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RESEARCH ARTICLE

Ubiquitous geographic information in the emergent Metaverse

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Abstract

We sketch a brief history of the development of virtual geographic environments which build on online gaming, three-dimensional representations of cities, and the notion that computer technologies are now so all pervasive that many different models of the same phenomenon, in this case, geospatial systems, can now be built. This enables new forms of analysis that let us explore future spatial scenarios which address key urban problems through virtual environments. These allow us to experiment with the near future and to this end, we identify three key issues. First, we look at how we can use new technologies to develop all-embracing digital environments which are loosely called the "Metaverse"; second, the development of many models which form various kinds of digital twins having different degrees of "closeness" to the real system; and third, the emergence of platform economies that are beginning to push Metaverse-like technologies into the economic world of networked markets. We conclude with suggestions that these technologies can be used to inform our plan-making capabilities, for example, through geodesign, and we suggest how we might address the key challenges that need to be addressed to make their approaches ever more relevant to urban planning.

1 | SETTING THE CONTEXT: A BRIEF HISTORY

Digital technologies first emerged as computers in the middle of the last century primarily for scientific calculations, but right from the onset, their inventors realized that anything that could be reduced to digital form–the binary code–could be manipulated and transformed using this logic. In this sense, the pioneers such as Alan Turing, John von Neumann, and Vannevar Bush argued that computers were "universal machines" and could be adapted to a very wide array of physical and human activities which went well beyond our original perceptions of them as machines for simply crunching numbers. In the beginning, another critical feature without which the digital world would never have developed was the fact that their operations using the switching of electric circuits could be dramatically miniaturized using silicon chip technologies and thus began a process of miniaturization accompanied by ever faster and ever-smaller machines which have now reached the point nearly 80 years after the invention of the transistor where they are small enough to be embedded into just about everything, even into ourselves. This process shows little sign of stopping, and we are about to confront a world where there are many, many more computers than there are people. As we write this short article, the number of computers we have switched on around us simply to help produce this text while handling other activities like email and web search in parallel is a lot more than ever envisaged when the computer first appeared. Indeed, the notion of a computer as a stand-alone object is beginning to disappear as computational technologies begin to define entire environments in which we live. A computational skin to the planet is fast being developed, and it is this that will provide new tools to manipulate and define ubiquitous geographic information.

In this sense, we say that computers have become all pervasive and the development of digital communication networks linking them together (loosely called the Internet) is now parcel of this emerging digital skin. In fact, if we look back to the time when the first industrial revolution began which was based on steam power, this heralded the invention of machines which led to a second revolution based on electric power. This prompted the third revolution which was the invention of computers, which has merged into a fourth where digital and biotechnologies are currently merging. We now stand at the threshold of a fifth revolution where such technologies are fusing into one another, and it is this that is dramatically disrupting organizational practices that are widely underpinned by digital technologies. To an extent, these revolutions have moved the world from a focus on energy to one on information where most of what we do in terms of the media we engage with for work and play, indeed life in general, now touches us digitally in some way.

In terms of the development of new computable environments that pertain to geospatial systems, computers led to big advances in the way we began to represent such systems in the 1980s when computer memory for the first time was directly associated with graphical-pictorial representations. This was dominated by the personal computer which led to the development of gaming technologies, largely but not exclusively for entertainment, and in parallel, there were unprecedented advances in computer graphics. In terms of cities and other spatial systems, in the 1990s, new ways of representation in the form of geographic information systems (GIS) rapidly emerged, while at the same time, new theories of how cities are structured and grow were implemented as computer models. We can now make a distinction between *GIS Technologies* (*GISt*) and the urban science built around this which we currently call *Urban Analytics* (*UA*); but, we also must make a distinction between the use of computer technologies to represent and model the system of interest and the way we can use computers to develop new planning methods such as computer-based *Planning Support Systems (PSS).*

2 | THE EMERGENCE OF DIGITAL ENVIRONMENTS

In this sense, the way we represent and model the world computationally represents one side of the same coin with the other pertaining to procedures and tools that enable us to pursue planning and problem-solving using digital technologies. In the sequel, we will refer to digital geographic environments as *representation*, new forms of analytics as *simulation*, and new digital problem-solving and decision-making processes as *organization*. We could write the history of the last 80 years in terms of these themes that define the broad scope of the digital world, but they are much more resonant with contemporary issues for the terminology has changed since digital computation began in the middle of the 20th century.

Computation first began with digital simulation. The first models were developed pertaining to the spatial structure of cities in the 1950s and 1960s, and there has been a proliferation of model types since then: land-use transportation based on social physics, spatial econometric models reflecting economic concepts involving markets and the optimization of utility and welfare, cellular automata models of physical development reflecting the growth and renewal of cities, microsimulation models reflecting individual demographic processes, and more generically agent-based modeling that can be applied to all these model types through their disaggregation down to the level of the group and individual. As computers have got ever faster and smaller and as data have got ever more extensive, and bigger, more disaggregate models have been developed, but their significance has been the development of more than one type of model for a single phenomenon.

In short, the idea of building more than one model of the same phenomena–pluralistic modeling as Helbing and Argota Sanchez-Vaquerizo (2022) refer to this–has become significant and in fact, more than one model is becoming the new normal. All of us have different perspectives on the key processes and structures that define geospatial systems and these are now being reflected in many different models that range from simple variants of one model type to many different ways of articulating the system of interest. Into this focus has come the idea that we need to consider models as having different degrees of closeness to the real thing and in this context, the *Digital Twin* has become important. There is considerable ambiguity relating to digital twins, not least in the terminology used, for if a twin is as close to the real system as it can be, then it merges with the real thing and becomes the real thing. But every model is an abstraction, a simplification that can be far from the real thing. The idea of many twins, many models, represents the new environment that developments in computation have begun to define. We will explore this idea of digital twins as our first focus on the new digital environment that is being defined for geospatial systems.

Our second focus is on representation. As soon as geographic information systems emerged, they began to embrace more than the two-dimensional world. GIS came to be integrated with 3D representations that were built on developments in computer graphics, while GIS began to broaden to create new types of virtual environment in which users could represent themselves as avatars and manipulate and explore geographic content in a virtual world. Although this kind of VR and its extension to augment physical realities in digital terms has been under development for more than 20 years, progress has begun to speed up dramatically of late. The idea of extensive human working in a 3D world, in virtual realities, was first popularized in online gaming environments, one of the best examples being **Second Life**. But, there are now many such environments that define what is now being called the "Metaverse" named by Neil Stephenson in his science fiction novel **Snow Crash** published in 1992 as speculation about where the early Internet might be headed. The *Metaverse* is our second concept that is defining the new digital world, and there are strong synergies with the first component of these environments based on digital twins as well as those that pertain to our third concept relating to these wider interactive environments referred to as platforms.

Our third focus on the platform like many of these foci are not new. Almost from the time when software became an activity distinct from hardware in the 1960s and 1970s, aggregations of procedures into bundles of software came to be called platforms, but the term became widely used once organizations began to distribute their own software products using networks. These organizations are dominated by what is now referred to as Big Tech—**G**oogle, **A**mazon, **M**eta, **A**pple, and **M**icrosoft, often referred to as **GAMAM** which are a massive mix of software products that pertain to a wider range of computation that most of us are using in scientific, industrial, and service environments. On top of these, perhaps, alongside these platforms, there are several that seek to develop a marketplace on the net which brings producers and consumers together, decentralizing many market activities to the users of such platforms, the organizations themselves simply providing the software. In fact, as we all make use of a relatively free Internet, then these platform companies like Uber and Airbnb, but also various App Stores and payment systems, rake in enormous profits. Equivalents exist in China such as Huawei, JD.com, China Mobile, Alibaba, and Tencent, but globally there are tens of thousands of similar platforms that are defining the organizational reality of business, government, entertainment, and education.

In the remainder of this article, we will explore these three constructs of the new digital environment in which geospatial analysis is beginning to function within. We begin with representation—VR, VGE (virtual geographic environments), and interactive 3D worlds, which are all merging into what we call the *Metaverse*. We will then explore simulation which is part and parcel of urban analytics, and in particular, we will focus on the development of *Digital Twins*, exploring the conundrums and tension between when a twin is a model and when it is the real thing. Our third focus will be on platforms, which we will refer to as the *Platform Economies*, suggesting how we organize ourselves across many activities such as social, economic, business, scientific, and so on.

3 | THE METAVERSE AND ITS MIRROR WORLDS

The idea that we can invent digital environments goes back almost to the beginning of digital computation as reflected in Vannevar Bush's remarkable predictions in his 1945 paper "As We May Think". Nearly 50 years later, Gelernter (1992) fashioned this emerging Metaverse in his book *Mirror Worlds* with one of its subtitles … *or the Day Software Puts the Universe in a Shoebox*. He envisaged the city as the prototypical example of such mirror worlds saying: "… a software model of your city, once set up, will sustain a million different views … each visitor will zoom in and pan around and roam through the model as he chooses … perhaps most important, the software model can remember its own history in perfect detail…" The notion of merging one environment into one another, recursively almost, again predated the notion of interactive graphic environments built around the Internet (Batty & Hudson-Smith, 2007). The Internet had become established largely in science and academia by the time the world wide web was invented in the early 1990s. This led to a convergence of quasi-independent networks that had emerged around entertainment and email and by the millennium; the Internet was beginning to merge in different ways with 3D computer graphics environments that enabled single users and even small groups to interact with one another over networks. These environments referred to as "virtual realities" (VR) were developed into virtual worlds, primarily for online gaming but also for social interaction. One of us, Hudson-Smith (2002), used VR directly to fashion his 3D city models that he placed in various online gaming environments, mixing geographic information technologies with entertainment, using the platform *Active Worlds*. This supported the development of virtual geographic environments which focused on mixing different geographies in ways that enabled us to construct new environments for geographic science and analysis (Lin & Batty, 2009).

The environments that are now being created imply infinite flexibility in comparison with early models of virtual spaces built around virtual worlds. As Borgmann (1999) predicted, such environments can "illuminate, transform, or displace reality" while at much the same time Benedikt (1996), one of the earliest proponents of cyberspace, argued that virtual worlds are not real in any sense, the laws of physics within them can be violated, suspended or reinvented, creating a digital sandpit for exploring different kinds of urban development. All these developments are converging on a multitude of virtual worlds that can be fashioned in as many ways as there are human beings enabling and interacting with them. This is what is coming to be called "The Metaverse," a term gaining in popularity and hijacked somewhat by Zuckerberg, one of the founders of the social media company Facebook, to describe the future ways we will interact with computers when virtual realities enable us to control our physical realities in countless ways.

There are many definitions of the Metaverse and indeed many emerging metaverses. As Roy noted in 2021, there were over 160 companies building the Metaverse, a term which arguably implies one singular space; but, in reality, they are many, coexisting metaverses under development. In a similar way to our argument on digital twins, the idea of an Internet which brings people together, not through remote messaging and web-based interaction but through virtual worlds, is one that has caught the attention of many. The traditional definition of virtual worlds is largely based on one network of users and one virtual reality, but the Metaverse is more than this, based on more than one network, and more than one virtual world. How these are integrated or even linked is unknown for we stand at a threshold marked by the beginning of such convergence and use cases are barely available other than through experiments. Indeed, there are likely to be many more than one Metaverse where different variants are continually integrating, disintegrating, morphing into each, and splitting apart. We might think of these metaverses as being composed of platforms of various sorts with their representation as a kind of 3D version of today's Internet in which users will work, learn, play, and shop in immersive environments.

New web technologies such as Web 3 introduce various natural language processing where extensive manipulation of content is the focus in Web 2 in contrast to Web 1 which was largely based on simply providing readable data. The Metaverse, in fact, is likely to change Web 3 and some argue that it will be a Web 4 that embraces this Metaverse. This might integrate many different networks and virtual worlds with a new infrastructure coming to dominate the Internet. The rebranding of Facebook by its owner Zuckerberg is likely to reflect the future ways we use social media, indeed every media. But this will only be possible if the current channels of the Internet can break out of the resource limits posed by low bandwidth. Only then will environments be possible based on the sorts of communication and collaboration which reflect rich enough social experiences for this kind of Metaverse to exist. There is little doubt that if the current progress in new digital computation continues and it has never faltered in the last 80 years, then the Metaverse will come to define a new reality, not just a virtual one, alongside the reality that we take for granted in the physical world.

The infrastructure which reflects shared immersive experiences is not big enough yet for social interaction to embrace Zuckerberg's vision. Limited versions of this are available in some software such as Google Earth and in the more sober gaming style environments which break through barriers to social interaction; it is already possible to live and work in virtual worlds that enable one to teleport to set up environments reflecting the past and the future. In this context, it is easy to see the Metaverse as providing an environment for very effective urban design, forming online design studies in which other tools such as those we will define as digital twins will provide new software systems to both understand the complexity of the city and to explore future city forms.

It is difficult to graphically represent the Metaverse because it consists of so many virtual realities and interactions, but our **Vi**rtual **Lo**ndon project has been extended into such an environment where we can replicate the 3D physical representation in diverse ways. In Figure 1, we show portions of the 3D model focused on London's Olympic Park with real-time data being represented in the visualization. Tube trains rumble around the model from real-time data (or at least for the moment, from the data that are archived for the connections to APIs working in real time are not yet in place). The whole construction has been ported into Unity and a video of these interlocking 3D spaces can be viewed at https://vimeo.com/226303585.

4 | PROBING AND CONSTRUCTING THE METAVERSE USING DIGITAL TWINS

The tools we use to construct the Metaverse overlap with those tools used to understand it as well as understand the reality that the Metaverse relates to. As computers have got faster and smaller and as data have become easier to generate and access, we have begun to construct more than one model for the same problem. These models are different from one another in that any model is a simplification and an abstraction where the model-builder throws a lot more away from the real world than is incorporated in the model. Despite there often being a strong theoretical discipline from which the theory behind the model is derived, a portfolio of similar models may all be subtly different, reflecting differences between how different model-builders articulate and simulate the system in question. The fact that we are now able to construct many models is largely due to our abilities to do so, and this depends on the computer resources we have at hand. Different variants

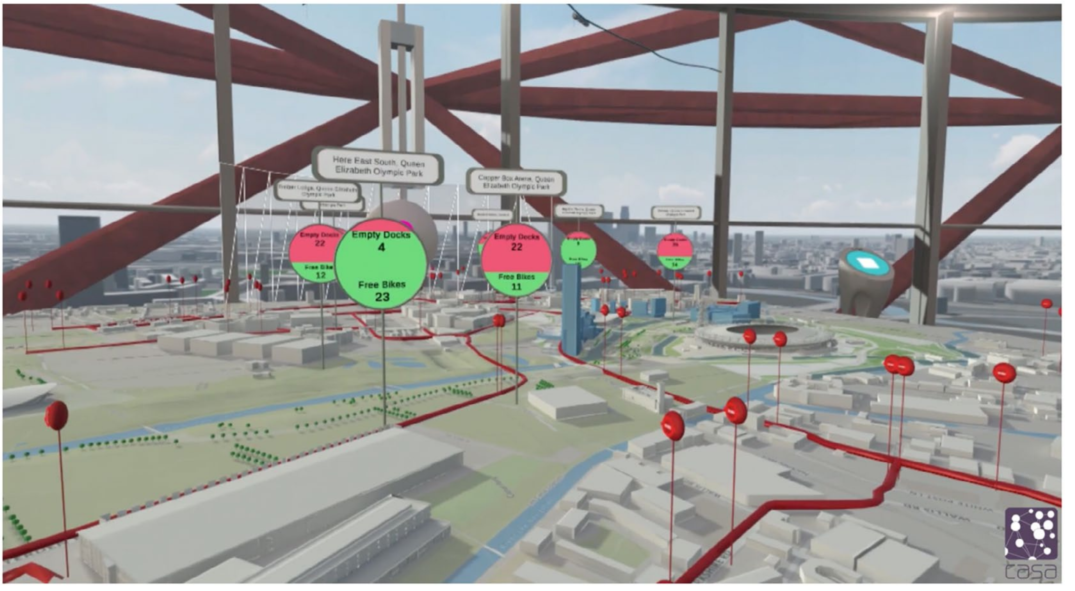

FIGURE 1 **ViLo**: the Virtual London Metaverse

of climate and financial models in which differing predictions are pooled and averaged led the way, but it has taken much longer for city models to embrace this perspective. Forty years ago, there were very few 3D computer representations of cities, but as computers got more memory intensive and data pertaining to maps and the third dimension got easier to generate and collect, more than one model could be built for a single place. In 2000, there were no more than a handful of such 3D models; all are very different, but now, we can construct our own model from scratch given the availability of open source or free software and data and the fact that even the most modest of personal computers enables the builder to run such simulations quickly and easily. The sorts of software environments that are populated by such models are now easy to construct, and in this sense, the Metaverse is already here. Figure 1 implies as much, and if one probes this environment, there are several different model types that are used to define it.

How close one can get to reality has always been an issue in geospatial modeling. In the last decade, the ideas of models that are ever closer to the reality have emerged in the form of the digital twin. A digital twin is essentially a model close to the real thing, but of course, it cannot be too close, otherwise it would merge with the reality itself, it would be the reality. In fact, what characterizes a digital twin is that it must have links to and from the real world; in short, it must exchange information between itself and the reality it attempts to simulate. The easiest examples to define are those where the model or twin represents a controller of the real system in some way while the real system provides the twin with the data that are needed for such control. In fact, the way the term is being currently used is broader than this; it embraces the idea that there is more than a single digital twin for there are often many such twins. The idea of an ecology of twins is now being explored, the twins being federated in different ways, and this is much close to the kind of **ViLo** environment that is pictured above in Figure 1.

One thing missing in our debate so far is the fact that in any modeling context which links the real world with the model, we–the human being–are always in the loop. In the last analysis, we are able to switch the system on and off, but more significantly, we make many personal decisions and use much personal knowledge in configuring the way we use models as digital twins in any context. We act as the intermediary(ies) between the real world and their models and in this sense, decide on many issues pertaining to how the models are built, applied, and used in solving problems of control, management, and policy. Arguably, the wider policy environment itself is subject to being simulated, and this adds another layer to the tools and methods that we are able to bring to bear on this style of thinking. Digital twins, in fact, focus our concern on how close the model is and should be to the real thing. Before computers reached the point where many models could become the norm rather than one model, model-building as an activity was a fairly closed affair, but now, the fact we can build more than one model, and there are more than one model-builder blows this activity wide open with many implications for the kinds of model environment we have sketched here that we are only just beginning to explore.

To an extent, the idea of a model has become ever common currency in science, and it is now impossible to catalog all the models that are developed for any problem, largely because these models range from systematizing our intuitions all the way to fully fledged model frameworks that are developed by countless model-builders over many years. To illustrate the notion of many models, each of which could be regarded as a twin but with the human very centrally in the loop, we illustrate in Figure 2, four different aggregations of the geospatial system used for a particular class of land-use transportation models. As these models have been developed at different points in time, they are all a little different in that their data and their structure continue to be "improved" as we successively generalize them to different spatial systems. We can easily see how a virtual infinity of model types emerges by aggregating their spatial map systems in different ways and by going beyond this in tweaking their spatial systems to reflect different articulations of the applicability to model the physical form. This is simply for land use transportation model types, but there are countless models at these different scales, too many to identify. All we show here are different spatial systems, not the changes in the structure of each model, different model types, or different problem contexts to which these tools relate. As well as structuring the debate in this way in terms of the "idea of many models," we open a veritable Pandora's box of possibilities, and it is this that makes the notion of "many digital twins" a rich way of defining new forms of virtual geographic environments that now form the cutting edge of geospatial modeling and analysis.

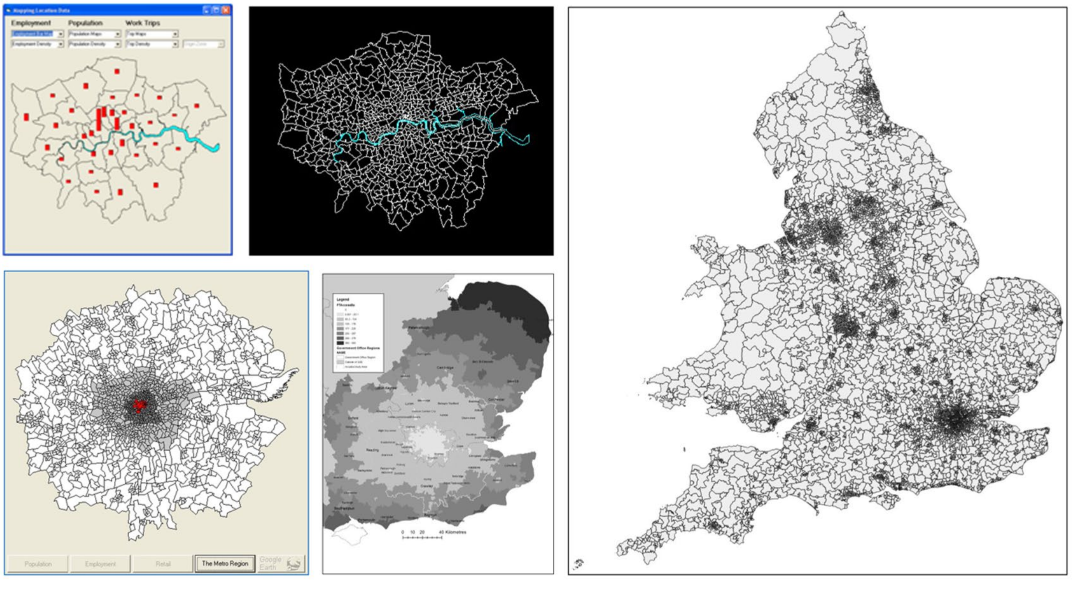

FIGURE 2 More than one realization at different spatial scales of the geospatial environment for a single model type based on a land-use transportation model being generalized to the UK. From the top right down to the bottom left: Greater London at 33 zones, at 633, with the outer metropolitan area at 1767, at local authority level in the southeast of England, and finally England and Wales at 7201 zones

5 | THE CONSTRUCTION OF A PLATFORM ECONOMY: MOVING MARKETS ONLINE

As part of the automation of society in terms of the way we work, the way we construct our physical environment as well as nurture and protect our natural environment, the way we organize our institutions, and the way we interact socially is being radically affected by the emergence of platforms that develop new forms of interaction across all levels. The simplest marketplaces are the first to organize themselves into these new environments and ride-sharing in transit is one of the key developments. ***Uber***, the system that enables you as a consumer of travel to link to a potential supplier or producer of the travel, normally in the form of a physical vehicle that offers trips, is the prototypical example. The really important innovation here is that the means of production and the marketplace are owned not by the company but largely by the consumer and independent producer. The producer owns his/her own vehicle and smartphone, while the customer also owns a phone that is able to connect with the producer. In short, all the companies–***Uber***, in this case-does is produce the software that enables consumers and producers to interact. There are many issues involved in such platform economies, in particular the whole question of regulation and privacy which are issues that the developers of such platforms barely consider in setting them up. The profits that such platform companies cream off the top are not acceptable, given that the infrastructure to enable these online marketplaces to function has been provided by society at large. A free Internet lies at the basis of many of these new environments, not only these platform companies but also the whole range of virtual realities that we have alluded to in this article.

It is harder to see the physical impact of ride-sharing transit systems such as ***Uber*** on the physical structure of the city. Clearly, the software that consumers and producers generally use on their smartphones is fairly straightforward, but these companies do little to ensure that connectivity is optimized in such contexts. This depends on the telecom providers that fund the networks that form part of the wider Internet technologies. The home-sharing system ***Airbnb*** is a little more obvious in terms of its impact on the housing market. Here, homeowners (and various renters with access to homes) can offer their dwellings for short-term accommodation. The impact on the city can be profound in that large areas of housing in some cities are dominated by Airbnb rentals, and this does conflict with more stable communities. Housing is somewhat more than simply the provision of dwellings for schools, retailing, and a whole range of medical services which are key functions in residential areas. The same problem as with ***Uber*** pertains to ***Airbnb***, but regulation is more complex because there is a fine line between temporary housing which is more like hotel accommodation than permanent housing. To give some sense of the impact of these new kinds of economies–transit and housing–we show the growth of Airbnb in London in Figure 3 which if we were to generalize to all kinds of land use and activities, would show an increasingly complex picture of how and where activities are being located (Shabrina, Arcaute, & Batty, 2022). Arguably, as the pandemic becomes endemic, some of the movement from work at work to work at home is being supported by a "free" Internet where the costs of linking work and home are now changed substantially from those generated from traditional patterns of the journey to work. Much of the local connectivity need to make this possible in fact is borne by the user working at home.

What we have not done so far is allude to platforms that are part of the process of planning and problem-solving and thus to conclude this short paper on new forms of virtual geographic environments, we will outline developments in the activity called "geodesign" as defined by Steinitz (2012). Geodesign, as it has developed, engages individuals and teams to "compete" in a mild sense of the word to explore different alternative scenarios largely for problems of physical and landscape planning. The framework as elaborated defines individuals and teams working in different alternative scenarios which are communicated continually to each group with each group moving toward some agreement about the best possible scenarios. In fact, there may not be consensus, but the process which is highly automated using GIS technologies provides an environment for conflict resolution for continued sharpening of the set of best alternatives. This kind of process could and may well be extended to virtual environments and during the pandemic, there has been rapid development of these possible forms. If we

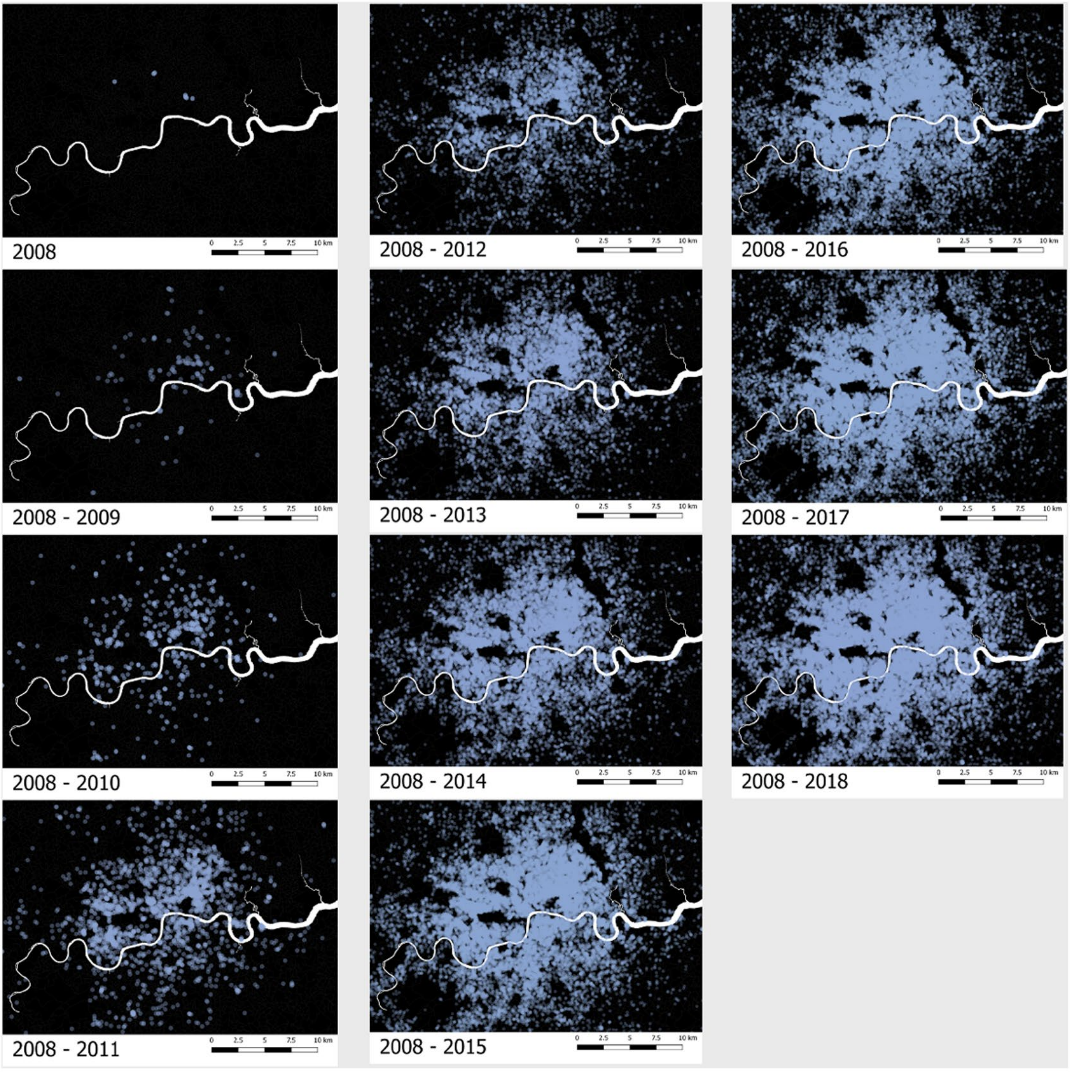

FIGURE 3 The growth of Airbnb in Greater London from 2008 to 2015

look again at ***ViLo***, it would be possible to link geodesign tools to the manipulation of the physical content which is articulated using models within the virtual environment as pictured in Figure 1. There is much more we could say about these possibilities, but it is early days in the development of these new forms which resonate very well with other articles on this collection.

6 | CONCLUSIONS AND NEXT STEPS

Since the first developments of virtual reality technologies and their incorporation into geographic environments, there have been many developments that seek to improve the way we are able to understand, simulate, and explore future scenarios for resolving the key grand challenges that face our cities and regions as part of a global world. We urgently need to improve our understanding of what it means to develop different models of the same phenomenon and how we can deal with the tensions that exist between them. In the past, we might have considered these tensions problematic, but in a pluralistic world, where no one model or theory is necessarily better than any other, these tensions are essential to sharpen your questions and produce relevant plans for the future.

The digital twin idea is useful, notwithstanding its relative ambiguity in terms of the language used. This ambiguity is largely because we need to embrace the idea that models and perhaps metaverses if they are to be used in a geographic context, should be as close as possible to the system of interest, and this in itself means that we need to define different perspectives on the system so that different models can be articulated. At the extreme end of this spectrum, the model begins to merge with the system and in the context of geospatial systems, we need to see how close we can get without the twin being the same as the system it is attempting to represent. There are many challenges that spin-off from these questions and a research agenda is urgently required.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Research data pertaining to the examples are not shared and are not used in this article.

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REFERENCES

Batty, M., & Hudson-Smith, A. (2007). Imagining the recursive city: Explorations in urban simulacra. In H. J. Miller (Ed.), *Societies and cities in the age of instant access* (pp. 39–55). Dordrecht, The Netherlands: Springer.

Benedikt, M. (1996). Information in space is space in information. In A. Michelsen & F. Stjernfelt (Eds.), *Billeder fra det fjerne/Images from afar* (pp. 161–172). Oslo, Norway: Akademisk Volrag.

Borgmann, A. (1999). *Holding on to reality: The nature of information at the turn of the Millennium*. Chicago, IL: University of Chicago Press.

Bush, V. (1945). As we may think. *The Atlantic Monthly, 176*(1), 101–108.

Gelernter, D. (1992). *Mirror worlds: Or the day software puts the universe in a shoebox…How it will happen and what it will mean*. New York, NY: Oxford University Press.

Helbing, D., & Argota Sanchez-Vaquerizo, J. (2022). *Digital twins: Potentials, limitations, and ethical issues*. Preprint, version 0.17. https://www.researchgate.net/publication/358571489_Digital_Twins_Potentials_Limitations_and_Ethical_Issues/link/6208dc8aafa8884cabdf33ab/download

Hudson-Smith, A. (2002). 30 days in active worlds: Community, design and terrorism in a virtual world. In R. Schroeder (Ed.), *The social life of avatars: Computer supported cooperative work* (pp. 77–89). London, UK: Springer. https://doi.org/10.1007/978-1-4471-0277-9_5

Lin, H., & Batty, M. (Eds.). (2009). *Virtual geographic environments*. Beijing, China: Science Press (republished by Esri Press in 2011).

Roy, A. (2021). *Who is building this Metaverse, 160+ companies and you*. Retrieved from https://www.xrtoday.com/virtual-reality/who-is-building-the-metaverse-a-group-of-160-companies-and-you/

Shabrina, Z., Arcaute, E., & Batty, M. (2022). Airbnb and its potential impact on the London housing market. *Urban Studies*, *59*(1), 197–221. https://doi.org/10.1177/0042098020970865

Steinitz, C. (2012). *A framework for geodesign: Changing geography by design*. Redlands, CA: Esri Press.

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