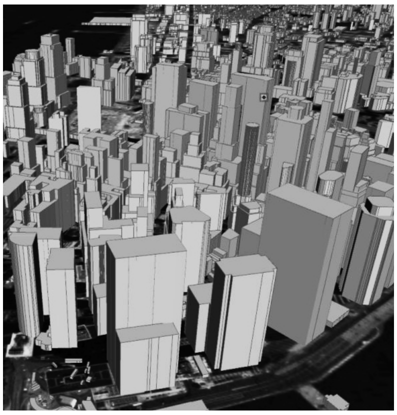
CAD, 3-D GIS and the Global Digital City



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Abstract

We are on the edge of a revolution in the way we visualize and query digital data about our environment. To date, computer displays of our environment in the third dimension have been limited to computer-aided design (CAD) packages and the query of related data limited to geographical information systems (GIS) packages in two dimensions. The current innovation wave across the spatial data information field is based on the development and dissemination of three-dimensional GIS (3-D GIS) which allows data to be visualized and queried on an x, y and z axis plane. A number of the key players in information visualization allow conventional two-dimensional data to be viewed and exported in a three-dimensional format, currently using the standard Virtual Reality Modeling Language 2.0 (VRML 2.0). However such methods of visualization and data query are limited in their practicality. The move towards 3-D GIS in standard packages has been rather hit and miss, with the third dimension often only used as a substitute for basic CAD-like visualization. We argue here that 3-D GIS will only become a reality when it is directly linked with CAD models; and that the Internet is the most appropriate medium through which this is most likely to occur. We illustrate these arguments in an overview of research into the virtual city in general and our own development of 'Virtual London' in particular. Further, we explore the rise of the global virtual city, a network of virtual cities that provide an insight into the future of digital space.

KeyWords: CAD, 3D-GIS, Virtual London, Visualization, Global Digital Cities

1 The Virtual City

Computer screens are the electronic nodes of the virtual city, just as real cities are nodes in the global settlement system. The term 'virtual city' is now common parlance on the Web and, at the time of writing, a query for the term on the Google search engine returns over 26 million links. Google is an emerging force in the field of Virtual Cities and one with the capital backing to significantly influence future research which we will explore more fully later. The term Virtual Cities has a wide range of connotations including: digital cities (Mino, 2000), city of bits (Mitchell, 1995), Web-city (3-D Net Productions, 2002), telecities (telecities, 2000), wired cities (Dutton, 1987), infocities (Infocities, 1997), cybercities (Graham and Marvin, 1999), but to name but a few. The common theme to all of these is the use of the city metaphor to describe a network of people and/or information, information that is digitally communicated with relevance to either a real or imaginary city. In short, the virtual city is a merger of the community and the city, embedding the current functions of the physical city in a digital form. These real-/non-real communities have been defined as either 'grounded' or 'non-grounded' digital cities respectively (Aurigi and Graham, 1998; Aurigi, 2005). Beyond this, however, the characteristics of virtual cities are rather wide-ranging. They can be both grounded and non-grounded, two-dimensional or three-dimensional, service-based or information-based. We will concentrate here on the three-dimensional nature of the virtual city and our abilities to append information directly to their 3-D representations. Currently we are in the process of developing our own rendition of a large world city - 'Virtual London' - and before we detail this, we must briefly examine the rise of CAD and thence 3-D GIS in Virtual Cities.

2 Large-Scale Adoption of 3-D GIS

A recurring theme in the development of digital media is the way in which emerging technologies are enabling us to query and manipulate our environment at a distance. Applications of 3-D models which can now be effectively 'streamed' over the Internet open up a range of possibilities for development of 3-D GIS for geographically extensive areas. The main driver in the UK behind the current development of 3-D GIS in general and the move towards virtual cities in particular is central Government's Electronic Government initiative with its objective to deliver electronically, and in a customer-focused way, all government services by 2005 (Office of the e-Envoy, 2002). This has garnered political support for the vision of a 'Virtual London' and the 3-D GIS research necessary to create it. We are at the point of moving into a new era of data delivery and query via the Internet. Such research towards virtual cities can be seen in the wider context of the development of Planning Support Systems (PSS) (see Brail and Klosterman, 2001). Snyder (2002) notes that there has been disappointing progress over the last 20 years in the adoption and use of PSS and geographical tools in the field of land use planning and community design, but there is growing evidence that we are on the cusp of large scale adoption of these tools. Snyder's views in 2002 are similar to Klosterman's (1998) prediction that we are on the edge of a new revolution in the use of digital tools for planning and environmental visualization. But Klosterman's prediction remains as yet unfulfilled, with the 1990s seeing only the development of interesting academic prototypes (Klosterman 1998).

We are nevertheless at a tipping point in 3-D GIS, especially with the development of 'Google Earth', which we discuss in more detail later. Gladwell (2001) reflects how major changes in society happen rather suddenly, and Snyder (2002) develops Gladwell's (2001) key ingredients for the rapid adoption of ideas, practices and products in his discussion of PSSs. He identifies several reasons which are directly applicable to virtual cities:

* government departments and communities are increasingly grappling with the growing complexity of land use planning, resource use, and community development.
* emerging tools for community design and decision-making have the potential to dramatically change the planning profession. In particular, computers are becoming more powerful and less expensive.
* data are becoming more readily available and challenges with respect to interoperability of GIS (across different platforms and among different models) are being resolved.
* tools are becoming user-friendlier. In addition, the growing number of early adopters of these systems have demonstrated their usefulness and power.
* PSS have the potential to transform decision-making in two ways: they can help communities shift land use decisions from regulatory processes to performance-based strategies, and they can make the community decision-making process more proactive and less reactive.

While Snyder's (2002) arguments are made in the wider context of PSS, we believe that it is the domain of the virtual city that has the most potential to create a dramatic change in how we view, distribute and communicate data.

In terms of Virtual London, the fully functional complete model is being developed in different ways for different audiences. There are at least four potential audiences for which the three-dimensional model and its underlying data will be used. The level of usage is likely to be dependent on the delivery method and the method of visualization used across the network (specifically the Internet). We envisage four broad categories of use:

* fully professional usage - the use of the model by architects, developers, planners and other professionals who are anxious to use its full data query and visualization capabilities. For example, an architect might place a building within the model and use this to assess a variety of issues, from its basic visualization to the impact it might have on traffic and surrounding land use. This could potentially be set up with 'subscription-only' access, raising revenue for the continued development of the model. Subscription-only access would also allow potentially delicate data to be distributed and queried via the three-dimensional model, with users requiring a password and user name to view restricted levels of data.
* concerned citizen usage/public participation - the use by citizens and the role of public participation would be both educational and participatory in the sense that interested groups and individuals would use the model to learn about London and/or to visualize development and traffic proposals. This is seen as the main level of usage of the model with obvious links to the development of e-democracy and the evaluation of 'what if' scenarios to enable digital planning at the citizen scale.
* virtual tourism - the use of such models for tourist navigation and visualization is a side product of the development for digital planning. A version would be developed in which users of the model on the web can learn about London as tourists, using it to navigate and view scenes, picking up web sites of interest, not unlike our Wired Whitehall (http://www.casa.ucl.ac.uk/vuis). With the appropriate level of underlying data, such a model could also be used for marketing areas in London to encourage outside investment in the city.
* educational usage - 'Virtual London' will provide a resource for education, linking into the UK National Curriculum for high schools through subjects as diver-

se as geography, civics, and history. Education is a key aspect of the virtual city as it reaches out to an audience which is often not a part of the consultation or data query process. Educational visualization would be through a multi-user collaborative system such as that used in our project 30 Days in ActiveWorlds (http://www.casa.ucl.ac.uk/30days/). This would form part of a secure closed educational network in which schools would meet up and discuss issues relating to the National Curriculum in a virtual environment. The model would also be able to link in with university-based education for urban planning, architecture, and virtual environments. In the same way as professional users, students would be able to load in their own models in closed sections of the networked site for visualization and evaluation of design in the London context.

We will now detail the elements of its construction, and identify the various options involved, issues which are central to the development of our 3-D GIS and virtual city concept.

3 Technical Development

The goal of Virtual London is to develop a truly virtual city which can be occupied, queried and manipulated by citizens within a collaborative environment. As we have identified, interested citizens will comprise professionals working in London, those using it for educational purposes, and those from outside London using the virtual environment to pursue other interests. As such, the technical development is based not only on the visualization of London's built environment but also on the integration of underlying data and the production of bandwidth-friendly multi-user models. The development route entails a combination of data capture, model development, optimisation, and deployment using various technologies and via the Internet. This is illustrated in Figure 1.

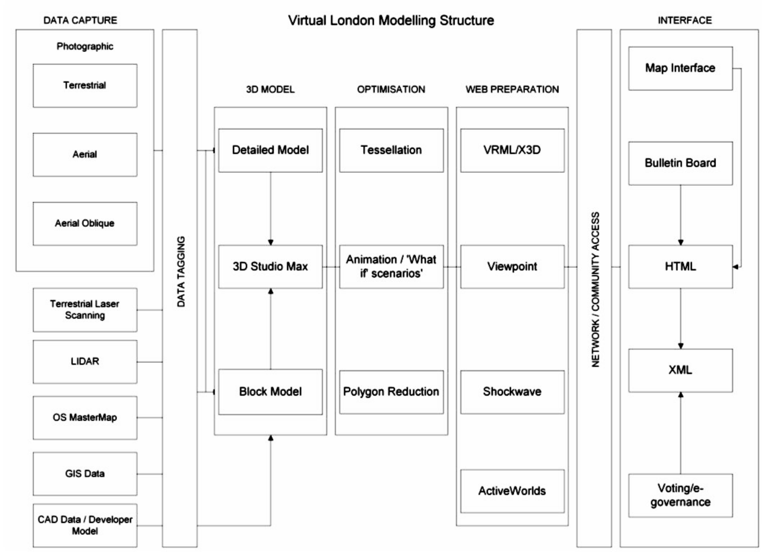

Figure 1. The Modelling Structure of Virtual London.

The current cutting edge applications in Internet-based three-dimensional visualization are Viewpoint (http://www.viewpoint.com), Shockwave 3-D (http://www.shockwave.com) and ActiveWorlds (http://www.activeworlds.com). Each of these technologies allows data to be tagged to its objects, which is central to the development of a 3-D GIS. We do not have time to explore these in detail here but examples from each of these applications can be found on our web site (http://www.onlineplanning.org.uk/).

The acquisition of suitable digital data is central to the development of virtual cities. A number of the academic prototypes, developed as part of the Shared Architecture project (http://www.casa.ucl.ac.uk/public/meta.htm) were built from simple postcard images, resulting in low resolution texturing. The use of high quality oblique aerial image data is important if quality is to be maintained in the sections of the model which will be photo-realistically rendered. Oblique aerial data has been acquired from helicopter based image capture. Helicopters are suitable for the capture of oblique aerial photography for a number of reasons as they can focus in on pre defined areas for data capture. They are however expensive and other means are available from simple kite borne photography to mini-cameras linked to model helicopters which can hover around buildings, beaming back image data. A combination of oblique imagery and ground based photography is central to creating photorealistic buildings. Figure 2 illustrates a building constructed using 6 photographs.

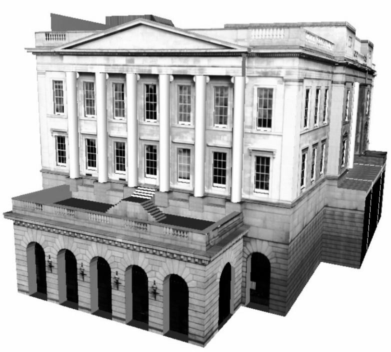

Figure 2. Photogrammetric Reconstruction.

Photorealistic imaging, while allowing a strong sense of location and place is time consuming, as such it is limited to key buildings and areas of interest. For rapid modelling of buildings, a number of different techniques are required, centred on 3D-GIS.

To ensure that the model is geo-referenced and constructed in a manner which makes it applicable to capture additional data, the Ordnance Survey has contributed its MasterMap(tm) data for London. MasterMap(tm) data are layered into nine themes: roads, tracks and paths, land, buildings, water, rail, height, heritage and structures and boundaries (Ordnance Survey, 2002). Each feature has a unique TOpographic IDentifier, known as a TOID with the data supplied in Geographic Mark-Up Language (GML). TOIDs provide a unique 16-digit code for each feature enabling easier data analysis and data sharing (Ordnance Survey 2002). Previous applications, such as the Dounreay Nuclear Power Plant model (http://www.casa.ucl.ac.uk/olp/) used Ordnance Survey Landline data (a precursor to the MasterMap(tm) data product) merely as topologically unstructured background data. MasterMap(tm) is a cleaner, richer, updateable version of this dataset. As a result, the data are presented as a series of closed polygons, in which each feature is referenced as part of the TOID system.

For the non-photorealistic sections of 'Virtual London', simple prismatic models have been extruded from the footprints of MasterMap(tm) using LiDAR data provided by InfoTerra (http://www.infoterra-global.com/laser_spec.html). LiDAR is a relatively new remote sensing technique that is revolutionising topographic terrain mapping. This is a very rich data source, with some laser scanners acquiring 33000 individually heighted points per second and in typical survey mode, over 700000 points are measured per square kilometre. In an urban context, these points can be averaged out for individual buildings by overlaying MasterMap(tm) data and calculating average height. We illustrate such an example in Figure 3, constructed using OS 1:10000 scale topographic maps and LiDAR.

With this model we have worked around the issue that arises from using surfaces to model urban environments using a GIS. The problem that arises is due to the fact that a functional surface cannot have vertical walls (since it cannot have two different Z values at the same XY location). By buffering the building footprints inwards by a small amount (approximately 10cm) and using this polygon to represent the eaves or roofline of the building we have managed to create near-vertical walls. These give the model the appearance of being vertical, and yet allow us to carry out analysis (like line-of-sight) and to drape imagery (such as orthorectified aerial photography).

Figure 3. LiDAR Derived Model combined with Photorealistic Buildings and Landmarks.

Work is also being carried on extracting roof morphology from LiDAR data in the remote sensing group attached to our team. Such research links are important to the success of such a data rich project; the ability to tap into graduate student projects from specialist departments allows a broadening of the research, consistent also with the objectives of digital planning. Roof morphology is key to a sense of location and place from the bird's-eye level, yet it proves difficult to obtain if the model is not derived from photographic data. The Cities Revealed data set which is based on aerial photography has categorised its average height data with a range of roof types and while this will not provide a true representation of London, it will supply a rapid prototype for producing surrounding context into which more detailed models can be inserted.

Data such as aggregate deprivation data, property ownership and size, building use and condition, land use activity types, and so on, can be tagged to the model using TOIDs. We aim to integrate London based GIS data with the model for analysis, to achieve on-the-fly visualization of data queries. Figure 4 illustrates air pollution data, highlighting the effect of traffic densities linked to the model.

Figure 4. Air Pollution Visualised as Part of Virtual London.

A final part of the modelling technique is the integration of panoramic imagery. Panoramas, providing a full 360x180 degree field of view, provide data on two levels. Firstly, they allow imagery to projected onto a globe in the three-dimensional space, whereby users can fly into a panoramic scene and look around a photorealistic view. Secondly, and this is an emerging technology, they allow photogrammetric scene construction. As panoramas cover a wide field of view they provide an invaluable source or spatial and textual data without the cost of oblique imagery. We illustrate an example panorama below in Figure 5.

Combining these techniques allow the construction of a Virtual City, in our case London. Once the model is constructed, the question arises as to how to display and visualise data within the model. We have seen in our Air Pollution work that data can be visualised within a GIS, in our case ArcGlobe by ESRI. ArcGlobe is a notable move towards data visualisation on a planetary scale. ArcGlobe is however a professional tool, aimed at desktop use is not as such constructed to allow sharing of 3-D digital data over the Internet. This is set to change however with the release of Google's 'Google Earth', at the time of writing the software is in beta testing with the aim to include 3-D data from Virtual London. The importance of Google Earth in terms of Virtual Cities is one of a new tipping point in data visualisation. Google Earth's basis is the use of Virtual Cities as a 3-D search engine whereby any locationally correct data can be tagged to the 3-D buildings, allowing one, for example to fly through a city to their closest coffee shop etc. We illustrate a beta screenshot of Google Earth in Figure 6.

Figure 5. The Swiss Re Building, London Captured in a Panorama.

To date, Google has 3-D Cities covering the United States, with plans to cover Europe and the rest of the world in the near future. As such this represents the cutting edge of Virtual City visualisation and takes data to a global level. An important aspect to note is the ability of users to add in their own data and share it with the global community. Imagery, vector and 3-D data can be uploaded to a web server and streamed direct into Google Earth, allowing a unique concept in GIS data sharing. A separate layer can be turned on to highlight data that has been contributed by users. If a user makes a post in the Google Forum, the software knows the users location by their registration details and displays a hotlink to their data within the 3-D browser. This will no doubt see 'data hubs' develop around research labs and individuals sharing data which can be streamed into a Virtual City. Issues of copyright will no doubt raise their heads; in some ways the concept of free data sharing is to GIS what Napster was to the music industry and is a development to watch.

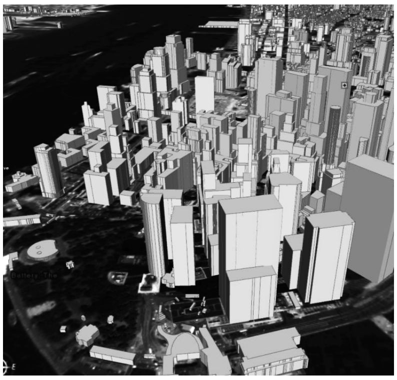

Figure 6. New York, (c)Google Earth.

4 Next Steps

The techniques we have highlighted show how a Virtual City can be created, populated with data and now ultimately shared with other users around the globe. All that is left for true Virtual Cities to develop is firstly photorealism and the development of this is simply down to advances in graphics card technologies rather than new methodology. Secondly it is the integration of social elements into the scenes. The reason cities are vibrant is due their dense population and interaction between the inhabitants. Communication software such as simple text systems like MSN Messenger could be easily integrated into systems such as Google Earth, showing all the people 'chatting' in a city at any one time. At a more advanced scale it could be moved into fully avatar based system, allowing individuals to walk around the streets and interact with other users online. While software such as ActiveWorlds and Second Life, to name but two, allow avatar-based chat, they are not on a global basis. The prospect now exists of finding out your contact is online in London, flying from a 3-D New York to your contact's address in London and walking around the streets of the city while querying data, all within a seamless interface. This is the true Virtual City, and it may not be that far off.

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