of real-time streaming of data from computers and sensors embedded in the built environment or used in a mobile context to capture media as through smart phones, such data can provide a visual animation of how geographic space and its attributes is continually changing. Rather than provide an animated map – and such maps are also part of the wider domain of virtual reality – what we demonstrate here is how we can use the 3D model to tag data that changes in real time to the building blocks. If we then associate the numeric values of the data to the building heights – in effect, we are proposing a mapping of a real-time locational data set to the locations associated with the building blocks – we can vary the building heights according the real-time data. In Figure 2 (a), we show another virtual London model which is built using ESRI's **City Engine** software where the heights of the buildings are proportional to the number of persons located at those buildings who are sending Tweets which are tagged to the geographical coordinates of the place. The key features of such a visualization is to associate the number and time of the Tweets with the buildings (http://en-topia.blogspot.hk/2013/07/tweetcity-re-populating-london.html). The snapshot in Figure 2 is taken from 15 hours worth of geotagged Tweets in central London on July 1st 2013 where is is clear that the dominant places where people tweet is in places of entertainment such as museums, places where people come together at transport hubs such as mainline railway stations as well as places where people cluster for shopping. In Figure 2(b) we associate the 3D visualization of Tweets in London with a real-time map of who is tweeting taken from the **GoGeo** site (www.gogeo.io) which displays the last 48 hours worth of geotagged Tweets worldwide. We show the intensity of the Tweets and it is possible to zoom in and pull up the text of individual Tweets. We have not seen anyone link this massive data base of Tweets to 3d visualization – linking Figure 2a) to 2b) – but this seems eminently feasible and such possibilities of extending this kind virtuality now appear endless at the time of writing (early 2016).

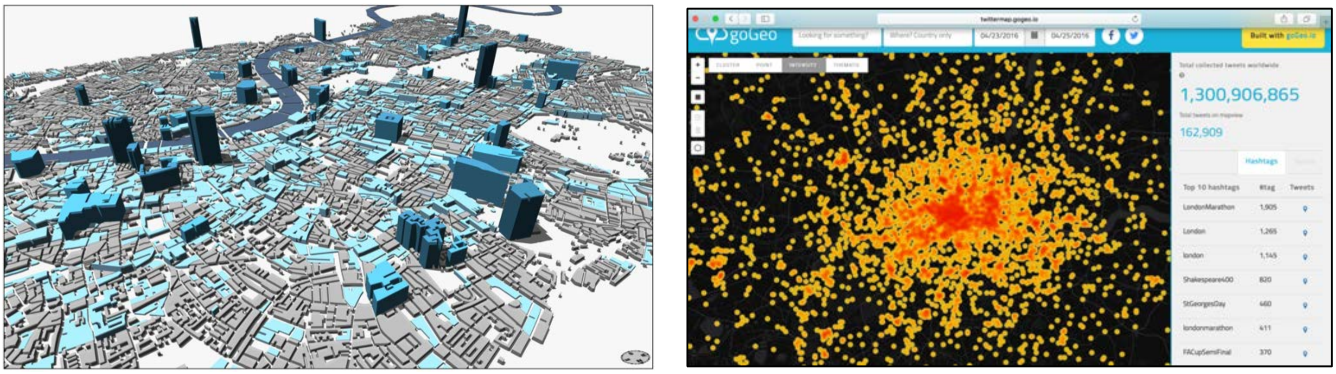


*Figure 2: Representations of Real-Time Tweets a) 3568 Tweets in Central London Over 15 Hours and 40 Minutes (1 July 2013) b) Geotagged Tweets from **GoGeo's** Twitter Access Over a 48 Hour Period in Central London (23-25 April 2016)*

To an extent we have already moved beyond traditional desktop VR. The current Virtual London model is networked as is the visualisation of real-time data within it. It is now quite straightforward to give access to many users and this changes the nature of traditional VR quite substantially. But to progress we now need to outline the virtual worlds movement which has long been headed for convergence with 3D media, and indeed requires this for its continued realisation and development.

Virtual Worlds: Mixing Humans, Computable Agents and Geographic Motion

Our examples so far have mixed various computer technologies in diverse ways and do not show any of the purist focus of VR characterising earlier developments. In our extensions to 3D technology on the desktop, networked systems enable agents and real users to be mixed while real-time streaming of data associated with the emergence of the smart city is now providing a strong direction to such virtual worlds. Figure 3 indicates the kinds of developments that have taken place during the last 30 years. The picture on the left shows two well-known British planners pointing to an iconic model for the reconstruction of the town of Plymouth which was heavily bombed during World War 2. The picture from 1944 shows all the science that has since become computerised. Of course the iconic model has become digital and the participants can now appear as avatars in a virtual world where they engage in immediate interaction even though they might be linked in from remote sites. Other features of the traditional scenes as portrayed in the maps on the wall show flow systems and histograms which have all become computerised and whose data can be easily ported now to the virtual world. In the right panel of Figure 3, traditional iconic models of inner and central London are augmented by various digital technologies, mixing the real with the virtual, the direct with the augmented in different blends, and this is fast becoming the norm in cutting edge virtual reality systems.

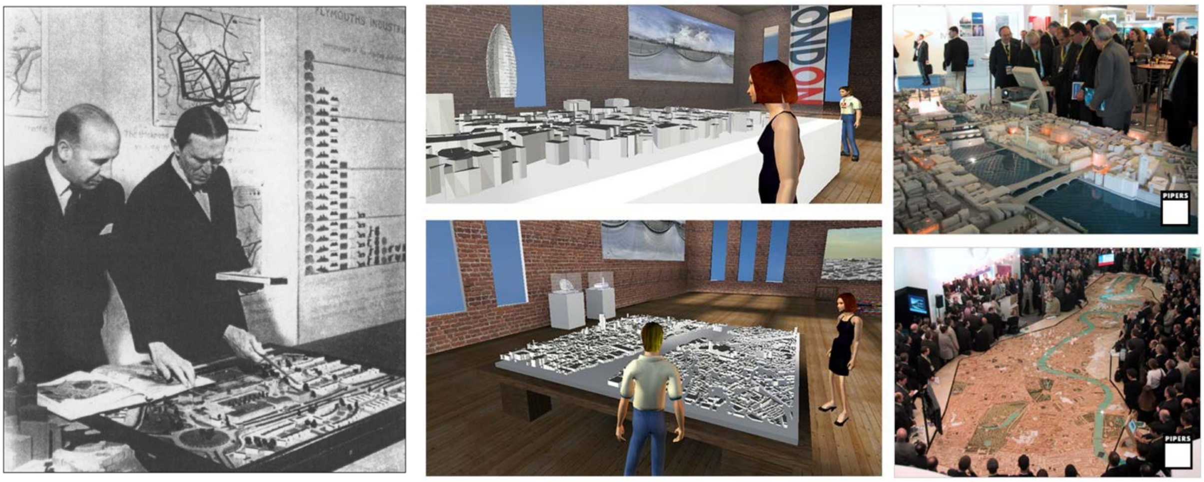


Figure 3: From Real to Virtual Worlds: Professionals and Iconic Models to Avatars and Networked Digital 3D Environments

(left) James Paton Watson and Sir Patrick Abercrombie use an iconic model of Plymouth (1944) to point to specific developments while (centre) two avatars controlled by users from remote places engage in discussion to position the Gherkin building in the City of London (2005). Professionals (right) associated with the planning of London examine large scale iconic models of London augmented with various information technologies that complement traditional media (2005).

There are many types of virtual world in which these realities can be constructed and in the one shown in the centre panel of Figure 3 – **Second Life** – gained enormous momentum during the early 2000s. But continual innovation almost guarantees a fast turnover of software systems which make use of new media, and one of the platforms that we are illustrating in this chapter is **Unity 3D**. In Figure 1(d) we show a working prototype of this platform where the media is the virtual 3D city through which a user can navigate and upload and download attribute data associated with any location which has been populated with such data. **Unity** is not strictly a virtual world in the sense of **Second Life** but this is simply a matter of taste in our view for **Unity** is essentially a games engine which has multi-user capabilities through the usual kinds of networked systems that enable many users to interact in a virtual environment. In fact, VR systems like **Unity** tend to be more restrictive than massively multi-player online worlds but much depends on what extent the user requires rapid motion in navigation. In the somewhat more research-based worlds that we are involved with here, shoot'em up capabilities are not required and thus there is an increasingly wide choice of platforms. Moreover, more custom-built platforms are likely to characterise geographic applications such as the one that has been built for the campus of the Chinese University of Hong Kong which we will demonstrate here.

In Figure 4, we show the kind of virtual environment constructed for a major university which can be used for many different purposes. Our focus here is not on navigation through the campus *per se* but on how we can capture and import information about the experience of the real users and how this can be incorporated in virtual movement through the campus. Imagine a 'user' or participant walking through the campus and being equipped with sensing devices that pick up noise and pollution that is experienced as the users encounter different sensory experiences relating to what they see and hear and what they are exposed to (Hu et al., 2011). This kind of data can be captured via mobile devices which we show in Figure 4 –

sensing devices which are portable linked to smart phones that enable these sensory data which is captured to be imported continually into an archive of data on the web that is thence picked up by the apps on the smart phone. This then controls the user as an avatar providing immediate feedback as to the way the environment is perceived. This is an ambitious project that seeks to encode the avatar's behaviour into a form that is influenced by the sensed data (Che et al., 2014). In short the virtual world and its avatars behave according to the real world data that is imported into the world and users thus condition the behaviours of the virtual agents. One can imagine generating better behavioural data from this kind of experience which in turn produces much more realistic navigation in virtual worlds (Hu et al., 2014).

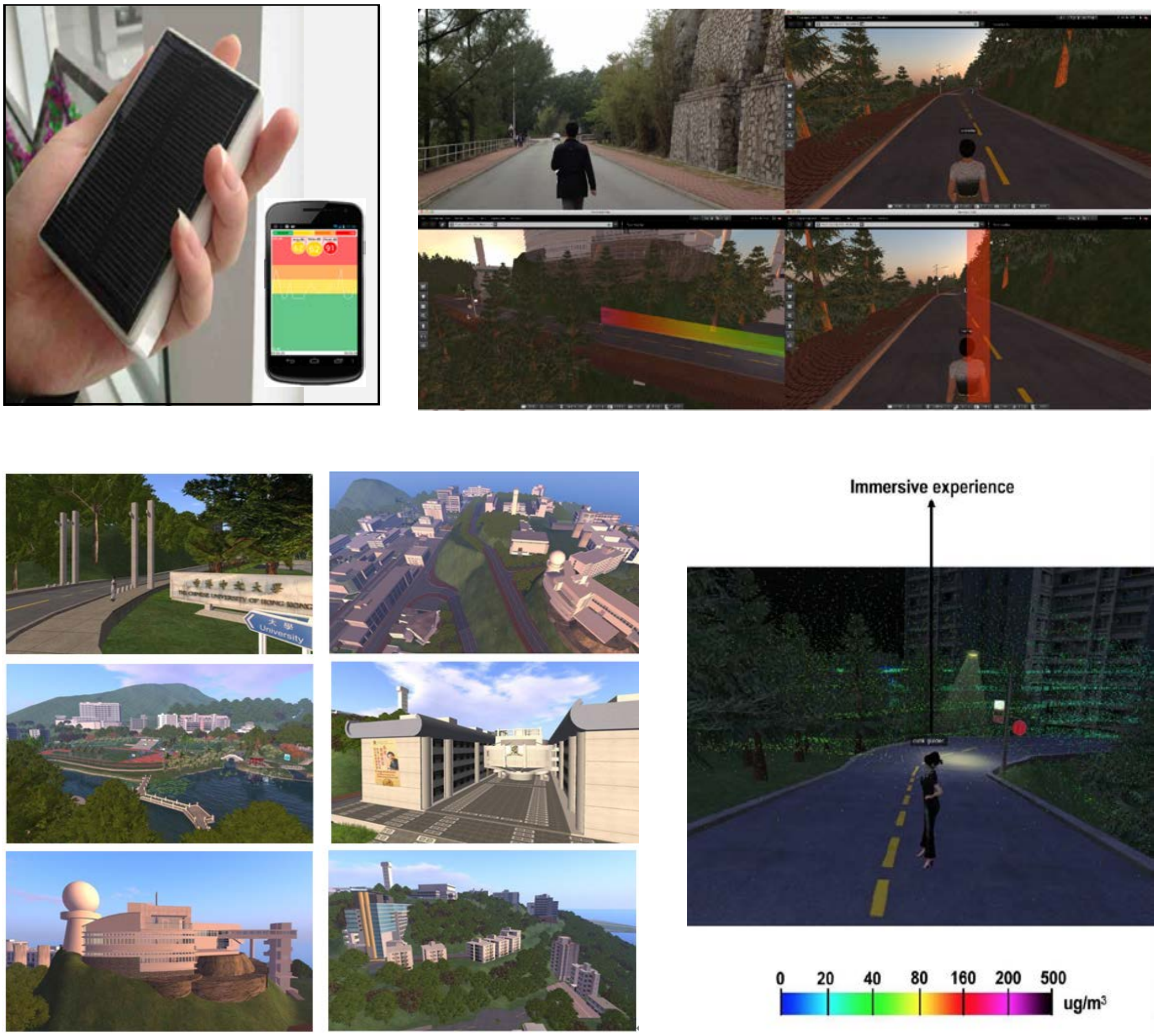


Figure 4: Inputting Environmental Data – Cognitive Responses to Light, Sound and Pollution – into a Virtual World Through Real-Time Sensing

All we can do to give some sense of how we build such a virtual environment is to show the impressionistic collage of devices and pictures in Figure 4. With the emergence of low-power and inexpensive sensing and wireless communication devices, the kind of crowdsourcing and mobile sensing we show in Figure 4 has the ability to monitor a wide variety of environmental change and human activity at the city scale. Using geo-sensor and mobile data collection approaches, massive and timely environmental data can be acquired for simulation and analysis through a virtual world. To achieve this, in Figure 4 (at the top left) a portable kit based on a sensor, mobile application and an external network server collects environmental information by specific sensors and communicate using smart phones via Bluetooth transferring the measured data (e.g. air quality, temperature, humidity, noise, etc.) to the user's phone in real-time. The mobile sensor along with a hand-held sensor system makes up the basic environmental data collection station. As an integrated platform for data management, analysis and representation, this is our basic example of a geographic virtual environment (VGE). The virtual world – a university campus composed of an interaction between a natural and social environment – is characterized by hilly terrain, complex buildings, composite road and path networks, unique geographic phenomena and social behaviours. In this example, the project is building a sharable virtual cognitive space that can help in enhancing our understanding of environmental protection concepts and awareness.

The Move to Virtual Geographic Environments

VGEs are essentially digital environments that integrate diverse VR technologies. They have strong graphic image-ability as do all VR systems but they also link input data to process simulations of many kinds (Lin et al., 2013a). They are beyond representation *per se* although they invoke all the main features of computer cartography, GIS, and 3D visualisation through models of geographic systems that are driven by natural and human processes. The key to VGE is that they simulate processes in the geographic environment as well as engaging multiple users in analysis. Unlike VR games environments that may be networked to involve many users, VGEs are more analytic in their usage and enable professional and research users to engage in analysis in a coordinated but active way. They thus represent a form of crowdsourcing but without the frenetic activity that characterises many games and they also require users to be expert or at least to be exposed to learning and generating greater expertise about the project and problem of their concern. To an extent, the virtual world of the university campus and the extended model of Virtual London that we illustrated in previous sections were VGEs but at a much finer scale and did not involve the kinds of analytics that characterise the examples here which are at a much larger, coarser regional and global scale.

In Figure 5, we extend our modelling of air pollution from the campus scale virtual environment to the regional where we show that environmental pollution has a wide sphere of influence, high occurrence, strong outbursts and intense spatial and temporal incidence due to global climate change and related human activities. Its impact on regional ecological security and sustainable development is substantial and thus a collaborative system for sensing and measuring its impact is required and this lies at the basis of this collaborative VGE where we are able to carry out a distributed regional environmental simulation. These experiments not only help construct environments that are difficult to build, but also save costs and resources in developing policies to mitigate the dis-benefits that such environmental pollution generates. The system is a convenient way to package information for experts and decision makers who are able to communicate through the VGE, and collaborate in designing and testing the impact of environmental policies. For instance, this VGE is designed for the analysis of air and water pollution management across the Pearl River

Delta which includes over 60 million populations in Guangdong province, Hong Kong and Macau. The system integrates point, line and surface source data, is able to reconstruct data for coupled climate and pollutant dispersion models while imitating related problems, and it can advance forward different early warning programs through joint-selection models. Decision makers can engage in discussion of many policy initiatives that relate to such early warning systems as well as coordinate environmental policy through many different agencies across a very diverse region (Lin at al., 2013b).

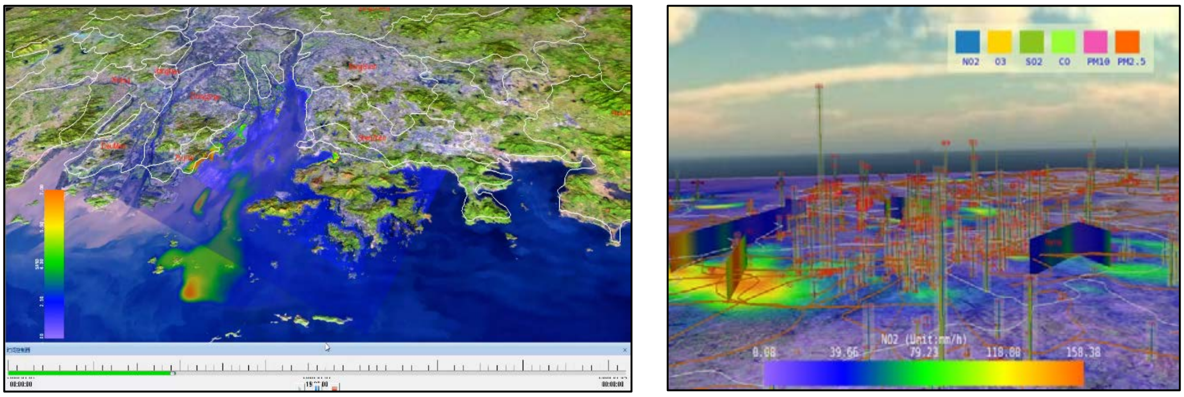


Figure 5: A Collaborative Virtual Geographic Environment Showing Regional Sources of Different Air Pollutants in Map Form (left) and 3D (right)

Moving to the national and global scales, VGEs tend to be less visually interactive but nevertheless embrace many more decision-makers of different types reflecting local elements in the global picture. Global change is both a complicated and comprehensive issue involving population, land use, the earth system, and multiple agencies reflecting very kinds of mission and politics. In this context, human activities are affecting the earth system at an unprecedented rate. Meanwhile, urbanization, the continuing but changing population explosion and its consequences for migration coupled with an excessive use of resources has severely hindered sustainable development. Utilizing a multi-dimensional representation at the geospatial system science level, VGE can visualize the spatiotemporal variational processes of the earth system's mechanism which help define the impact of human activities on the global system. VGEs which encapsulate global change are being built as open platforms for collaborative simulations and evaluations focused on model integration, reuse, optimization and collaboration. Model integration considers how scales which are mismatched can be fused, how different VGE models developed by different teams with different development styles can be integrated and reused, while flexible patterns of interaction and collaboration for different modes of collaborative modelling and optimization can be developed (Hu et al., 2011; Hu et al., 2014; Che et al., 2014). These systems are rapidly being developed at the present time and promise to extend VR technologies way beyond their traditional game-like usage, merging more generally with a massive range of new technologies from real-time sensing and the streaming of big data to global decision-making which is informed by models and data that are essentially being developed in remote locations and accessible through cloud computing.

The Real and the Virtual: Analogies Incorporating Mixed, Augmented and Blended Environments

Earlier in this chapter we illustrated traditional iconic models and how these had become digital forming the essence of 3D virtual environments such as those that characterise the virtual city. In the rapid move towards the digitisation of society, there is now a feeling that something is being lost by separating the virtual from the real, and there are a variety of initiatives in VR which are moving these technologies back to the material world. We have found that it is extremely difficult to engage users to their full extent in a purely virtual world where they appear as avatars even if their presence is controlled by themselves from remote locations. In short, users are much more receptive to discussion of the problems that virtual worlds seek to represent and motivate if they are able to do this in the context of the real world. To this end, there are various ways in which physical projections of the virtual world onto the material might be used to structure this kind of engagement. For example, touch tables of various kinds projecting data and simulations onto the physical medium of the screen as a table, the table as formed by sculptural surfaces such as sand, or by harder physical media such as wood or plastic are being used in ingenious ways. In Figure 6(a) we show how data associated with Greater London which is generated digitally can be projected back onto what we call the London Data Table which engages people in discussion, analytical thinking and design in ways that are much richer than solely within a virtual world. In Figure 6(b), we show **SimTable** which is a sand table developed by the Redfish Group in Santa Fe, NM to simulate hazardous diffusion of wild fire and associated phenomena where a cellular automata model simulates the spread while the user activates various policies to stop the spread by pointing at the displayed visual functions in the media on the surface of the sand. The same kinds of rich engagement as in the case of the London table are encapsulated by this media.

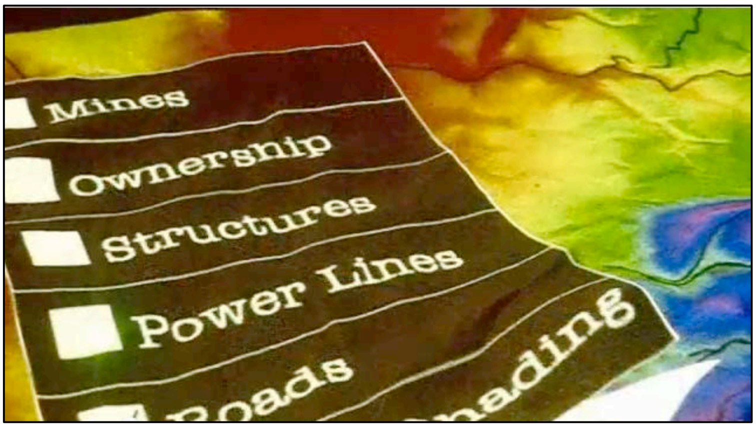


*Figure 6: Projecting the Virtual onto the Material: a) The London Data Table (Wood) b) RedFish's **SimTable** (Sand) see https://www.simtable.com/portfolio-items/a-defense-case-study-here/*

There are many other blends of the virtual with the material. In Figure 7, we illustrate how a person can fly through a virtual world built from **Google Earth** in which various other media exist, navigating by performing various actions – essentially flying through the scenes as a bird might navigate. This facility in built using Microsoft's **Kinect** – the motion sensor for the Xbox

360 gaming console – which provides an intuitively obvious medium for navigation without any obvious controller other than the human user. This is a kind of augmented reality but in the same scene we show the more immersive form where the user wears the Oculus headset whose goggles converge on the 3D experience of flying through a virtual city. As we noted above, these technologies are now quite affordable such as the Samsung **Gear VR** and there are now countless ways of enabling many users to coordinate and share experiences using such technologies.

Figure 7: Flying Through Virtual London: Augmented Reality Using ***Kinect Xbox*** *Console (main picture) An* ***Oculus Rift*** *Headset Fly Through (inset)*

Figure 8: A Model of the London Riots: Choosing Policies that Minimise Damage Using Material Objects – Lego Police and Vehicles – to Control Policing and to Contain Rioters

Our last example shows how we can augment the reality by using material objects to activate and control a simulation of movements across a city region. We built a model of the London Riots in 2012 using agent-based simulation (Davies et al., 2013) whose media is projected on the touch table shown in Figure 8. To manage the riots there was a considerable police presence and we enabled this using icons of the police agents to activate certain policies and policing. The agents' positioning above the table and their activation through pressure/touch enabled the riots to be contained – the diffusion of the other agents to be manipulated – and to this was added a cost-benefit calculation associated with minimising the damage that was done by the rioters. In this sense, it is easy to see how users of the system can configure policies that will optimise the role of policing.

Conclusions: Whither VR in Geography?

We are still in the midst of a digital revolution which has moved computation from the main frame to the smart phone and has seen digital usage spread out from the laboratory to the city, the nation and the globe. Virtual realities now dominate usage to the point where the traditional usage which was largely immersive is now being augmented by all kinds of media juxtaposed in diverse and often unusual ways. What we have not explored here which is almost bound to be significant in the next decade is the spreading out of computers into ourselves. The spaces we inhabit are being rapidly computerised but our own bodies will be the next frontier as modern medicine continues to embrace computation. Medicine as software will continue in the treatment of illness but the notion that we will embed computers into ourselves is likely to generate all kinds of unprecedented and strange uses that will move this field on once again as we find new ways to communicate with one another.

Much of what we have discussed in this chapter involves ways in which we can now interface these technologies with one another as well as with ourselves. We have not however talked very much about the smart city and the way our environments are becoming digital. Most of our uses of VR have been to address traditional geographies, of nature or of human spaces that we have generated, not about how computers are entering those geographies and changing them. After all geography is about how we interpret our spatial world and as we change It through technology so our geography will change. Perhaps the most challenging aspect of computerised technologies is the notion that in the past we have used such technologies to study material space but these same technologies are now being used to construct digital spaces. This idea of using machines to study spaces composed of the same machines presents a recursion in thinking that is both profound and challenging. What is clear is that we are but at beginning of a long journey through the rest of this century when reality is being reconstituted in virtual terms and this promises to change the geography of technology as well as the technology of geography in ways that will continue to challenge and amaze.

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