CASA

WORKING PAPER SERIES

http://www.casa.ucl.ac.uk/working_papers/paper98.pdf

ISSN: 1467-1298

98
09 | 05

IMAGINING THE RECURSIVE CITY: EXPLORATIONS IN URBAN SIMULACRA

Michael Batty
Andrew Hudson-Smith

UCL

www.casa.ucl.ac.uk

T +44 (0) 20 7679 1782 • T +44 (0) 20 7679 1813 • F +44 (0) 20 7813 2843 • E casa@ucl.ac.uk

Centre for Advanced Spatial Analysis • University College London • 1 - 19 Torrington Place • Gower St • London • WC1E 7HB

Rocco C. Siciliano Forum at the University of Utah
Societies and Cities in the Age of Instant Access: Salt Lake City, Utah, 10 – 12 November 2005

Imagining the Recursive City: Explorations in Urban Simulacra

Michael Batty and Andy Hudson-Smith
{m.batty@ucl.ac.uk, asmith@geog.ucl.ac.uk}

Centre for Advanced Spatial Analysis
University College London
1-19 Torrington Place
London WC1E 6BT, UK

http://www.casa.ucl.ac.uk/

Abstract

Cities are microcosms of societies, worlds within worlds, which repeat themselves at different spatial scales and over different time horizons. In this essay, we argue that such recursion is taken to an entirely new level in the digital age where we can represent cities numerically, embed them within computers, scale and distort their representations so that we can embed them within one another, even believing them to be 'computers' in their own right. We begin with the conundrum of recursion, showing how its occurrence in cities through spatial similarity at different scales, leads to worlds within worlds. We illustrate these ideas with a large-scale digital representation of the core of a world city, London, showing how we can generate different realizations of the city for different purposes. We embed these representations within one another, building virtual worlds, moving from the material to the digital and back again, using the digital model to represent the material world in different ways, and finally printing – fabricating the model. Our message is that digital representation opens a cornucopia of possibilities in representation and communication through a variety of devices which in turn can be embedded in the city, Escher-like, and which indeed are rapidly becoming the city.

Acknowledgements

Stephen Evans worked on the model and we thank him for his insights. The work was funded in part by the Greater London Authority, London Connects, and ESRC under their e-Social Science Program. Ordnance Survey and ESRI Inc. generously donated data and software.

> “In a riddle whose answer is chess, what is the only prohibited word?”
>
> I thought a moment and replied, “The word *chess*”
>
> “Precisely,” said Albert. “*The Garden of Forking Paths* is an enormous riddle, or parable, whose theme is time; this recondite cause prohibits its mention.”
>
> Jorge Luis Borges (1964, written circa 1941) *Labyrinths*, New Directions Publishing Co., New York, p.27

And so it is with the riddle of recursion and the recursive city. In a strict definition, recursion is the process where the same set of rules or function is applied to some phenomena over and over again, successively, in such a manner that the phenomena is repeatedly transformed as these rules are sequentially applied. Such a process implies that time passes even if the rules appear to operate near instantaneously. Recursion is normally observed not in the operation of its process but in its output, in its patterns whose signatures show the function of the recursive process in time or space or both. Indeed, this is usually the way we identify that recursion is at work, by detecting similarities in successive outputs. In cities for example, evidence of recursion might be seen in the physical patterns of its development where certain modules repeat themselves in different places, at different times, evidence enough of similar processes at work. But recursion may not show itself physically. The way populations in cities behave in space and time, the way individuals, groups, institutions organize their activities, the way economic and social functions determine modes of living and work can all show evidence of such patterning. The social world is full of clichés that imply such recursion: “History repeats itself, first as tragedy, second as farce”, the famous maxim of Karl Marx; “Great fleas have little fleas upon their backs to bite 'em, And little fleas have lesser fleas, and so ad infinitum”, from Augustus de Morgan, parodying Jonathan Swift’s early 18th century quip: “So, naturalists observe, a flea Has smaller fleas that on him prey, And these have smaller still to bite 'em, And so proceed ad infinitum”[1]; Zeno’s Paradox of the Tortoise and Achilles, and so on …

In this essay, we will explore the recursive city in terms of its physical patterning and the use of these as icons in the digital age. Our key thesis will be that for the first time, due to our newfound abilities to represent the city digitally, we now have tools at hand which enable us to explore it in a kaleidoscope of different ways, at different scales, in different times, in different contexts. This symposium is about the age of instant access which has

[1]This quote comes in various guises. Lewis Fry Richardson, the climatologist, following De Morgan and Swift, summarized his own work in a 1920 paper entitled ‘The Supply of Energy From and To Atmospheric Eddies’ with the wonderful poem: “Big whorls have little whorls That feed on their velocity, And little whorls have lesser whorls, And so on to viscosity” (Richardson, 1920, 1993).

been fashioned during the last 200 years as first mechanical analog technologies, and more recently digital technologies have given us opportunities to communicate ever faster (Gleick, 2000). In terms of replicating our own responses to this emerging spatial world, we are now able to intersect the digital with the material, in Negroponte's (1995) terms, to intersect 'bits' with 'atoms', and this is giving us new ways of copying what traditionally has always been material. Moreover, the abstraction that the digital world provides enables us to replicate it at different scales, to distort it, and to embed in ways that we can manufacture quickly, almost instantaneously. In fact, although recursion can occur in time as history repeating itself, there is a real sense that as the world speeds up, as we get faster, in the age of instant access, space and time collapse to a point, a singularity where recursion converges with simultaneity.

This essay is an experiment and a speculation. As we have already implied, there are many types of recursion for what is recursive can be perceived individually as well as collectively. Here we will focus simply on spatial recursion and although we will begin with some abstractions about patterns, our central focus will be upon how the material city as we see it in three dimensions can be represented in digital form. Once we have such a representation, we can scale it, we can transform it, we can repeat it in countless ways and we can begin to embed each replica within any other, thus providing windows on the world that enable us to switch between diverse representations. Why one would want to do so is simply predicated on the very plausible assumption that if we can represent the world in different ways, we gain insights that add to our knowledge and experience (Hofstadter, 1979). Moreover we are able to construct model worlds for different purposes, for different audiences; in short, we are able to use our new found digitality and virtuality to communicate more effectively.

We will focus our discussion around the idea of 'models' which we define as simplifications through abstraction. This approach is as old as the hills and as we all know, there are many models but they are usually distinct. Individuals usually create one model, not many, at least at any one time. The power of recursion for digital representations however enables us to design models that are subtly different, that merge into one another; in short to define models of models, 'simulacra' as Baudrillard (1994) calls them. Here we will build our recursive city as models within models, emphasizing not the abstraction of two-dimensional urban patterns but the iconic world of three-dimensions. In what follows, we will begin with simple recursion, some definitions. We will then illustrate our simulacra from a large scale digital model of central London, Virtual London we call it (Batty and Hudson-Smith, 2005). We explore how to embed various media into the model illustrating a kind of recursion. Then we launch into embedding the model into a virtual world, Escher-like, where we have models within models within models. But these transformations help us to stay with the material world, distributing the model at different scales on different devices from CAVES to hand-helds, printing the digital model as hard copy, augmenting traditional models with these new virtual realities. Our quest is to impress on our world the idea of recursion, the idea that instant access means access to plural realities, virtual and otherwise. We are but at the beginning.

Simple Recursion: Recursion Defined

In formal terms, a common definition of recursion is the definition of an object or objects in terms of previously defined objects of the same class, while in mathematics, a recursive function is a function that is defined in terms of itself, usually so that there is some transformation of the output implied by the function. A good example is $f(n) = n * f(n-1)$ for any natural number $n > 1$ which, as you can see, leads to the factorial expression $n! = n(n-1)!$. Repeatability but also transformation marks recursion of this kind and in cities, this transformation is often one of scale. For example, households organize their living at the smallest scale around different functions which are spatially diversified in the dwelling, dwellings form neighborhoods which require some kind of central place for exchange, a local market, and thence districts are composed of neighborhoods. So on up the hierarchy to the largest cities which have a structure that mirrors the tiniest dwellings in terms of the way space is organized. It is little surprise that such hierarchical organization mirrors a tree-like form in which smaller spaces are embedded in larger but with the same sorts of functions, suitably transformed for smaller populations and markets and for more routine purpose as one travels down the hierarchy: this is the cornerstone of human geography, central place theory.

Hofstadter (1979) has attempted a much more general analysis of recursion suggesting that this kind of logic is the one that underpins the most elaborate music, art, and logic. He builds on the idea of the 'strange loop', elements that repeat themselves by transforming and repositioning, reflected in and through 'tangled hierarchies'. The idea that recursion is asymmetric dominates in that its transformation through hierarchy over and over again with as many repeatable modules as one cares to define, soon destroys the logic of symmetry. Hierarchies blur into lattices (Alexander, 1966) as the modules that form the system spread epidemic-like through the medium. As an aside, however, effective recursion where the experiences are meaningful imply some strictness of control over these strange loops, tangled hierarchies they may be but hierarchies that are structured, not random. We illustrate this below in the animation of Escher's *Print Gallery*.

We can travel the strict hierarchy from top to bottom, successively subdividing space in the manner shown in Figure 1 where we generate a fractal structure revealing different levels of detail but following the same pattern as we move to ever finer scales. But we can also grow the same structure from the bottom up which we show in parallel. There is a strict mathematical form to such recursion from the top down where a unit is successively subdivided according to a standard pattern – in this case where an array of 3 x 3 cells, 5 of them (at the centre and NW-NE-SE-SW) are filled as the scale successively decreases. Seen from the bottom up, we can grow the city in the same way, repeating the basic 5 cells from the module of 9 and positioning it at successively higher levels as the city grows from a single seed. That such models appear to replicate how actual cities grow has not escaped our attention but our purpose here is simply to impress the power of recursion.

The Sierpinski carpet which the patterns in Figure 1 have been called (Mandelbrot, 1983) are only transformed through a simple scaling but more elaborate designs can be formed if the patterns are rotated. In fact, simple rotation does not change the Sierpinski carpet very much but were the basic module somewhat more irregular – jigsaw-like for example – then one could devise many kinds of tessellation which show not only a spatial recursion but a translation towards infinity. In Figure 2, we begin to show how we can scale and distort in this way, with the final figure based not on a 3 x 3 module but on the simpler 2 x 2 cellular array – a quad-tree used here to generate an Escher-like pattern. What we are not able to show through scaling and transformation is how worlds sit within worlds which are only accessible by peeling away the current image for this involves recursion through time. But in Figure 1 were we to embed the recursion is one specific location, starting with one world and subdividing this successively into our 5 from 9 cell pattern without translation from the starting point, we would

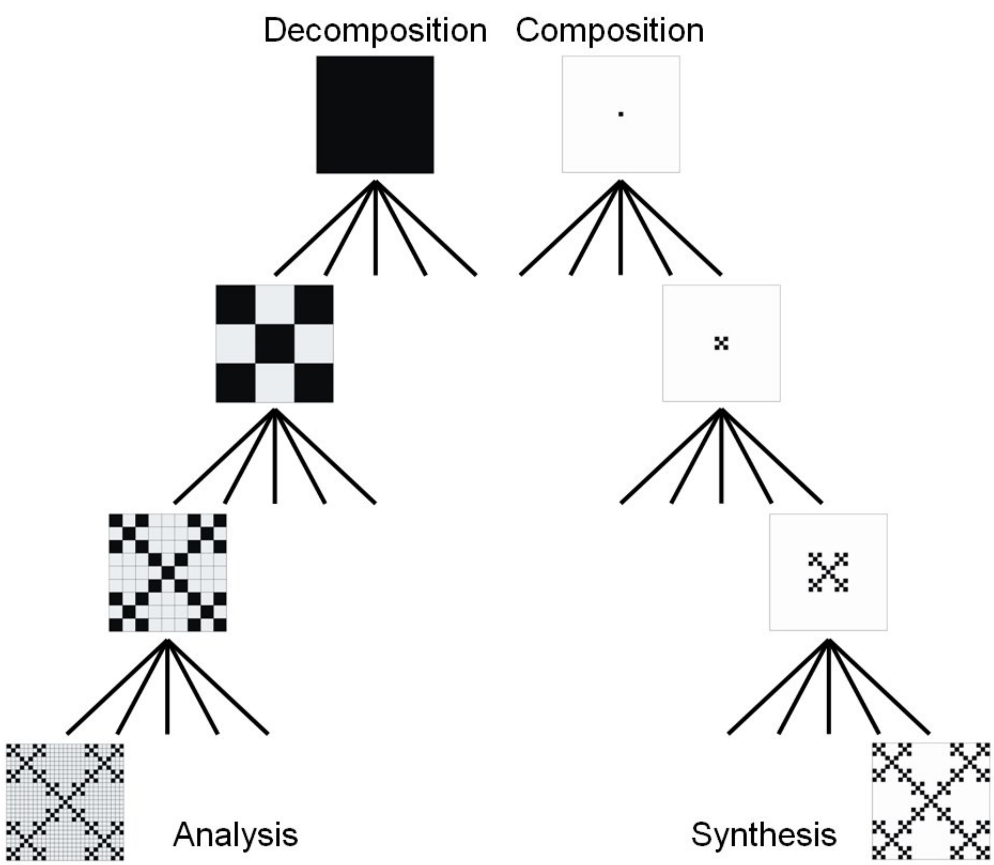


Figure 1: Hierarchical Recursion Generating Fractal Self-Similarity: Top-Down (left) to Bottom-Up (right)

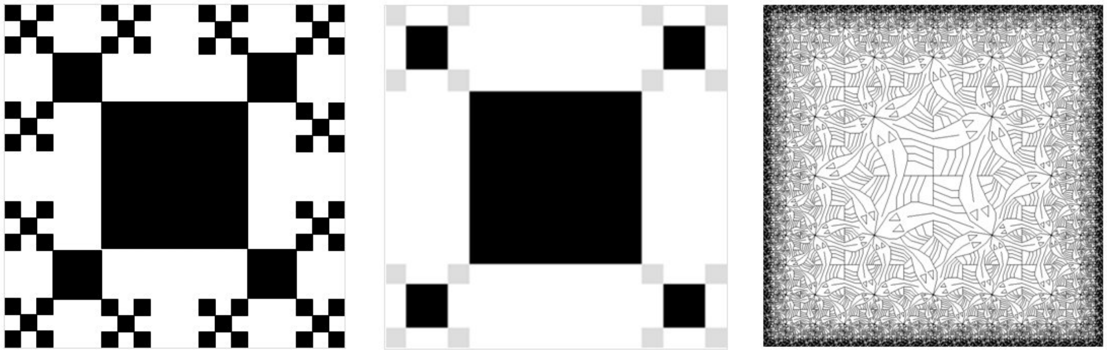


Figure 2: Recursive Pictures: Transformation and Scaling
Generating Escher-Like Fractal Self-Similarity
From http://w3imagis.imag.fr/Membres/Fredo.Durand/Quad/escher.gif

generate a sequence of truly embedded worlds. The best example that we are able to give here is also taken from Escher's 1956 lithograph *Print Gallery* set up as a movie within a movie so that the viewer can access a world within a world as a picture within a picture. The temporal recursion in Figure 3 is generated by ***CTRL+click*** on …

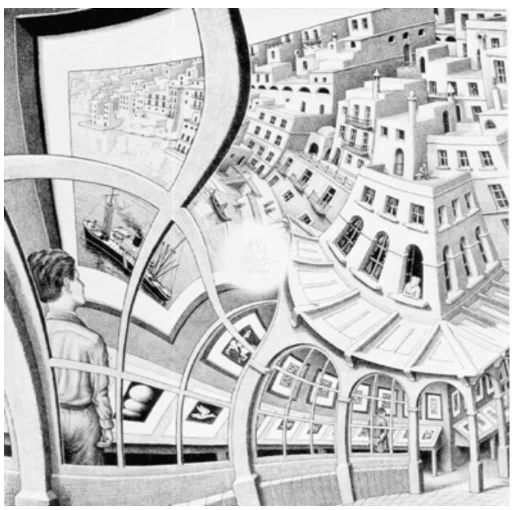


Figure 3: Escher and the Droste Effect
from http://escherdroste.math.leidenuniv.nl/

Hofstadter (1979) describes the *Print Gallery* as the tightest of strange loops, "an Escher vortex where all levels cross" – a tangled hierarchy in which "… we see … a picture gallery where a young man is standing, looking at a picture of a ship in the harbor of a small town, perhaps a Maltese town to guess from the architecture, with its little turrets, occasional cupolas, and flat stone roofs, upon one of which sits a little boy, relaxing in the heat, while two floors below him a woman – perhaps his mother – gazes out of the window from her apartment which sits directly above a picture gallery where a young man is standing, looking at the picture of a ship in the harbor of a small town, perhaps a Maltese town – What? We are back on the same level as we began though all logic dictates that we cannot be.” (page 715).

Our purpose in this short section has not been to develop techniques that we will use in the more realistic virtual realities introduced in the rest of this paper but to show how we can embed worlds within worlds and how both space and time are woven into one another when we enable such embeddings. But there is another important dimension to our focus and this involves the idea of a model. In a sense, the basic module in Figure 1 is a model of how space is organized, and when we begin to populate a larger space with various transformations of the way parts of the space can be modeled, we are in a sense developing a model of a model: this is our urban simulacra. At the top of the tree, the model covers the whole space and as we successively disaggregate, we place a model of the model at finer and finer scales. If the model is not translated in space but simply placed behind the previous one, then we require a temporal recursion to access it in the same way as our Escher-animation works. And if we loop this forever, then we generate an infinity of recursions. Of course, the digital world lets us use the trick that we only require one model behind another to scale back to the first to give the impression of infinite regress as the animation of *Print Gallery* above suggests. But this is for the future. Our examples which follow will not take the argument this far for to begin, it is sufficient to indicate a couple of levels of recursion to show the power of such simulacra.

An Urban Simulacra: Virtual London

The first digital models of cities were thought about as soon as the digital computer was invented half a century or more ago. After all, pioneers such as von Neumann and Turing impressed upon the world the philosophy of the universal machine in which the computer could do anything that in principle might be reduced to a string of binary numbers. Computer graphics was an early quest although it has taken 50 years for us to accept the idea that pictures are computable. The first realizations of cities inside a computer in iconic rather than in more abstracted mathematical form were mooted in the 1960s with the Skidmore, Owings and Merrill wire frame model of Chicago an early exhibit of these possibilities (Jankel and Morton, 1984). In fact, the development of computer graphics and computer games has always been tied to examples involving cities with some of the first experiments in recursion being developed almost unwittingly in gaming environments: adventure games, MUDS and MOOS invite a degree of recursion.

Our digital model of central London is in the first instance a spatial skeleton, literally a shell in which the 3D geometry of the city is used as a container for as many attributes of its spatial tags as we are able to collect. These tags or identifiers are elements of the geometry, the buildings and streets but also the terrain and the utilities, and the watercourses, indeed anything that has an x-y-z coordinate that can act as a marker for some significant quality of the city. The model is thus a geographic information system viewable as a database in a variety of ways. Its geometry is not the only lens through which it can be viewed but it is of course the most suggestive for the widest audience. And like all geometry, like our Escher pictures before, this represents the most obvious way in which a digital representation can be transformed and scaled to a different physicality and reality. There are of course many different digital realities which depend on capturing attributes in different ways but the commonality of digital representation enables different renditions to be linked together. In principle, one rendition can be placed within another and recursion generated through looping.

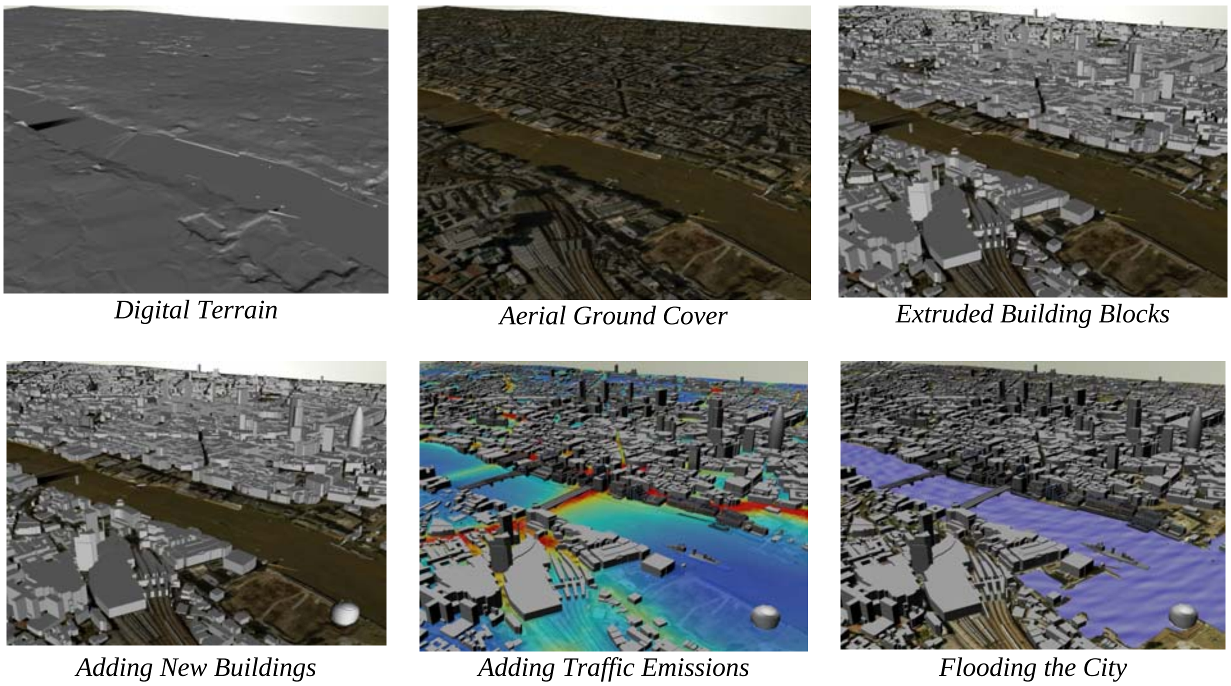
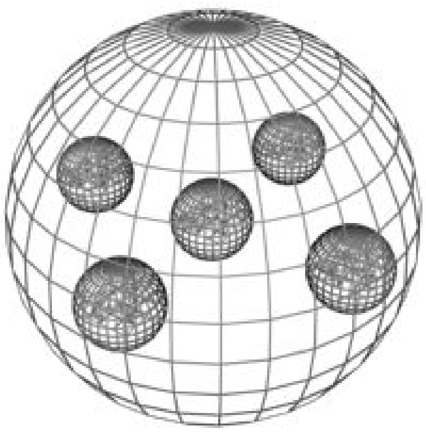
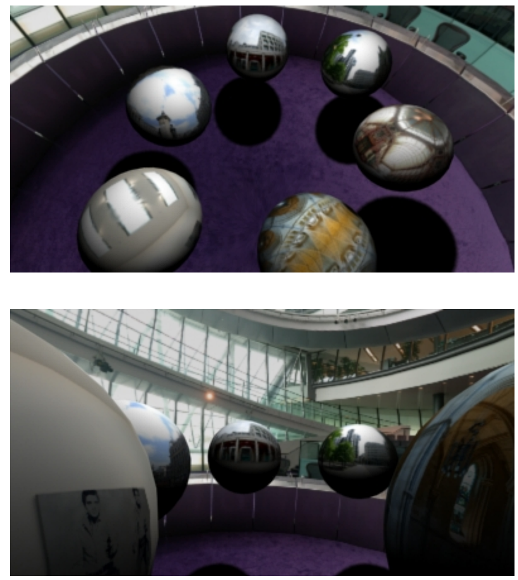


Figure 4: Digital Representation: Building the Shell

To illustrate the model, we show first how the skeleton or shell is built in layers from different geometries. We start with the digital terrain, then layer an aerial image onto this to give a feel for the actual ground cover, adding a digital street map and then extruding building parcels to heights which are given by remotely sensed LiDAR data. Into this shell, we can insert more detailed renderings produced by others and we show this construction process in Figure 4. A rather different realization of the city can be produced using much more superficial realisms, digital photographic media, which is captured in panorama form. These are wrap-around images which can thence be embedded into the shell to provide a different experience of the real city. Navigating the model is usually accomplished as fly-throughs but at any point, panoramas can be embedded within the scene, thus providing a degree of realism hard to manufacture in the shell itself. In this way, the user can move from one world to another and back and this form of recursion is simply one of switching between different media. Yet it does provide a plurality of experience and with two different media, each capable of being scaled geometrically, the possibilities are endless. In Figure 5, we show for example how we can embed panoramas within panoramas: as the user moves around the panorama, other panoramas at different scales which enable one to hop between different spaces, reveal themselves as globes floating in the space. We can embed this into the shell of the full model, thus using this media as a way of navigation as well as a pointer to how our experience of the city can be enriched in alternate ways. We are not able to show this here but we will demo it within the lecture. It represents our first Escher-like world in which we can interpenetrate one digital media with another both in terms of moving from one to the other in time as well as moving from one to the same at a different scale in space.



Worlds Within Worlds, Literally



Floating Panoramas

Figure 5: Scaling One Form of Digital Media to Enable Navigation Through Space

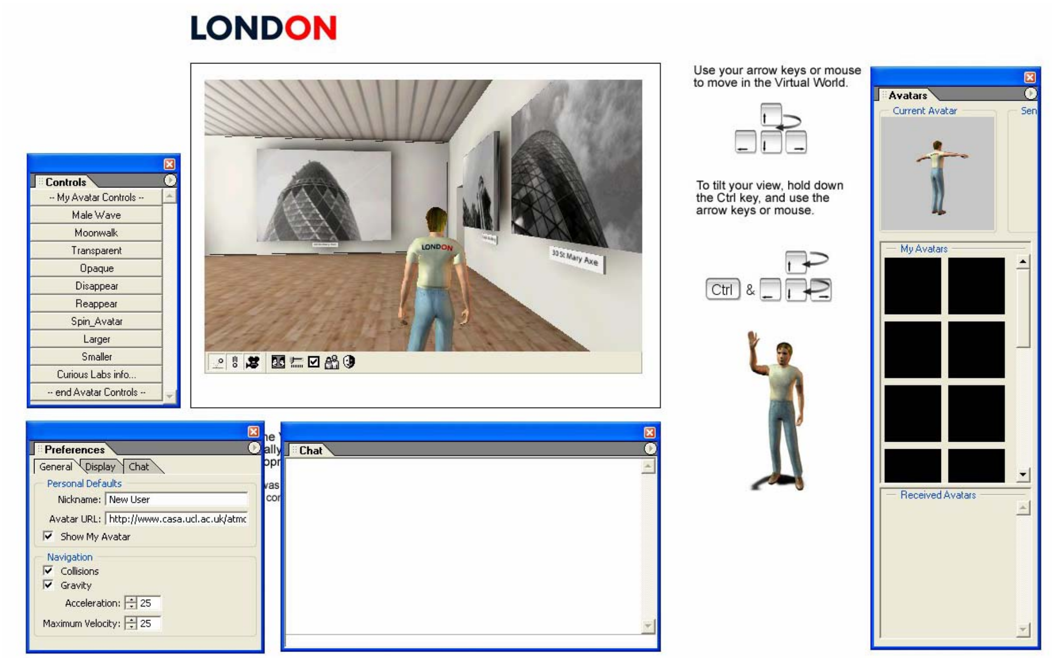
There are several other ways in which we can begin to enrich the experience in this recursive fashion. We can link digital to traditional media building augmented realities: material models can be endowed with digital media. We can also deliver models in different forms of media – on desktops, on hand-held devices, in VR theatres, CAVES, as tabletop holographs and so on, and in this way, we are able to build plural experiences of what the city is like. Some of these we will exploit below as we continue to embed ourselves and our realities ever deeper into the digital domain.

Generating Virtual Worlds

The simplest recursion with our GIS shell is to embed a scaled down version of the model inside a component of the model and so on, ad infinitum, but for the experience to be worthwhile, it must be meaningful. One obvious way would be to place the model inside one its buildings which may in reality be an exhibition space. The large-scale material model of London used by the City – the Piper Model – is in fact located in the Guildhall and we could easily scale our model in the model Guildhall. But this of course is pure serendipity. The digital world allows us to create different kinds of digital environment which we can populate with the same or similarly transformed modules and it is the nature of these different environments that enriches our experience. The simplest alternative to the digital model which we can represent and navigate through on the screen itself is an environment once removed which is called a ‘virtual world’. Such a world is in and of itself a rather different 3D environment in which the user can appear as an avatar and behave in different ways that may or may not mirror real behaviors. It is into this kind of world that we can import our more traditional visual media – our GIS shell, our panoramas, still pictures of the city and so on, and we can thus arrange them to impart various experiences which are different from navigating through the shell and its panoramas directly.

In a sense, this throws the kind of media for visualization into the spotlight with the earliest versions of such environment entirely immersive. The world we will use here is in fact a networked world in which the environment – the virtual world – exists somewhere on the net – and those interacting with the world – from anywhere on the net – appear as avatars within the shared environment. The world can be configured as an exhibition space – a virtual room or a maze of rooms through which you might navigate – with the spaces sequenced to develop an experience of the phenomena. In the digital world, one can hop from place to place without any friction of distance and some of the earliest virtual worlds – *AlphaWorld*, for example, juxtaposed real and virtual space in such away that unusual effects were generated (Dodge, 2001; Schroeder, Huxor, and Hudson-Smith, 2001). In our example here, we have constructed such a world as an exhibition space focused on bringing together various pictures of the City of London and arranging these so the avatar or avatars can move from one specialized space or room to another through a portal or gateway – a kind of wormhole or visual hyperlink. We show the mechanics of this virtual world in Figure 6 which is developed using *Adobe Atmosphere* and in which users can appear as the avatar of their choice, beginning to interact with each other, and discussing the environment which they are sharing (Hudson-Smith, 2002).

If we port our GIS Shell and our panoramas into such a world, then the number of possible recursions explodes. In dealing with such models, there are many who are uncomfortable with navigating the raw digital model and thus we can place the model in the space as though it is a traditional model. Avatars can cluster around it just as people view a traditional model and generate discussion about key issues. The model is still digital but with the great advantage that avatars can now manipulate it, move buildings virtually and reconfigure the scene in a way that cannot be done with a physical model. We might add our panoramas to the scene, intersecting and hopping from room to room within our panoramas, entering a building in the tabletop model and moving through the space this way. The possible manipulations are endless in that we can further embed the virtual world within another and so on, but once the loop becomes more than two or three steps deep, it loses its meaning as the variety of experiences overwhelm. In Figure 7, we show how we port our GIS shell into the virtual world and how we can move buildings, engaging in virtual urban design. In a sense, our virtual world becomes a virtual design studio but networked in such a way that in principle at least, a very large number of participants who are part of the city itself are able to engage in design and discussion.



Setting Up the Virtual World

Navigating from Room to Room in the Virtual Exhibition Space

Figure 6: Avatars Enter the Virtual City in a Closed Exhibition Space

We will make one final foray into this kind of virtual world which threatens to tangle the web still further. We can set up the environment of the virtual world itself as the GIS shell or as a panoramic backcloth, being no longer restricted to the exhibition-like space. The world is thus the model and as we enter the model itself, we appear as an avatar. In this way, we can scale ourselves to fit the scene or dominate King-Kong like as in Figure 8. Or we can scale it so we populate our rooms with panoramas which enable us to move seamlessly through the city. Think of all these possibilities as being embedded within one another and you are soon drawn back to Hofstadter's (1979) argument that although the best experiences are based on strange loops, these loops must be tightly configured.

The GIS Shell in a Virtual World

Manipulating the Shell Virtually

Traditional Design and Negotiation

Figure 7: Virtual and Real Exhibition Spaces

An Avatar Entering a Digital Panorama

An Avatar Entering the GIS Shell of Virtual London

Figure 8: Navigating Out From the Exhibition Space

It is hard to generalize the possible recursions that we have hinted at here for we have begun from a very specific position, that of working with traditional physicality in its more superficial digital representation. We could have begun with much more abstract spaces changing our level of abstraction accordingly but one way of visualizing the loops we have developed is in the logic chart in Figure 9. Here we pose two types of direct digital representation – the GIS shell and the panorama(s) – which can be woven into one another as we did in the previous section. This we call the 'Real World' although it digital in its presentation. The 'Virtual World' is where we can exercise true recursion and here we show how we can embed the real into the virtual from level to level but with the real world components being used to form the virtual world itself. In a sense, our starting point in the real world is important although the logic suggests that we could drop the top level of the flow and simply refer to all worlds as virtual, the real being just one case of a multiplicity of worlds, all being in some sense virtual in the true spirit of Baudrillard (1994).

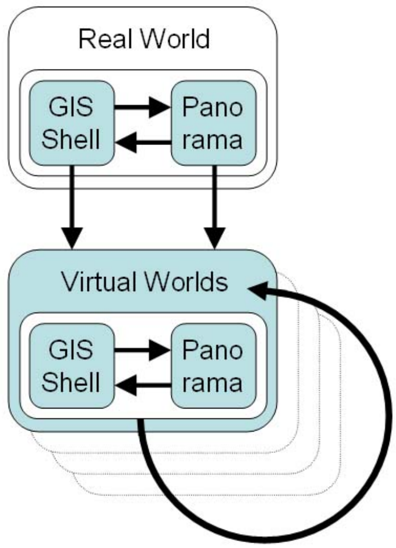


Figure 9: Recursively Embedding the Virtual City

Completing the Loop: Back to the Material World

The last stage in our exploration of urban simulacra involves returning to the material world. Just as we can move from the real to the virtual, we can move back again in the sense that just as every model has inputs from the material world, it has outputs which manifest themselves materially, in the first instance on the screen from which we can print some visual copy. But printing is just one realization of the virtual environment – the model – in material terms and we are so accustomed to printing in two dimensions on paper that we are often amazed by the fact that we can print in three. But our GIS shell, for example, has all the information which is necessary to print a 3D model by either attaching a milling machine to our computer or a machine for printing layer upon layer – for subtracting material from a 3D material or by adding slices as layers (Gershenfeld, 2005). This process of fabrication is the simplest possible and in Figure 10, we show how this can be done for a segment of our Virtual London model.

The fabrication we produce is a somewhat simpler form than the 3D geometry that we constructed the initial model from. It does not contain any detail or interior although this is simply a matter of configuring our printer into a form that would enable us to print such detail and engage in an automated process of constructing the printed output. But what is missing is all the attribute data that pertains to the city itself for the geometry is only a set of tags or coordinates on which hangs the real flesh of the city's skeleton. Our fabricated reality is thus somewhat different from our observed reality and a major question is 'how close are we ever able to get to our starting point?'. We will address this question in a somewhat speculative way in the conclusion but here it is worth indicating the nature of the loop we are proposing diagrammatically as we show in Figure 11.

Figure 10: Printing the Fabricated Reality

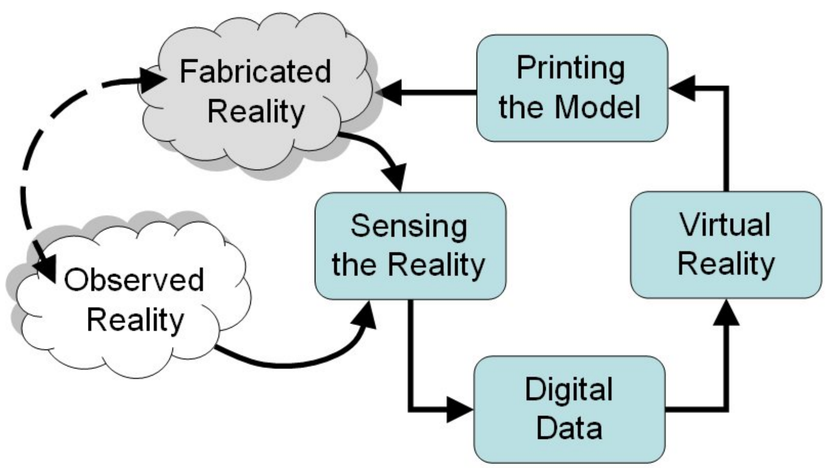


Figure 11: Closing the Loop: The Ultimate Recursion

Even at the level of the geometry, the observed and fabricated realities are somewhat different but in principle they could be the same if we had a good enough printer which we able to scale up to the city level. This sounds somewhat bizarre but in principle, even with fabrication at a much smaller, more toy-like scale, it is possible to merge the two in such a way that the 'sensing' of both real and fabricated leads to the same. In this way, then the model becomes a true rendition of the real, much truer than simply assuming that the digital and non-digital coincide in the computer. Of course cities are not geometric skeletons but are full of processes and behaviors that work within these structures and occasionally import and expend energy which changes these same structures. Once again, if our observed reality extends to what goes on within the geometry, we would be building models of how people and activities behave as our virtual reality and then we might fashion some analogs of how the printed version of the virtual reality might encompass some working parts. However this tests the limits of what we are able to do and although the implied recursion and implicit symmetry of Figure 11 might seem some sort of quest to aim for, in the last analysis the real and the virtual are intrinsically different, despite what Baudrillard (1994) has argued. Nevertheless the recursion set in motion by completing the loop in Figure 11 brings us full circle to the very idea of 'computer' which we will extemporize in our conclusion.

The Future: Turing's Dream

The notion of connecting the loop in such a way that what <u>is</u> being computed is what <u>has</u> been computed is central to much science and science fiction which depicts how we ourselves are beginning to merge with machines. From William Gibson's (1984) ***Neuromancer*** on, there has been a steady stream of science fiction that shows a future in which we cannot live without computers and of late, various movies such as ***The Matrix*** have taken this to the logical conclusion of a visually recursive world. In fact, all we have been demonstrating here is yet another perspective on the idea that computers are universal machines, a fact first deduced mathematically by Turing whose notion of a machine that was able to compute itself would hold the prospect for artificial intelligence. In this sense, computers are universal machines, Turing machines, and the notions of successive embedding and looping that we have posed in this essay, impresses on us the fact that we are now able to intersect different perspectives of the world in ways that we can control and manipulate much more effectively than hitherto.

If our real cities were actual working models, then it is clear that once translated into virtual realities, then this is just one way of illustrating their template from which we would be able to produce an identical working model. The reality and the model would thus be one and the same. In fact, our models, both real and virtual, would be the computer, with the computer producing or fabricating itself as a kind of artificial life. The analogy might seem far-fetched but we yet to attempt to show how the city itself is becoming computable (Batty, 1997). This will be another essay but linked to this one. There are many other levels of recursion in which we can embed computable elements into the city as hardware and software (which in the Turing context are the same) although in the material world, the virtual will always remains at arms length.

Our speculations might seem inconclusive and contestable for in this essay, we are acutely aware that we do not have a good model or template for getting to grips with the extent to which the new digitality and virtuality enables us to develop layers and layers of urban simulacra. Hoftstadter's (1979) analysis is as near the mark as we have found but this needs extending into contexts like cities where the medium is extensive and where multiple opportunities exist for different types and styles of embedding. This is for the future. In the meantime, what we have shown is how we can twist virtual realities for diverse purposes and in doing so, change our perspective, thus providing a medium for generating new insights into the way cities are structured and can be changed through the power of recursion.

References

Alexander, C. (1965), A City is not a Tree, **Architectural Forum**, **122** (1), 58-61 and **122** (2), 58-62.

Batty, M. (1997) The Computable City, **International Planning Studies**, **2**, 155-173.

Batty, M. and Hudson-Smith, A. (2005) Urban Simulacra, **Architectural Design**, forthcoming.

Baudrillard, J. (1994) **Simulacra and Simulation**, University of Michigan Press, Ann Arbor, MI.

Borges, J. L. (circa 1941) The Garden of Forking Paths, in **Labyrinths: Selected Stories and Other Writings** (Edited D. A. Yates and J. E. Erby, 1964), New Directions Publishing Co., New York, 19-29.

Dodge, M. (2001) Explorations in AlphaWorld: The Geography of 3D Virtual Worlds on the Internet, in D. Unwin and P. Fisher (Editors) **Virtual Reality in Geography,** Taylor and Francis, London, 305–330.

Gershenfeld, N. (2005) **FAB: The Coming Revolution on your Desktop – From Personal Computers to Personal Fabrication**, Basic Books, New York.

Gibson, W. (1984) **Neuromancer**, Ace Science Fiction, New York.

Gleick, J. (2000) **Faster: The Acceleration of Just About Everything**, Vintage, New York.

Hofstadter, D. (1979) **Gödel, Escher, Bach: An Eternal Golden Braid**, Basic Books, New York.

Hudson-Smith A. (2002) 30 Days in ActiveWorlds: Community, Design and Terrorism in a Virtual World, in R. Schroeder (Editor) **The Social Life of Avatars, Presence and Interaction in Shared Virtual Environments**, Springer-Verlag, Berlin, 77-89.

Jankel, A., and Morton, R. (1984) **Creative Computer Graphics**, Cambridge University Press, Cambridge, MA.

Mandelbrot, B. B. (1983) **The Fractal Geometry of Nature**, W. H. Freeman, San Francisco, CA.

Negroponte, N. (1995) **Being Digital**, Vintage, New York.

Richardson, L. F. (1993) **The Collected Papers of Lewis Fry Richardson: Volumes 1 and 2**, edited by O. M. Ashford, H. Charnock, P. G. Drazin, J. C. R. Hunt, and P. Smoker, Cambridge University Press, Cambridge, UK.

Schroeder, R., Huxor, A., Hudson-Smith, A. (2001) Activeworlds: Geography and Social Interaction in Virtual Reality, **Futures**, **33**, 569-587.