Developing an Organisational Framework for Sustaining Virtual City Models

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Developing an Organisational Framework for Sustaining Virtual City Models

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ABSTRACT

This research thesis presents an organisational framework for the management of virtual cities for hosts to adopt when seeking to produce and maintain a virtual city for use as a tool for urban planning related activities. The framework functions as an over-arching business model or structure, a general methodology for defining the organisational processes of virtual city enterprises. In achieving this aim, the research outlines standards and protocols for its creation, legal issues for its distribution and suggested processes for the update of 3D data. The diverse issues and needs of various stakeholders are addressed (Horne *et al.*, 2006) in order to challenge the organisational issues and common concepts involved in creating, hosting and managing a city model (Voigt *et al.*, 2004). Preliminary investigations showed that extensive research has been carried out on 3D and virtual city modelling techniques and their application, but the theoretical organisational and management issues for hosting 3D virtual city models needs to be addressed (Hamilton *et al.*, 2005; Dokonal and Martens, 2001) through a 'guiding source book' for the creation and use of 3D city models(Bourdakis, 2004).

This thesis explores the current state of virtual city modelling and its origins through literature research as well as an investigation into suitable business modelling practice. Pilot studies and an interview process with current virtual city hosts informed the research of current practice in the field. An organisational framework is subsequently put forward that combines elements from each of these investigations using a business model 'canvas' that can be adopted by current or prospective hosts and adapted to suit their circumstances, applications and users. The framework addresses the technical aspects of establishing a virtual city model, such as 3D data capture methods, spatial data infrastructure and modelling protocols in order to present a roadmap for virtual city enterprises. This correspondingly outlines a development from traditional and static datasets of geometry in '3D city models' to more serviceable and user-centric 'virtual city enterprises'. The organisational framework introduces 7 key areas that virtual city hosts should address for sustaining their enterprise that encompasses the technologies and expertise. Hence, this research makes significant contribution to knowledge by bringing together the many considerations that virtual city hosts must consider when creating a sustainable process to support urban planning.

PUBLICATIONS

The following publications have resulted from this research:

Podevyn, M., Horne, M., Fisher, P., 2009*. Virtual Cities: Management and Organisational Issues.* In *CUPUM 2009*.In CUPUM 09, 11th International Conference on Computers in Urban Planning and Urban Management, Hong Kong, 16–18 June 2009

Podevyn, M. *et al*., 2008.*Global Visualisation Engines – Issues for Urban Landscape Planning Participation Processes*, Digital Design in Landscape Architecture 2008, Proceedings at Anhalt University of Applied Sciences, 29–31 May 2008

Horne, M., Thompson, E.M., Podevyn, M., 2007.*An Overview of Virtual City Modelling: Emerging Organisational Issues*, CUPUM 07 10th International Conference on Computers in Urban Planning and Urban Management, Iguassu Falls, Brazil, 11–13 July 2007

A research website was created in 2007 to engage with the virtual city community:

www.virtualcityexchange.com

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AUTHOR'S DECLARATION

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others. The work was done in collaboration with Northumbria University.

Name:

Signature:

Date:

GLOSSARY

AM/FM	Automated mapping/ facilities management
AI	Artificial Intelligence
API	Application programming interface
BIM	Building information modelling
BLPU	Basic land and property unit
BOD	Building object database
CAAD	Computer aided architectural design
CAD	Computer aided design
CAVE	CAVE Automatic Virtual Environment
CEN	Comité Européen de Normalisation
CERN	European Organisation for Nuclear Research
CA	Cellular automata
CG	Computer graphics
CGI	Computer generated imagery
DARPA	Defence Advanced Research Program Agency (formerly ARPA: Advanced Research Program Agency)
DBMS	Database management system
DIS	Data integration service
DNF	Digital National Framework
DNS	Domain name system
DSM	Digital surface model (see also DTM)
DTM	Digital terrain model
EDM	Electronic Distance Measuring
ESRI	Environmental Systems Research Institute
Fps	Frames per second
FTP	File transfer protocol
geoVE	Geo-virtual environment
GI	Geospatial information (also referred to as geographical information)
GIS	Geographic information systems (also referred to as geographical information services)
GISc	Geographical information sciences
GML	Geography mark-up language

GSDI	Global spatial data infrastructure
GUI	Graphical user interface
HCI	Human-computer interaction
HMD	Head mounted display
HTML	Hypertext Mark-up Language
IBM	Image-based modelling
ICT	Information and communication technology
IFC	Industry foundation classes
INSPIRE	Infrastructure for spatial information in Europe.
ISO	International standards organisation
ITN	Integrated transport network
KML/ KMZ	Keyhole mark-up language (KMZ is a zipped KML)
LBS	Location-based services
LDF	Local Development Framework
LiDAR	Light detection and ranging.
LLPG	Local land and property gazetteer
LPG	Land and property gazetteer
NGD	National Geographic Database
NGDF	National Geospatial Data Framework
NIMSA	National Interest Mapping Services Agreement
NLPG	National Land and Property Gazetteer
NMA	National Mapping Agency
NMCA	National Mapping and Cadastral Agencies
NSDI	National Spatial Data Infrastructure
NSG	National Street Gazetteer
OGC	Open Geospatial Consortium
OSCAR	Ordnance Survey Centre Alignment of roads
PARSOL	Planning and regulatory services online
PDA	Personal digital assistant
PC	Personal Computer (in this context a PC includes Mac-based computers)
PPS 12	Planning Policy Statement 12
RSS	Rich site summary
RWO	Real world object
SDK	System Development Kit
SDI	Spatial Data Infrastructure
SGML	Standard Generalised Mark-up Language
STEP	Standard for Exchange of Product (model data initiative).
TOID	Topographic identifier

UKSGB	UK Standard Geographic Base
URL	Uniform resource locator
USRN	Unique Street Reference Number
VRML	Virtual reality modelling language (also virtual reality mark-up language)
W3C	World Wide Web Consortium
(The) Web	The World Wide Web

CHAPTER 1: INTRODUCTION

The two words 'information' and 'communication' are often used interchangeably, but they signify quite different things. Information is giving out; communication is getting through. (Sydney J. Harris)

The 21^{st} century city is responding to widespread population growth and urbanisation in many countries. This imparts an increasing burden to update the infrastructure and resources available to its citizens on those who are charged with its maintenance. Ichioka (2008) explains that this densification of urban centres has implications on planning policies, such as through the protection of view corridors. Urban Planning exists to control a region's urban and natural environment. Although this control differs significantly between cities and countries, the broad intention is to protect the aesthetic and historical fabric of the built environment while maintaining a high standard of living for its citizens.

Technology has been used in a variety of ways to assist the design and administration tasks that are required in managing cities. Two dimensional (2D) maps have been used for centuries to visualise the landscape and the consequent development of Geographical information systems (GIS) allows (digital) cadastral information to be enhanced by diverse information for improved analysis. Similarly, wooden models of buildings and cities have been an effective resource for spatial analysis and evaluating new developments, but have recently been superseded by advances in computer aided design (CAD). Information Technology (IT) has become invaluable in all aspects of personal or professional life and its presence as a resource in urban planning processes is no exception.

The emergence of IT has simultaneously presented a facility for three dimensional (3D) computer-based designs, most conspicuously exploited by users in architectural and engineering fields. As with CAD, 3D city models have been adopted not merely to improve production or construction processes, but to visualise the end results. The internet has ensured an immeasurable audience by creating an interminable resource that has helped these 'virtual worlds' progress from large collections of 3D geometry into linked, geo-relational databases.

Previous examples of virtual cities were often produced and managed as a single entity, in both a physical and organisational sense. In this way, city models began as seamless

CAD models that displayed the buildings, streets, roads and features of the city. They were managed as a single object, a snapshot of the city at a particular point in time, bought or commissioned as a single product. Researchers in academia accounted for the vast majority of early city model creations, experimenting with advanced visualisation techniques or seeking better solutions to existing traditional urban planning processes. Users from telecommunications, surveying, programming and GIS eventually began to employ city models for a variety of applications (Dokonal, 2008). Their predecessors – physical scale models have been used for centuries as an essential part of the design process, architectural visualisation and even for marketing. Similarly, larger urban models have been a useful way to reproduce a cityscape and test new developments for the same purposes.

The latest incarnations of cities are represented as dynamic virtual city projects, with individual components held within a database structure. Dollner *et al.* (2006, p3) exemplifies that "the virtual 3D city model of Berlin acts as an integration platform for 2D and 3D geo-data and geo-referenced data instead of being only a 3D geometry or graphics model". Where originally the end model was driven by the process of modelling and appearance, focus now lies on the application and its end users. This technology push has been accompanied by a market pull, not only from the increasing users of mobile technologies but from the planners and designers of the expanding cities around the world.

Thus, a virtual city project and its dynamic dataset can garner the interest of varied stakeholders, which raises questions about the initial capital, income streams and maintenance costs. Who will pay for a virtual city that will be used by many? Who will pay for its continuous update? And who should provide the expertise to maintain and deliver the city model, in a variety of formats to satisfy these various stakeholders?

Arguably, computing and IT have become tasks or responsibilities in their own right, rather than the tool for carrying out tasks. Information is gathered, recorded, processed, consumed and applied across a breadth of platforms. Those who manage our cities have access to vast amounts of this political, geographical and social information. Although there are many examples worldwide of Virtual Reality (VR) technologies and 3D city models being used to assist the planning process, the issue of how VR functions as a means of communication for planning applications is insufficiently researched (Sunesson *et al*., 2007). Current literature informs us that not only are there still many technical barriers to the inclusion of various stakeholders in the planning process, but also that methods for communicating development proposals to the general public are difficult to understand and do not give appropriate opportunities for participation (Mantle *et al.*, 2007). Wang *et al.* (2007) suggest that the insufficient integration and interoperability between software applications have caused considerable barriers to communication between these stakeholders. A key aim of virtual city models is to assist communication between its users and stakeholders highlighting the importance of appropriate software and data management from the outset. A problem that faces the hosting and management of city models is the issue of merging those involved in the participation, planning and the development processes together within a common framework of understanding (Brown *et al*., 2005). Hall (1996) categorises four relevant parties in the urban planning process: city planners, architects working for clients, the clients and the general public, all of whom are seen as legitimate 'stakeholders'.

Much progress has occurred over the course of the research in the standardisation of city model data, such as the recognition of the CityGML (City Geography Mark-up Language) data standard, which is a multi-purpose representation for the storage and interoperable access to 3D city models (Kolbe *et al.*, 2005). More recently, the KML (Keyhole Mark-up Language) language was announced as an official ISO standard, emphasising Google's foothold in the Geographic Information (GI) industry. This is also in line with the development of Industry Foundation Classes (IFC) and Building Information Models (BIM), which are likely to have much application in data-rich city models. 3D laser scanning, image modelling and other methods of data capture are increasingly competitive. During the course of the research, technologies have improved but the methods of delivering or applying the fruits of these technologies have remained in isolation. Beside the technical issues of these large complex models (Wang *et al.*, 2007), it is the lack of high-level commitment by key players in both the construction and software industries that hinder the standardisation efforts in the Architecture, Engineering and Construction (AEC) industry (Behrman, 2002). The uptake of BIM in practice will present information rich, accurate geometric models into larger 3D virtual city models (Kohlhaas and Mitchell, 2007). Although CityGML does outline some thematic methods of representing digital building models ('Level-of-detail 0-3'), established recommendations are necessary for quality levels and methods of depicting the content of a building proposal (Bourdakis, 2004). This is essential for better understanding of a planning scheme and a democratic aspect of city planning decision-making (Sunesson *et al.*, 2007). Furthermore, different stakeholders involved in the development process require a representation of the virtual city model from different perspectives and qualities (Brown *et al.*, 2005).

Although virtual cities have been developed by a range of users, from educational establishments to private urban modellers, Le Heron (1999) highlights the importance of the careful hosting of a city model for specialist applications. This is necessary to ensure that information is secure and to protect certain individuals' rights, as well as the need to control the information so that it does not become a commercial and/ or marketing tool. Furthermore, the risk of enfranchisement or disenfranchisement raises obvious concerns to most of the stakeholders in the urban planning decision-making process (Bishop and Forster, 2007).

Legal issues concerning 3D city models can be associated with the data acquisition and management. Data acquisition for constructing 3D models is often sourced from third party aerial imagery or specialist city modellers. This approach can be restrictive of the communication, distribution and intended use as the necessary Intellectual Property Rights (IPR), security or privacy laws may be applicable. It has been noted that the lack of proper copyright protection or digital signature stamping in 3D geometry, coupled with the relative ease at which files can be transferred across the internet is hindering the development and availability of urban models (Bourdakis, 2001). Architects who submit 3D models frequently request to retain their rights to certain data, not solely for IPR purposes, but for fears of misrepresentation, particularly during the course of planning proposals. For these reasons, more recent examples of city models have acquired data using laser scanning technologies to avoid legal restrictions and produce ‘as-built’ 3D geometry, rather than relying on architects’ drawings (e.g. Glasgow, Westport) (Pritchard, 2007).

1.1 JUSTIFICATION FOR THE RESEARCH

Preliminary studies carried out as part of this research project illustrated that much research has been carried out on 3D (virtual) modelling and its application, yet little work has been carried out on the theoretical organisational and management issues that these technologies and their users encounter. Hamilton *et al.* (2005) verify this notion that, in general, the ability to manage urban planning data leaves much to be desired and that practical aspects such as the management of 3D virtual city models and how they can be sustained must be addressed (Dokonal and Martens, 2001). It has also been recognised that the majority of GI (Geographical Information) users do not yet know what they require from 3D building data (Sargent *et al.*, 2007), which adds to the knowledge gap between virtual city users, practitioners and contributors. Despite this, elements within the literature investigation show that many of the technologies are beginning to synergise, approaching their peak of use that corresponds to Gartner’s ‘hype cycle’, which attempts to rationalise the maturity of a developing technology (see Figure 6, page 18).

It is widely understood that virtual city projects have a limited life due to technological changes and the relatively short lifespan of the data that defines them. “The technology is moving so fast” (Fisher, 2000, p61) has become a cliché in the many communities of Information Technology (IT), Information Systems (IS) and indeed, virtual city modelling.

So how should a host account for future trends, changing legislation and economies? Hence, this research project explores a variety of options that can assist in the decision-making process of an organisation and makes this distinction in the framework that a 3D city model is considered as a virtual city enterprise. Furthermore, the thesis and organisational framework is focused toward a higher quality of virtual cities, such as those used for urban planning related activities. There is a range of online 3D mapping or virtual globes, but these are currently of a level of accuracy limited for use in urban planning tasks. Data capture techniques, internet access speeds and data storage are the key components for their development and competitive use that are increasing at an extraordinary rate. However, enduring privacy issues that have affected online mapping products thus far highlight the need for the careful hosting of a detailed virtual city.

The field has been the subject of much academic interest in a range of fields, including Geography, IT and Urban Planning. Such interest has substantiated a dedicated international conference in 2012 (October), titled '3U3D2012: Usage, Usability and Utility of 3d City Models'. A number of virtual city models in the UK were originally created by universities to explore ways of improving the existing planning process (Hudson-Smith, 2005). These were usually established in architecture or geography departments due to their existing expertise. However, there is little evidence to suggest that these models were developed for a particular or specific purpose, aside from the general umbrella term of 'planning', which itself could include a range of tasks/ activities/ applications. In many ways the research project would have been suited for a case study methodology and this would have coincided well with the establishment of Virtual NewcastleGateshead, a collaboration to create a 3D virtual model of Newcastle upon Tyne and Gateshead. However, preliminary investigations showed that virtual city models can be sustained for longer when applied in a GI field, as seen in many European examples. Hence it was more appropriate to study a range of city models and their approach to the field, rather than focus on one particular project.

The research aims to address questions about a virtual city's infrastructure that can help to sustain its future: why do so many projects fail to endure? Or, how does a host balance the various stakeholders with their various requirements? In order to address these questions, a mixed methods investigation began with a literature research that included both virtual city modelling and business frameworks. Organisational and technical aspects were explored in a practical context in three pilot studies before 23 current virtual city hosts were interviewed on their experiences of managing a virtual city.

1.2 RESEARCH AIM AND OBJECTIVES

The primary aim of the research is to formulate an organisational framework that outlines best practice and recommendations for the process of 3D city modelling, focusing on virtual cities that are used for urban planning related activities. This organisational framework is designed for virtual city hosts or enterprises to adopt when seeking to produce and maintain a virtual city for use as a tool for urban planning related activities. This follows from research by Dokonal and Martens (2001) and Bourdakis (2004), who have recommended a 'guiding source book' for the creation and use of 3D city models. The diverse issues and needs of various stakeholders will be also addressed (Horne *et al.*, 2006) in order to address any issues involved with creating, hosting and managing a city model (Voigt *et al.*, 2004).To this end, the objectives of the research are to:

1. Review current virtual city modelling context and techniques
2. Determine current practice in technical integration of data
3. Survey virtual cities
4. Results analysis and dissemination
5. Engage with Virtual City community
6. Review methods of business modelling
7. Determine current practice in technical integration of data
8. Interview industry practitioners

1.3 Thesis Outline

The thesis begins with an introduction to the research in Chapter 1, establishing the research environment and the reasons for carrying out the project. The aims and objectives introduce the purpose of the study and the contribution to knowledge that defines it.

The first part of the literature review is presented in Chapter 2, an investigation into the technologies and methods from which current virtual cities have developed. This takes on the emergence of CAD and 3D GIS as well as an overview of the organisational issues involved in their management. Examples of 3D city models and their hosts from around Europe are presented in a virtual city audit at the end of the chapter. Chapter 3 continues the literature review for business models and frameworks. Key models are introduced that have similarities with the research topic, presenting important considerations upon which an enterprise is based. Over-arching frameworks, such as enterprise architecture and technology road-mapping, are highlighted for their relevance to the research field.

The research methodology in Chapter 4 introduces a range of research methods that were considered for this project. The mixed methods approach is justified and an explanation of how this developed from the literature review and the pilot studies formed the basis for the investigations and added practical context to the research. The subsequent semi-structured interviews are also discussed.

Chapter 5 presents analyses of the previous investigations, beginning with a report on the three pilot studies. These explored some of the technical city model processes, such as data integration, file formats and CAD/ modelling protocols in a practical context. The results from the interview process on 23 virtual city hosts are divided into eight themes that report on the specific methods for managing virtual city projects that are used for planning related activities throughout Europe.

Chapter 6 develops the organisational framework and the central contribution to the research project. It begins with its underlying business model that introduces the eight core concepts to manage a virtual city enterprise, including: applications, key partners, key resources, update and upgrade, data infrastructure, channels and delivery, clients and users and finance structure. The process and recommendations for hosting a sustainable virtual city enterprise are also summarised in the chapter and the model is contextualised in exemplar enterprises.

Finally, Chapter 7 concludes the research after summarising the central contributions in the previous section. Suggestions for future research are also outlined.

Chapter 2: Literature Review I - Virtual Cities

2.1 Introduction

The purpose of this literature review is to investigate the context of 3D virtual city models, indicating the technologies, trends and applications that are used. It begins with an outline of the methodology behind the literature investigation and the research questions that have guided it. This is followed with an introduction of the background or origins of virtual city modelling and its links to technologies like virtual reality. Subsequently it explores how city models are created with an indication of the modelling processes and the various organisational decisions that are made during this process. The final part of the chapter explores the application of city models, revealing how they are used, who they are used by and how they are organised. During this stage, results from a city model audit are presented.

Virtual city models play a role in a range of applications, for a range of purposes and therefore across a range of disciplines. Professionals from business or academia have employed city models to either fulfil a specific function or explore new ones. In order to understand the context from which city models have developed, this review explores the emergence of information and communications technology (ICT), virtual reality (VR), GIS and 3D city models. It aims to answer how and why city models have developed from these technologies and how they are related – technically and organisationally. Finally, an outline follows of the UK planning system and a study on how spatial information is communicated in this environment is presented to put city modelling into a specific context that is continued in the remaining research project.

2.2 Context and Origins

The emergence of Information Technology (IT) has presented a facility for 3D computer-based design, so architectural and engineering applications were fast to emerge from early pioneering work. As with computer aided design (CAD) and later, building information modelling (BIM), 3D representations of cities have been adopted not merely to improve production or construction processes, but to visualise the end results. Virtual cities have progressed from large collections of 3D geometry into linked, geo-relational databases. Originally, architecture and academia were the driving factors for the creation of virtual cities, but there has been a shift towards users from telecommunications, surveying, programming and GIS users who are driving the development of virtual cities for a variety of applications (Dokonal, 2008). Their predecessors – physical scale models have been used for centuries as an essential part of the design process, architectural visualisation and even for marketing. Similarly, larger urban models have been a useful way to reproduce a cityscape and test new developments for very much the same purposes.

Technology advances from developments in IT have been accompanied by market demand, not only from users of increasingly mobile technologies, but from the planners and designers of the world's expanding cities. It has been widely reported that the rate of urbanisation of most countries is accelerating (PRB, 2011). Ichioka (2008) explains that this concentration of urban centres has implications on planning policies, such as through the protection of view corridors and their concerned stakeholders.

Essentially, a virtual city can be described as a 3D digital map within a virtual environment. They are used to create a spatial and visual representation of a city. Richard Le Heron (1999) suggests that the most popular way of defining geographic space is to simplify the real world into two dimensions as a map, using Euclidean geometry to represent this space. However, this geometry provides a very inaccurate view of how most people experience many aspects of the world. An alternative view argues that most human processes are governed by cost and time factors rather than kilometres, which need to be defined relative to the process and actors involved:

> A rich business woman in a fast car sees the 'distance' to the nearest shopping centre very differently from a young mother without a car. The term relative is sometimes used for these spaces. Such distances change over time, and can create a very different idea of what a 'space' looks like. (Le Heron, 1999, pp42-43)

Hence, a 3D model of a city can be an effective tool for exploring an urban environment for a range of contexts, by a variety of users. The assistance of a PC (the 'virtual' component) can enhance straightforward, static geometry with freedom for navigation and enhanced with data, layers or detail for enhanced communication.

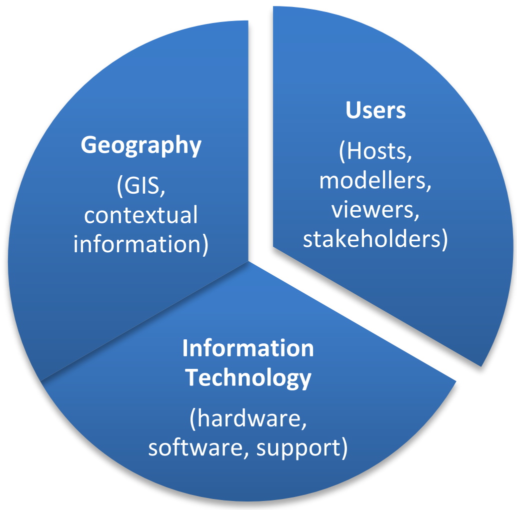


Figure 1: Key aspects of a virtual city

The terminology used to describe a virtual city broadly covers the data, technologies and resources that are required for storing, managing and using the information. Similarly, 'Digital City Model' (Voigt *et al.*, 2004) or 'Digital Cities' are often used to describe a model of selected features of real cities in virtual format. Alternatively, a number of authors (Dollner *et al.*, 2006; Dykes *et al.*, 2005) use the terminology '3D Geo-virtual Environments' that function as the interactive interface between city model contents and users:

> With geo-virtual environments, we can present contents to users, explore unknown geo-information, analyse geo-information, and manage the storage of geo-information. Virtual 3D city models, therefore, constitute a major concept in 3D geo-information systems (3D GIS). (Dollner *et al.*, 2006, p2)

The use of the term 'virtual reality' (VR) is often debated and used as a buzzword to describe any computer generated 3D model or immersive environment, although a more appropriate definition for the modern age is described by Roupé (2009) as "the ability to interactively manipulate and move around in a world represented by a digital three dimensional geometric mode". In this context, VR presents itself as an alternative medium, such as television or telephone (Steuer, 1995). Concepts such as interactivity, immersion and sensory input have been used extensively for characterising its nature (Bourdakis, 1997). Byrne (1996) simplifies VR as a computer-based technology that "gives the illusion of being immersed in a three dimensional space with the ability to interact with this 3D space".

Substantial developments in hardware took place from the 1940s,with the ENIAC (Electronic Numerical Integrator and Calculator) in 1946, which was developed for tackling processes that later become known as 'batch processing' (Whyte, 2002). The 'Whirlwind' computer was developed by MIT from 1944 and became the first 'real-time' computer in that it could respond instantly to user input and produce a visual output on a simple display (Waldrop, 2000). This machine was used up to the 1970s for simulations by the US Army and then for research and development (Waugh, 1998). These 'main frame' computers were based on the ability to run large amounts of data through a pre-defined system that produced numerical outputs often relating to spatial analysis (Hudson-Smith, 2005). Many practical innovations emerged in the 1960s, such as the 'Sensorama', a multi-sensory motorcycle simulator incorporating visual, acoustic and aromatic feedback (Biocca, 1995). The system had many characteristics of a VR system (Gigante, 1993) and was essentially a combination of many technologies that introduced methods of simulating an environment (Rheingold, 1992). Ivan Sutherland was one of the first researchers and developers of VR, exploring concepts for emerging technologies in a paper 'The Ultimate Display' (1965) and created the first VR head mounted display (HMD) system (Roupé, 2009). Physical wireframe representations of rooms could be navigated as its users' movements were tracked to update a display that reflected the new viewing position (Gigante, 1993). The potential of this new technology was described as:

> A display connected to a digital computer gives us a chance to gain familiarity with concepts not realisable in the physical world. It is a looking glass into a mathematical wonderland… The 'ultimate display' would, of course, be a room within which the computer can control the existence of matter (Sutherland, 1965, p760).

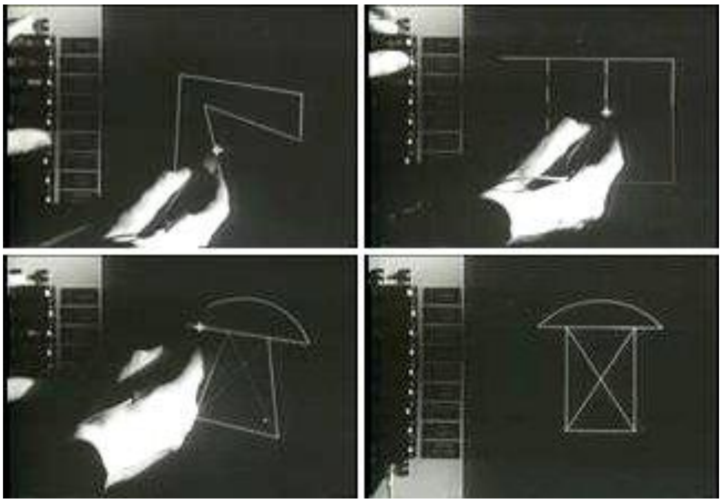


Figure 2: Sketchpad using a light pen input device creating simple geometry (Sutherland, 1963)

This research led to the development of Sketchpad, a graphical system that allowed users to draw and manipulate objects on a computer screen with a light pen (Myers, 1998). Whyte (2002) refers to this as the first CAD package that boasted sophisticated graphical interfaces those early computers lacked and outlined the foundations of computer interfaces (Myers, 1998).

Computer Aided Design solutions developed throughout the 1960s, but were limited by large costs and relatively poor hardware performance (Roupé, 2009) to research and military applications. Flight simulators developed for the aerospace industry were particularly prevalent. The Visually Coupled Airborne Systems Simulator (VCASS) was designed to simulate stressful data processing and decision-making that fighter pilots must handle. Gigante (1993) suggests that the development of these simulators had a significant impact on the subsequent development of VR and virtual environments. CAD was upgraded into the third dimension with Sketchpad 3 in 1963, which was followed by the first CAD/ CAM (Computer Aided Manufacture) system at General Motors. Methods for computer interaction were introduced with peripheral devices, such as the light-pen input device (mid-1950s). These expensive and impractical solutions were not effectively replaced for some time, despite the development of the mouse in 1965, but which only appeared commercially in 1981 (Myers, 1998). The advances in computer hardware and chip-making capabilities informed Gordon Moore's research (1965) at Intel and predictions that integrated circuits would eventually lead to home computing or terminals connected to central computers, automatic controls for automobiles, and personal communications equipment (Hudson-Smith, 2005). Moore proposed that computer technology would double in capacity every two years, a concept that has remained accurate (see Figure 3, below).

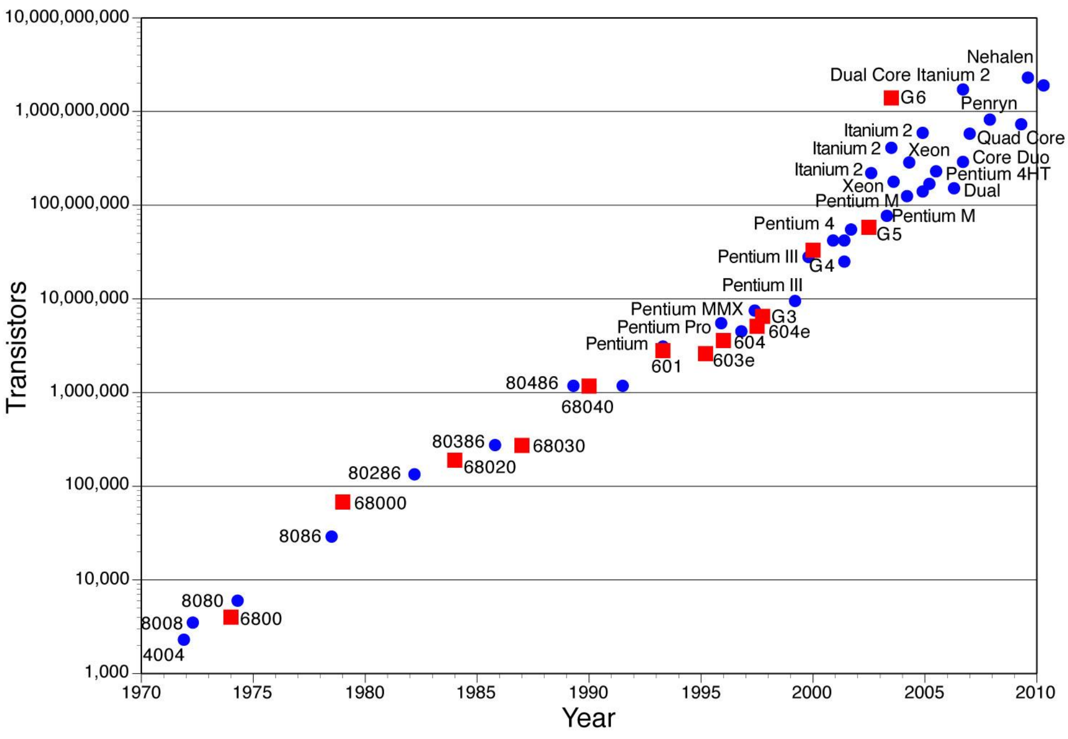


Figure 3: Moore's Law (Wall, 2009)

Developers of VR applications in the 1970s began to build digital simulations that engaged single users as closely as possible, 'immersing' them within the virtual environment through experimental peripheral devices such as HMDs and data-gloves (Heim, 1997). Kalawsky (1993) noted that these 'traditional' VR systems were divided between the kind of immersive activity that developed to embrace various human senses, and desktop VR based on animated computer aided design (CAD). Both activities were dominated by the direct viewing of virtual environments rather than by processes for undertaking non-visual activities within visual environments (Batty *et al.*, 1998), indicating a lack of integration between interaction and a practical application of VR that would emerge when the technology was more developed. Sutherland's continued research explored the rendering of 3D objects, creating images from geometrical data and the addition of colour, textures, lighting and shading or concepts that are now known as 'rendering' (Whyte, 2002). The team of researchers used networks of computers for processing power and developed the first interactive architectural walk-through system (Brooks, 1992). Another notable contribution that explored an alternative method of interaction was the Aspen Movie Map, created by recording thousands of individual video frames, stored on a disc and communicated through software that used the images to allow a user to navigate their way around Aspen (Gigante, 1993).

The development of VR in the 1980s was subject to much media attention, with computer generated films (e.g. 'Tron') in 1982 and William Gibson's books 'Burning Chrome' and 'Neuromancer' that explored the concept of 'Cyberspace'. Processing power and graphic capabilities became sufficiently developed for widespread use even in low-end systems during the 1980s (Whyte, 2002). These machines became known as microcomputers, due to their relatively small size. The US firm Autodesk was established in 1982, preceding the launch of AutoCAD for creating detailed, technical, 2D drawings in December of the same year. Although other CAD packages were emerging at this time, Autodesk's solution took advantage of the first wave of Microcomputers. In most cases, this was the newly developed IBM PC (Myers, 1998). Other software at this time generally ran on graphics terminals that were connected to mainframe computers. This became a highly competitive market for similar products aimed at smaller engineering, architectural or design companies. Furthermore, the rapid development of the microcomputer introduced a games industry alongside the Commodore 64, Atari ST and other popular 8-bit consoles. This decade was characterised by research that explored the use of many forms of media to visualise environments. The Interlab team at the University of Osaka generated numerous fly-throughs, including areas of Tokyo, Paris, Osaka and Shanghai (Maver, 1987) in order to visualise urban environments. These were created by generating large numbers of discrete views of an existing or proposed cityscape that were treated as frames in order to create animated films (Maver, 1987). Although these were extremely impressive for the time, the films offered no interaction or navigable features, which would require extensive re-editing if changes were to be made. Towards the latter part of the decade, VR packages became commercially available, particularly through VPL Research Inc. and W. Industries. In 1989, Autodesk Inc. demonstrated Cyberspace, a real-time 3D environment, using a PC at SIGGRAPH 16 (Special Interest Group on Graphics and Interactive Techniques), a conference that had been running annually since 1974.

ABACUS (Architecture and Building Aids Computer Units Strathclyde) had begun a research program into the latest developments of CAD and centred on the visualisation of the built environment, which led to a project to evaluate the relevance and efficacy of the Silicon Graphics Iris 2400 Colour Graphics Workstation. It was put to use modelling and manipulating large geometrical databases of urban topography (Ennis and Maver, 2001). ABACUS produced a 25 square kilometre area of the City of Glasgow by digitising a 2D plan of the city and capturing average building heights from stereoscopic imagery provided by the Council. The building geometry was combined with a digital terrain model (DTM) and road network. The intention was that the City's Planning Department would inherit and manage the model for its architects, planners, developers and other users could navigate the model, but this proved impractical and costly.

Figure 4: Perspective view of ABACUS' Glasgow city model (Maver, 1987)

This research continued to eventually develop a more detailed model for Edinburgh Old Town (Maver, 1987). Although there are some examples of the effective use of CAD for visualisation analysis in the planning process, the use of computers was actually used predominantly for improving the efficiency of administration tasks in planning departments throughout the 1980s (Hudson-Smith, 2005).

Whyte (2002) suggests that the success of the games industry drove the development of low-end systems and hardware during the 1990s. Scientific visualisation remained the driving force in developing virtual environments, the increasing interest in the consumer market in 3D computer graphics caused tremendous progress in games hardware and software (Fritsch and Kada, 2004). These emerging technologies led to related applications in VR, CAD, GIS and many fusions of the three fields, such as the first documented VR GIS – a simulation of the Georgia Institute of Technology Campus area (Faust, 1995). A coordinated approach to VR in the 1990s was typified by the development of Fakespace's CAVE Automatic Virtual Environment (CAVE) and similarly, the Immersadesk (Whyte 2002). Both were large displays that surround and immerse the user in a virtual environment. These systems have been used for a variety of applications since 1992, usually on high-end machines and large budgets due to the graphical strain required to run multiple displays and associated software. Myers (1998) suggests that prolific research in Human-Computer Interaction (HCI) has fundamentally changed computing, notably with the introduction of Microsoft Windows 95, which was the result of a series of research topics. In fact, much of the most celebrated HCI successes that were developed by software companies are deeply rooted in university research projects and in many cases were the culmination of two decades of research (see Figure 5 on page 17). While early CAD tools had enabled 2D drafting, more sophisticated CAD packages were developed in the 1990s that enabled 3D design (Whyte, 2002). Levy (2011, p2) reports that many cities in the US embarked on city modelling projects in the 1990s for their downtown business districts in order to enable communities to visualise and debate design issues, although these were only rare examples in the US and Canada. Furthermore, two clear methods for representation emerged: entity-based and object-oriented CAD (Greenwood *et al.*, 2008). Entity-based CAD was the more traditional approach using vector graphics, whereas object-oriented CAD uses parametric objects, such as walls, floors and roofs that introduces an element of intelligence into models and objects. This constitutes metadata that defines not only their geometry, but material, construction, associated objects, etc. (London *et al.*, 2008).

In 1994, the Virtual Reality Modelling Language (VRML) was conceived at the first annual World Wide Web Conference in Geneva during a session examining 3D visualisation tools for the web (Bridges, 1999). These 'tools' were based on the existing Open Inventor ASCII File Format, developed by Silicon Graphics. The first documented use of VRML to model an urban environment was Virtual Soma in 1995, a model of the South Market District of San Francisco and a prolific area for the development of internet software and animation (Bhunu, Ruther and Gain, 2002). Virtual Soma allowed its users to navigate fully textured streets and interact with some of the buildings (e.g. through hyper-link or video). Although VRML was a milestone in web applications and CAD, its use has not been as widely accepted as had been hoped, even after its eventual acceptance as an international standard (VRML 97: ISO/ IEC 14772-1) (Whyte, 2002). Bourdakis (1996) explains its limitations for urban planning applications due to its inability to handle large amounts of geometry, lack of VR hardware support and layering inadequacies. Furthermore, the user is unable to modify the model in the browser so there is only a one-way link between the GIS and the VRML, with no means of feedback (Smith *et al.*, 1995). Consequently, other 3D data standards were developed, such as Direct 3D and Java 3D, responding to rapid technological advances and widespread commercialisation in the IT industry. One of the first known examples of an interactive VE for urban planning at a national level was in 1997 in the Netherlands (Bourdakis, 1997), where a 3D VRML model of a proposed development in Amsterdam was broadcast repeatedly on local TV news. During the broadcast, residents could call a related phone service (one at a time) and use their telephone's keypads to navigate the model, vote for their approval/ disapproval of the scheme and leave a voice message. At the same time, the VRML Bath City model was being developed at the Centre for Advanced Studies in Architecture, which was intended to test the feasibility of VRML as a basis for urban planning 3D models and explore simple interfaces for interaction (Dokonal, 2008).

By the late 1990s and early 2000s, object-oriented CAD (e.g. ArchiCAD) was becoming more established and computer hardware had caught up sufficiently to be able to manage more demanding applications. The concept of a Building Information Modelling (BIM) was also introduced during the same period, describing a model that encompasses information that can be useful throughout the building's whole lifecycle (Greenwood *et al.*, 2008), as well as its 3D geometry. Consequently, the notion of 4D, 5D and nD models were developed that explore further dimensions in order to simulate a building's complete lifecycle. Although these efficient CAD packages were proving themselves in urban design, notions of interaction and real-time manipulation of the larger urban models was still yet to be tackled (Bhunu, Ruther and Gain, 2002). Advances in remote sensing and data modelling techniques, driven by a sudden interest in GI and mapping applications, influenced a distinct reduction in the cost of many Geospatial data and derived geometry (such as urban models). Furthermore, terrestrial laser scanning systems have been introduced commercially that allow building models to be produced 'as-built', rather than relying on CAD drawings or third party data.

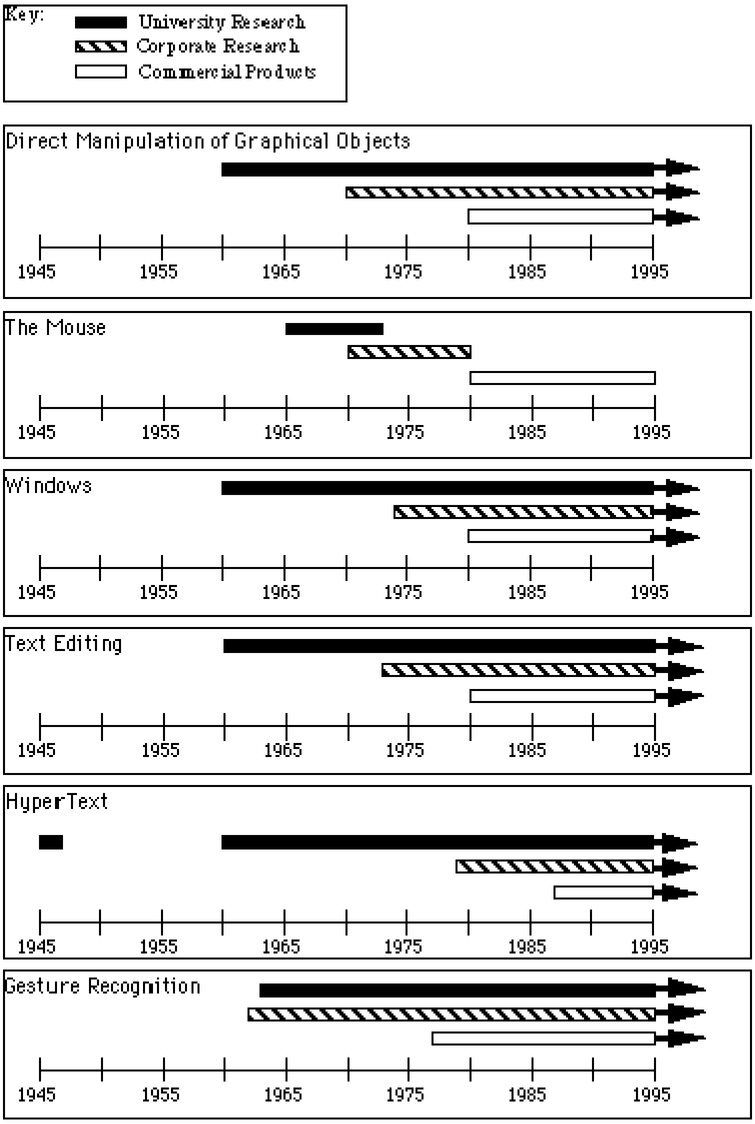


Figure 5: The relationship between research and commercial products (Myers, 1998)

Although many technologies and solutions were explored over the last 40 years, very few of these experimental developments had any lasting impact on CAD or VR. Dokonal (2008) reveals that the role of 3D city modelling using powerful computers was very much in the hands of academics, as the tasks involved were expensive, time consuming and it was unclear whether or not the end benefits would exceed the effort. Linden and Fenn (2003) use Gartner's 'Hype Cycle' (1995) in Figure 6 (below) to characterise the typical progression of such an emerging technology.

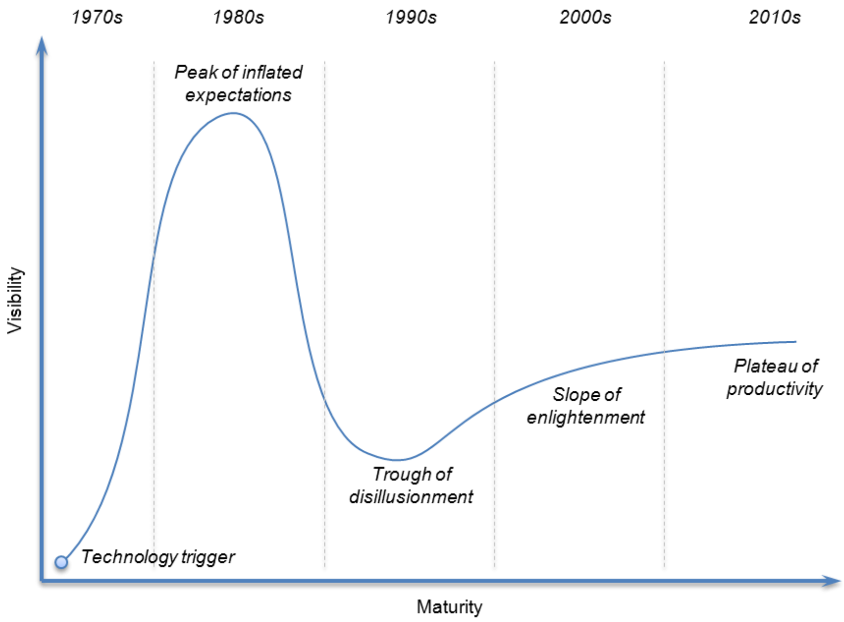


Figure 6: Gartner's Hype Cycle (Linden and Fenn, 2003)

The model explains the over enthusiasm that follows the introduction of a new technology after which there is a negative hype and disillusionment before the technology's relevance and role in a market is properly understood (Linden and Fenn, 2003). As early as 1995, the Centre for Advanced Spatial Analysis (CASA), demonstrated that a VR system comprising of a large screen display, an input device (other than a keyboard) and at least five frames per second (fps) was satisfactorily engaging without the need of complicated HMDs, position tracking and displays over 30fps (Bourdakis, 1995). Bhunu, Ruther and Gain (2002) demonstrate that earlier (pre 2000) immersive virtual environments were problematic due to their substantial reliance on resources. Byrne (1996) expands this notion, suggesting that interactivity is a more useful factor (than 'immersive-ness'). These comparisons were made in studying VR as a tool for education, rather than in a built environment context. Whyte (2002) reports that users from the construction sector associate VR with peripherals such as head-mounted displays, haptic gloves and joysticks, which were used in early demonstrations yet the leading industrial users of VR stress the relationship between the visualisation and the engineering and design data. Hence, the aim in using VR as a medium for the built environment is to gain insight into the processes of its construction and operation. Figure 7(on page 19), highlights the need for a balance between complex systems/ technologies with practical application.

The fundamental advantage that these early developers of VR technologies identified was that a VR architectural environment can provide a feeling of space, whereby a 2D image disposes most of the visual cues in producing a planar image (Gigante, 1993). However, in the context of the planning environment, Hudson-Smith (2005) notes that the past use of computing (in planning) has been about analysis, models and predictions, whereas future applications will rely heavily on networked systems. This enabling factor could move computing into the heart of the planning system for portraying place, space and information. Levy (2011, p2) suggests that planners and Government officials did not necessarily accept that the greater clarity that graphical information presents will reduce potential misunderstandings. Hence, public money spent on expensive visualisation projects may not guarantee a reduction in the time spent or an improvement in the quality of design consultation (Al-Douri, 2010; Levy, 2005; Mobach, 2008 cited in Levy, 2011, p2).

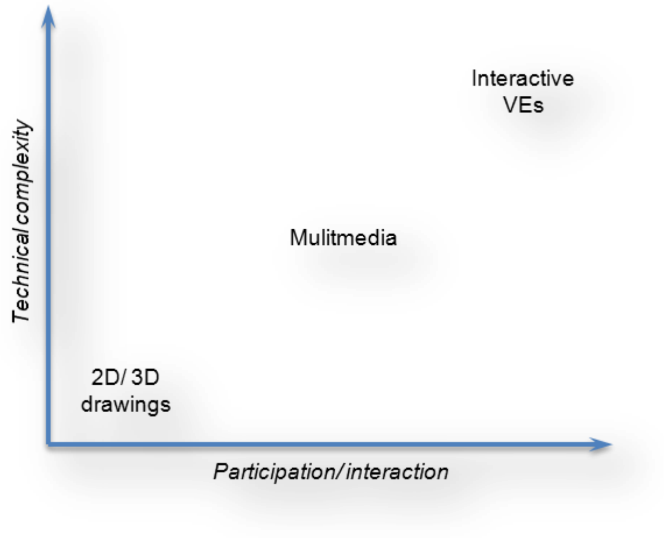


Figure 7:Interaction versus technical complexity Bourdakis, 1997)

2.2.1 The Web

The possibility of an integrated network was conceived in the 1960s, although its eventual realisation did not emerge for some time following Defence Advanced Research Projects Agency (DARPA) and the first network of computers (Hudson-Smith, 2005). Subsequently, ARPANET in 1966 was the project's first network system and allowed its users to send emails to one another. Domain Name Systems (DNS) and File Transfer Protocols (FTP) in the 1980s was eventually followed by the European Organisation for Nuclear Research (CERN) launched the first website in 1991 through the ENQUIRE (Enquire- Within- Upon- Everything) project. The research was aimed at developing internet technology and worked on the concepts of Hypertext from the 1960s and the latest developments of Standard Generalised Mark-up Language (SGML). Hypertext Mark-up Language (HTML) was thus conceived and allowed the linking of text and graphical information that allowed users to navigate from one piece of information to another on a PC (Hudson-Smith, 2005). Tim Berners-Lee's development of a hypertext browser called 'WorldWideWeb' was announced to the public in 1993 by CERN and that this technology would be made freely available to all (Bridges, 1999). HTML and the development of browsers and servers credited to CERN allowed the rapid growth of the internet into the current vast interlinked network of technologies, hardware, databases and applications. In the UK, it was determined that 18.3 million households (70%) had access to the internet in 2009 and 63% of households had a broadband connection (Office for National Statistics, 2009).

In relation to this, statistics from 2006 indicate an even greater increase of internet access by Enterprises in both the UK and the member states of the EU. (There were 25 member states in 2006; at the time of writing in 2010, there are 27). E-Commerce, the practice of enterprises receiving orders over the internet, has also risen steadily, with some countries accounting for 10% of their total turnover. Kim *et al.* (1998) explains: “...the internet environment changes not only the environment of computing but also the way people use the computer in business and everyday life”.

Web 2.0 describes the second generation of web platforms as evolved static web pages into interactive applications that enable more information sharing and collaboration. Typical examples of Web 2.0 sites are wikis, blogs and social networking sites that exist more as platforms or applications that continuously grow and improve. Reilly (2007) describes Google as a ‘standard bearer of Web 2.0’, explaining:

> …a native web application, never sold or packaged, but delivered as a service, with customers paying, directly or indirectly, for the use of that service. None of the trappings of the old software industry are present… No licensing or sale, just usage. (O’Reilly, 2007, p.20)

Virtual worlds have become synonymous with online 3D communities that have evolved over the last decade. These are a form of social networking, allowing their users to explore, navigate and interact with other users and their virtual environment, through the use of their own customisable avatar. In some cases, virtual economies have been established where users can purchase currency from their virtual world in order to buy (or sell) virtual goods or even virtual real estate. The ability to purchase land and create buildings has obviously generated interest from agents in the built environment, such as architectural practices using these communities to display their work. In 2008, a virtual architectural simulation of the new Palomar West Medical Campus in San Diego was built in Second Life to showcase the building’s communications features through immersive simulations (Arch Virtual, 2010). Mirror worlds are the latest adaptation of social, 3D virtual worlds, but are created as identical representations of real cities. Twinity is one such application that offers accurate 3D city models of Berlin, London, Singapore and Miami for its users to explore and socialise through their personalised avatars. The company behind this product is a German-based enterprise that seeks to create a thriving business based on virtual products, advertising and virtual tourism.

Many geographical applications have taken advantage of Web 2.0 methodologies with applications that exploit these technologies and demonstrate the interactivity of these web systems. Hudson-Smith (2008) argues that information that is geographically located or ‘tagged’ expresses not only its type but where such information is produced and by whom. The pace at which these technologies and virtual cities are developing is surprising, continuing at an almost exponential rate. Interestingly the advances are being led by large, privately funded corporations rather than academia. Although the city models do not demonstrate high levels of accuracy, these companies have exploited the advances in IT, 3D modelling and social networks, identifying a large market and potential in virtual or mirror worlds.

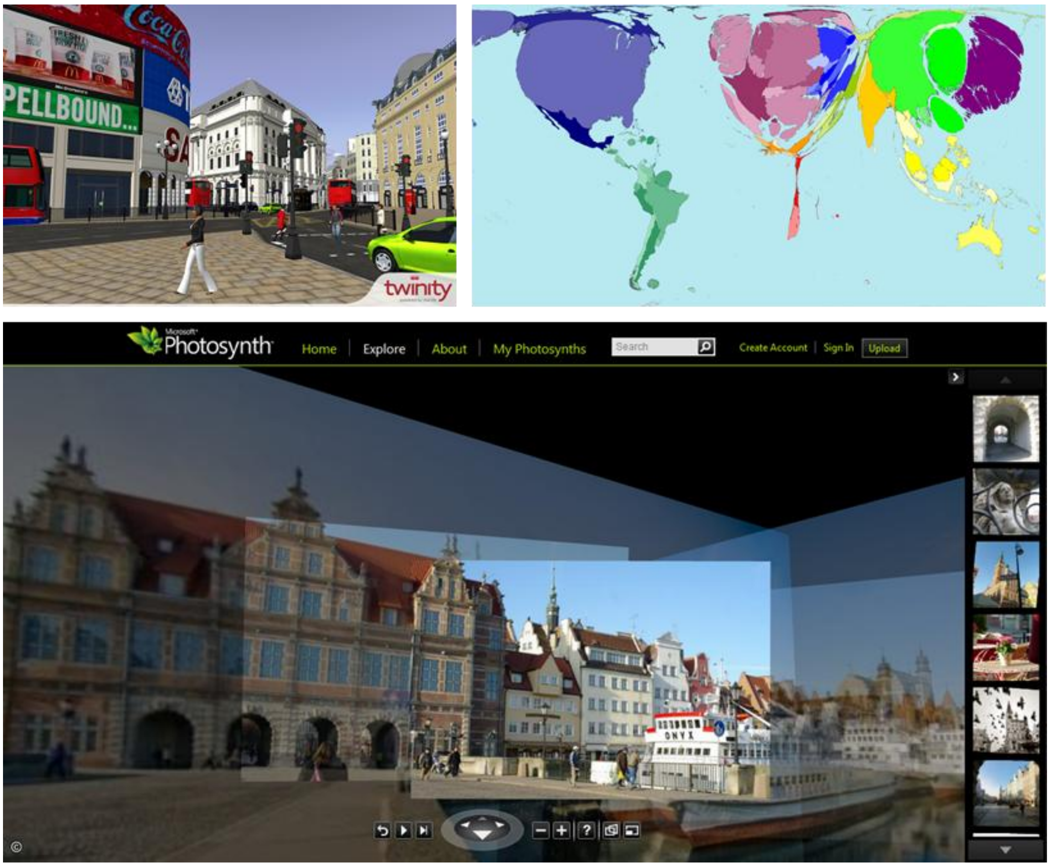


Figure 8: Innovations in digital geography: Twinity mirror world (top left) (Thomas, 2009); worldmapper ‘cartogram’ of worldwide proportion of internet users in 2002 (top right) (Worldmapper, 2010); Microsoft Photosynth of Gdnask (bottom) (Photosynth, 2010)

Another trend that has helped define the technologies behind Web 2.0 is cloud computing, a paradigm that describes the services behind internet-based computing. Rather than relying on the internet simply as a source of information, services within ‘the cloud’ offer software and resources accessed over the web: “Thus, the computing world is rapidly transforming towards developing software for millions to consume as a service, rather than to run on their individual computers.” (Buyya *et al.*, p599, 2009). More and more organisations and individuals are relying on cloud computing for data and software access as it is a more cost-effective service than the traditional complex IT infrastructure (e.g.

hardware and software) and support that they require. The National Institute of Standards and Technology (2011) suggest that cloud computing can be delivered as a service in three ways (software, platform or infrastructure as a service) and deployed as either a private, community, public or hybrid cloud depending on the type of service required.

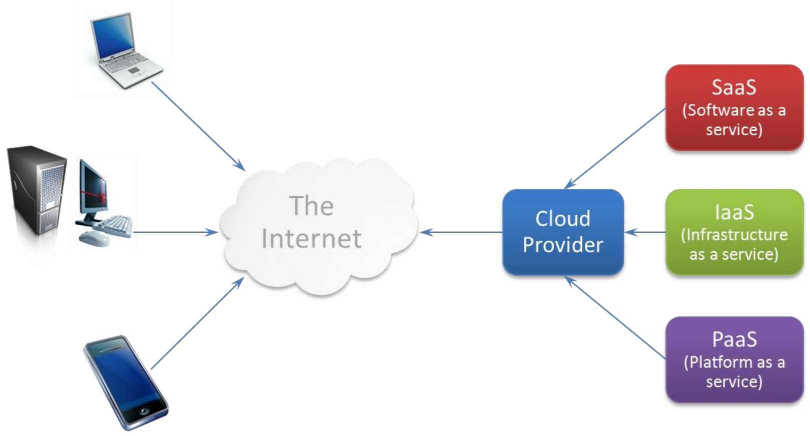


Figure 9: Cloud computing hierarchy (Davey, 2009)

The concept of cloud computing represents an altogether different IT infrastructure that requires greater standardisation and collaboration. It is thought that this new role in computing may eventually become a public utility, as with water, gas and electricity, whereby its consumers plug into a 'computing grid' (Carr, 2008). The concepts for more intelligent information on the web will be a key component of Web 3.0, the next generation of web applications. This notion of a 'Semantic web' was coined by W3C in 2001 and will require a common language that can allow large amounts of existing data to be analysed by machines automatically (Gutierrez *et al.*, 2010). The original vision aspires for the creation and availability of compatible metadata that would enable automated agents, such as those used by search engines, and other software to access the Web more intelligently, performing tasks and locating related information on behalf of the user automatically (Berners-Lee, Hendler and Lassila, 2001).

2.3 The Integrated Digital City

Brooker (2009) believes that there is now a demand to integrate the expanding geospatial data sector with engineering and architectural design that is driven mainly by the need to protect the environment and to create more sustainable communities for the future. Trends of increasing urbanisation in many parts of the world and a flight to the suburbs in others demands for clever, sensitive planning to ensure our urban environments are safe and pleasant places to live and work (Brooker, 2009). Moreover, government agencies and others (e.g. designers) require a fully-synthesised and holistic view of the structures within their city and across its entire lifecycle. This is not just a demand for integrated data sources but also for interdisciplinary design, covering all aspects of a building's design, construction and maintenance and all the associated stakeholders (e.g. planner, designers, architects, contractor, clients and Facilities Management). The complexities in the urban planning processes encompass dependent aspects of social, economic, physical and spatial significance (Bourdakis, 1997). Figure 10 (below) illustrates the diverse information that an nD model should integrate to support various urban planning application systems (Hamilton *et al.*, 2005).

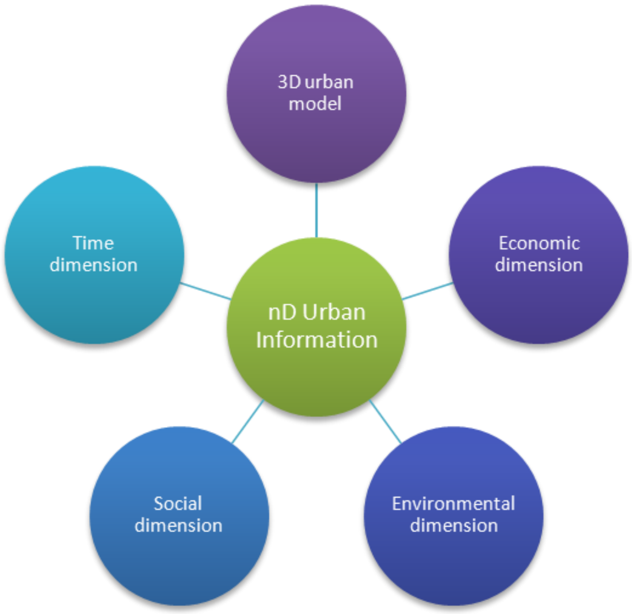


Figure 10: Concept for an 'nD' urban information model (Hamilton *et al.*, 2005)

Application-specific GIS implementation prevents the realisation of one of the key benefits of GIS use in an organisation – that of adding value to data collected for a specific purpose by using it for another. This raises third party issues, copyright and licensing issues surrounding the use, reproduction and publication of any map-based output from the analysis (Wyatt and Ralphs, 2003).

In 1998, U.S. Vice-President Al Gore articulated a vision of 'Digital Earth' as a multi-resolution, three dimensional representation of the planet that would enable users to find, visualise, and communicate vast amounts of geographically-referenced information (Craglia *et al.*, 2008). Such a system would allow users to navigate through space and time, access to historical data as well as future predictions based, for example, on environmental models, and support access and use by scientists, policy-makers, and children alike (Gore, 1998). Ten years later, many of the elements of Digital Earth are not only available, but used daily by hundreds of millions of people worldwide thanks to innovative ways to organise and present the data, rapid technological advancements and the growth of a geo-browsing industry (Craglia *et al.*, 2008).

Evidence shows a lack of balance between emerging VR GIS and their integration with high end 3D visualisations. For instance, Bodum *et al.* (2006) explain that trends in city modelling show that municipalities and developers that have adopted them have placed a high priority on their visual impact, placing an emphasis on realism rather than interoperability. The authors suggest that a focus on the latter would produce a 3D model that included semantic information and would make it useful for other purposes than visualisation. With the developments in VRML, 3D GIS began by 'loosely coupling' VR with 2D spatial databases (Smith, Dodge and Doyle, 1998). The results produce more abstract, less photorealistic VR, which can be more applicable when combined with other forms of data and has caused the re-evaluation of VR in this context as a simulation of reality, rather than an imitation of it (Gillings and Goodrick, 1996). The Open Geospatial Consortium (2008) concludes that (in recent years) "most city models were defined as purely graphical or geometrical models, neglecting the semantic and topological aspects. Thus, these models could almost only be used for visualisation purposes but not for thematic queries, analysis tasks, or spatial data mining" (OGC, 2008, pXV). Thurston (2009) recognises this need for greater collaboration when embarking on 3D GIS, BIM and related databases in this context, which have the potential to improve analysis and understanding of urban design.

Faust (1995) notes that there has been considerable research effort into developing the capabilities of GIS to handle 3D visualisation of built environment data during the 1990s, initially this was done by linking CAD technologies to a GIS database (Liggett, Friedman and Jepson, 1995). Cheewinsiriwat *et al* (2008) verifies the lack of focus on visualisation in a GIS environment may be due to the added complexity of required data structures. Capstick and Heathcote (2006) explain that interest in 3D GI has had a significant boost since the early 2000s, through the release of global exploration systems and 3D editing tools, such as Google SketchUp. The notion of these 'digital earths' has recently found much attention, not only in the scientific communities, but also in political, economic and ecological circles, as well as in the general public (Gruen, 2008). 'Virtual globe' software systems such as Google Earth are growing rapidly in popularity as a way to visualise and share 3D environmental data (Sheppard, 2008), providing users with the ability to walk, communicate and interact with a virtual planning environment irrespective of physical location (Hudson-Smith, 2005). Many of these systems have been developed for research or commercial applications and are fundamentally systems with a 'client-server' architecture that was originally envisaged in the 1980s. In this case, the client provides users with a viewer and navigation capabilities and the servers provide storage, data management features (Bodum *et al.*, 2006) and generally processes requests received from the client and sends back the results (Kim *et al.*, 1998).

The W3C defines a web service as "a software system designed to support interoperable machine-to-machine interaction over a network" (Haas and Brown, 2004). They are usually implemented as an application programming interface (API) that are accessed through the internet and executed on a remote system (e.g. desktop PC) that hosts the requested service (Peterson, 2009). There are many advantages to web services but notably, they help to reduce costs associated with the development, integration, and maintenance of software applications (Guah 2006). Institutions and organisations are beginning to consider their use instead of a traditional server and services infrastructure (Strobl, 2006), whereby the perceived capital cost barriers that can impede the use of VR in planning are rapidly decreasing as the variety and development of web service options emerge (Perkins and Barnhart, 2005).

Google Earth (2008) and Microsoft Virtual Earth/ Bing Maps (2008) are web-based virtual globes for viewing maps, aerial images, 3D buildings and an increasing amount of media and geographic content. Both are free software that requires an internet connection to receive data. The competing software have taken two separate approaches to the creation of 3D building data, whereby Google allows its users to import and submit their own 3D building data. It has been recognised that both of these platforms have had, and will continue to have a significant impact on city modelling (Capstick, 2006; Rodriguez *et al.*, 2008, Knapp, Bogdahn and Coors, 2007). Gruen (2008) explains that their comparative speed and freely distributed access to worldwide high-resolution image-related information can be more immersive and informative than traditional 2D and raster maps for more visual or indicative applications.

OpenStreetMap is one of many emerging Web 2.0 applications that are based on freely available, collaborative platforms. Similar to Wikipedia, the original platform was established for its users to create and edit its data. OpenStreetMap is a freely editable map that will accept data from portable GPS devices or aerial photography but is not restricted to either – users can simply modify a map based on their local knowledge. In 2007, Yahoo allowed their aerial imagery to be used by the OpenStreetMap community to assist in their mapping activities (Wasserburger, 2009). The platform has since received many donations from various organisations and even governments from around the world. Such a collaborative attitude to map creation raises the obvious question about data accuracy. However, manual quality checks showed a high level of standard and it transpired that the mapping community are very active in checking their environment as errors or changes in the real world were mirrored quickly in the map data (Wasserburger, 2009).

From the late 1980s through the 1990s, consumer PCs became powerful enough to display various types of media and overcome technical issues related to CPU power and bus bandwidth (to support the required data rates) (Grant, 2008). It is these developments that have allowed software providers and developers to stream large amounts of high quality data and information to a vast quantity of users. But despite these advances in technology and data infrastructures, Craglia *et al.* (2008) suggest that the vision or ‘Grand Challenge’ of Digital Earth has not yet been achieved.

2.4 VIRTUALGLOBES

Fusing the Web and spatial technologies, virtual globes or geo-browsers have developed from user expectations, web technologies and data availability (Tuttle, Anderson and Huff, 2008). Despite their rapid growth, they are currently restrictive as a form of GI that is only suitable for a small set of tasks which do not involve querying the information, such as how desktop GIS perform (Schöning *et al.*, 2008). There are a number of products currently available, notably Google Earth, NASA World Wind, Bing Maps and Marble (KDE). Dokonal (2008) reports a ‘footrace’ between cities to present their 3D cities and be amongst the first of their kind in Google Earth. Hudson-Smith (2008) explains Google’s dominance is based on releasing free software with high levels of functionality combined with low levels of required expertise, meaning that it is now possible to considerably reduce the time taken to produce high end 3D models. It is understood that these qualities present viable solutions to some of the technical issues and barriers that prevent access to city data for planning and public participation (Knapp, Bogdahn and Coors, 2007; Wang *et al.*, 2007; Kobayashi, 2006, Strobl, 2006). The popularity and performance of this software platform is consistently improving, in line with public access to broadband connections and increasing PC performance. Many of the navigation issues and barriers associated with VR models outlined earlier in the Chapter could be alleviated through the use of a simple interface and a familiar software platform (Bourdakis, 2001).

In 2008, it was reported that Google Earth (GE) had been downloaded 350 million times by worldwide users (Ohazama, 2008) which has grown to 1 billion downloads in 2011 that includes the desktop client, mobile applications and the GE plug-in (McClendon, 2011). Allen (2009) attributes this increase to its many smartphone users. Google entered the Geographical Information (GI) market by acquiring Keyhole Inc. in 2004 and ‘EarthViewer 3D’. The re-launch as Google Earth (GE) as a free program that enables its users to navigate the Earth through satellite imagery, terrain, data and a vast amount of geographical features and content shared by a ‘Google Earth Community’. The imagery and data is supplied from a range of data providers with varying resolutions depending on its source and contains a digital elevation model (DEM) to form a realistic model of the globe. In 2006, Google acquired the 3D modelling program 'SketchUp', continuing popularity with architects and designers (Levy, 2011, p4). Furthermore, the author points out that a revolution in the use of CAD design has occurred through the appearance of such affordable (and often free) software. The software has been particularly popular for applications in the built environment for the following reasons (Schreyer and Hoque, 2009):

1. Affordability – the basic version is free of charge to download along with its GIS counterpart, Google Earth. There are no license restrictions for using the software commercially, allowing the development of a range of applications without inhibitive development or distribution costs (Hudson-Smith, 2005).
2. Functionality – the software is particularly easy to use for creating simple geometry. Navigation is straightforward and the application of materials and textures to objects is a relatively simple process, compared to other 3D modelling software (Maya, 3Ds Max) (Rodriquez *et al.*, 2008).
3. Interoperability – models can be shared across many platforms (particularly with the 'Pro' version) and exported/ imported into GIS platforms. A digital terrain model (DTM) can be uploaded free of charge from Google Earth to produce an instant site, provided there is an internet connection.

The combinations of free access to data and software, coupled with a simple interface have made this popular for architects and designers in the design and development stages (Dobelis *et al.*, 2004). Another feature of GE is the ability to share a live data feed via a 'Network Link', which is a URL path that relates to a third party's server where a Keyhole Markup Language (KML) file is stored, allowing data to be shared across the web using GE as the platform. An example of this is Berlin City Council's network link that allows users to view more detailed 3D buildings of Berlin.

Microsoft's late entry to web mapping services with 'Virtual Earth' (now 'Bing Maps') came about with an ambitious commitment to city modelling and an interface that boasted a textured DTM enhanced with 3D buildings in many cities. It can be viewed entirely through a web browser in 2D, but requires a small downloaded 'Plugin' to allow 3D navigation. This program is similar to GE in many ways but has taken a different approach to its data collection. In 2006, Microsoft acquired Vexcel that develops and manufactures advanced remote sensing technologies, whose products specialised in the production of oblique or 'bird's eye' aerial imagery. LiDAR data (see Light Detection and Ranging (LiDAR), p39) was also captured during the same data capture stage so that 3D cities could be generated from a single source. In 2007, Microsoft began an extensive mapping program over five years, which involves the scanning and modelling of 3,000 major cities around the world and required the development of a unique remote sensing techniques for gathering aerial photography for web-based mapping and to facilitate their automatic or semi-automatic modelling techniques. This highlighted the different approaches between Microsoft and Google, with the latter offering a more user-centric approach to develop their content (Podevyn *et al.*, 2008), whereas Microsoft opted for a solution to capture and process most of their own data. The company has been heavily involved with many research projects into photography and visualisation that boasts properties that intelligently extract information from images for alternative uses (e.g. Photosynth, Street Slide).

2.5 GAME ENGINES

Levy (2011, p3) reports that the impressive commercial growth of the gaming industry has enabled development of cheaper computer hardware andassisted the creation of 3D virtual cities.Whyte (2002) suggests that users' expectations of professional VR packages are based highly on their experience with early games, such as SimCity, DOOM, Quake and Tomb Raider. SimCity has been notably influential for built environment applications, whereby its players create and manage a virtual city that Friedman (1995) considers is based on the belief that complex dynamics of a city's development can be abstracted, simulated and micromanaged.

3D game engines are the core software component for any application that uses real-time graphics displays, most commonly used in electronic video games (Sharkawi, Ujang and Abdul-Rahman, 2004). The development of game engine software is very cost effective so the packages are often used for several video game products (Fritsch and Kada, 2004), highlighting a certain amount of interoperability between game developers and their data. More recently, game engines have been released as open source software or as free lighter versions enabling a greater user group to take advantage. 3D engines often come in the form of packages known as System Development Kits (SDK), containing several core features that allow its users to develop their applications (Sharkawi, Ujang and Abdul-Rahman, 2008) by purchasing the license to use this middleware platform and distribute as a game. Generally speaking, 3D game engines are designed to handle large amounts of graphical data that far exceed the capacity of most CAD packages on the market. Fritsch and Kada (2004) tell us that they efficiently use a variety of rendering techniques (e.g. pipelines, special data structures and speed-up) to visualise real-time 3D scenes. It is the simple, intuitive interface coupled with powerful PC-based 3D real-time rendering that make 3D game engines appealing mediums for delivering or communicating city models (Ziele *et al.*, 2005). This would replace, in many situations, pre-generated movies and therefore allowing more freedom for navigation without losing the final quality in the rendered scene. The 'Unreal Engine' by Epic Games, now in its third release at time of writing,is considered to be one of the most successful game engines for research and architectural visualisation purposesbecause of its versatility and availability. Other popular engines are the Torque Game Engine from Garage Games and 'Unity' game engine (Unity Technologies). Although the most obvious advantage of using game engines is the superior visualisation results, a better sense of context is provided by the increased location awareness. De Chiara *et al.* (2006) agree with Loomis, Blascovich and Beall (1999) that it is recognised in psychology that the effectiveness of immersive virtual environments in studies on spatial cognition and orientation is positively influenced by the positioning.

The latest game engines feature the interface of a programmable system, that is supported by specialist engines for calculating the physics, sound, animation (De Chiara *et al.*, 2006), networking capabilities, artificial intelligence (AI) and graphical user interfaces (Fritsch and Kada, 2004). Callierie *et al.* (2006) show that modern hardware and software can be used to provide excellent real-time visualisation results that is both accurate and affordable. The techniques that were developed during this study could be integrated into existing visualisation systems and could potentially be used for large datasets, such as city models.

Devische (2008) supports the view of Batty (2005), that the most popular techniques for the development of simulation models for movement or growth in the urban environment (for the purposes of planning) are agent-based, cellular automata (CA) or a combination of the two. In many cases, the Games industry has tackled the complex processes of agent-based modelling for simulation with relative ease, through PC games such as SimCity. However, Fristch and Kada (2004) explain that although the games industry has much to offer geo-related applications, the question of how to make best use of these technologies and software to make the right solution is unresolved.

CA models have been developed to simulate both artificial and actual cities (Batty and Xie, 1994; Clarke, Hoppen and Gaydos, 1997; Li and Yeh, 2000; White, Engelen and Uljee, 1997; Wu, [*sic*] 2000; Wu and Webster, 1998, cited in Moghaddam, 2009, p.571). They are used to simulate the complex, nonlinear city behaviours ranging from population growth to pedestrian flow for the purposes of planning, which are beyond the capabilities of current GIS software. However, GIS data can be used as the basis for CA models and have been used in a variety of practical and successful situations in planning applications (Yassemi, Dragicevic and Schmidt, 2007).

2.6 3D MODELLINGPROTOCOLS

Buildings' spatial information and geometry are gathered by measuring and recording the shape, form and specification of its features. This information can be gathered directly, remotely, autonomously or even speculatively. Although hardware and computing advances have enabled the development of virtual cities, Levy (2011, p3) points out that there is now an abundance of skills in architectural and engineering and design that is allowing the modelling of virtual worlds on a global scale.

Photogrammetric methods of building geometry extraction and modelling have evolved over the last two decades. Hardware and software developments have led to the development of efficient manual and semi-automated procedures, with an increasing demand for much more complex buildings and complete city models (including DTM, roads, bridges, parking lots, pedestrian walkways, traffic elements, waterways, vegetation objects, etc.) (Gruen, 2008). Dollner *et al.* (2006) supports the view of Ribarsky and Wasilewski (2002) that the main barrier in developing virtual 3D city models represents the time and cost inefficient creation of model data. The manual geometric modelling techniques are acceptable for small-scale city models, but fail for large urban areas or if they should be managed in the long run; hence, 3D city models should be based on automatic and semiautomatic acquisition methods wherever possible.

Regardless of scale, Day, Bourdakis and Robson (1996) explain that it is necessary to make a decision about how much detail to include. Excessive detail is data intensive, which makes its manipulation and navigation on a PC slow, yet too little detail and the city becomes unrecognisable at street level. Standards for levels-of-detail (LOD) have been created by a range of users for these reasons among others (see section 2.9). There are fundamentally two ways to represent building detail. Firstly, by increasing the amount of geometry, or using photographic texture maps applied to building surfaces (Day, Bourdakis and Robson, 1996). Paar (2005) agrees with Danahy (2001) that the breakthrough for 3D landscape simulations came with texture mapping, which constituted a 'profound improvement' as the enhanced image quality opened the door for real-time rendering of virtual models. This 'hybrid approach' demonstrates more explicit, realistic information that is sampled from the real world, rather than computed information or textures (Paar, 2005).Coniff *et al*. (2010) suggest that an 'unfinished' appearance used in architectural sketches can encourage better discussion than realistic photomontages. Furthermore, little is know about the impact of varying rendering styles that are applied to CAD models for representing 3D buildings (Coniff *et al*., 2010). In research carried out almost two decades earlier, Orland (1992) claims that visualisation techniques for environmental management must also include analysis and modelling tools, as well as the ability to support multiple scales.

Capstick and Heathcote (2006) explain a consultation undertaken by the Ordnance Survey (OS) with a range of their customer groups, with regard to a 3D data specification. Organisations involved included those from planning, construction, telecommunications and insurance companies, and showed that a tremendous range of real world objects (RWO) were identified as being significant for their applications.

Table 1: Significant RWO's as highlighted by OS customers and users (Capstick and Heathcote, 2006)

Real World Object	Interview Source
Building storey	Local authority planning, flood risk modelling, telecommunications, urban design, risk management, landscape and architectural investigation.
Building roof	Local authority planning, planning application consultancy, telecommunications, urban design.
Wall	Flood risk assessment.
River bank	Flood risk assessment.
Tree	Local authority planning, telecommunications.
Road network heights	Public transport route planning, asset management for County Councils.
Tunnel	Telecommunications.
Wall	Flood risk assessment.
Land cover	Telecommunications.

In terms of data acquisition methods, geographic features are generally broken into four categories for the purposes of 3D modelling: terrain, the built environment, water and vegetation. Voigt, Linzer and Schmidinger (2004) suggest that a modelled digital city should contain at least the following datasets:

- Buildings (including storeys)
- Vegetation (particularly trees- sizes and groups)
- Roads
- Bodies of water
- Green areas
- Walls
- Urban structures
- Boundaries
- Civil engineering structures

Additional information could include building age, façades (including building heights and widths), roofs (shape and eave height) and surface structure of roads. There are a range of developed automatic modelling techniques that use digital data to extract building features and model them based on a range of programmed parametric building types (Gulch, Muller and Labe, 1999). In most cases, these techniques are used as parts of a larger process, integrated into a city modelling process. Despite the recent progress in automatic object detection and 3D reconstruction (Dollner *et al.*, 2006), Prandi and Brumana (2007) tell us that manual work in the process is still predominant. This manual intervention often involves completing automatic object extraction processes that are obstructed or incomplete, as well as deriving semantic information from an image. Trees or building overhangs can block parts of a building and complex building geometries can be difficult for software to recognise.

2.7 DATA ACQUISITION

Spatial information must be gathered from a variety of sources, employing various methods for recreating the 3D geometry (Bodum *et al.*, 2006). Voigt, Linzer and Schmidinger (2004) add: “The required datasets therefore originate from different sources, relate to different subject matter and time states, encompass different scales and levels of detail and represent different geometric dimensions (2D, 2.5D, 3D)” (Voigt, Linzer and Schmidinger, p2, 2004). Many methods for recording, measuring and capturing physical objects have been adapted for the purposes of 3D city modelling, although no bespoke techniques that are currently employed for this application has been designed exclusively for this purpose. A major obstacle to recreating a 3D city is that the raw data captured is rarely in the same format as is required for 3D data, with much data processing needed to create the end result. Hence, city modellers need to use an array of data capture methods to gather geometric and semantic information, which vary in data quality, accuracy, detail, speed and cost.

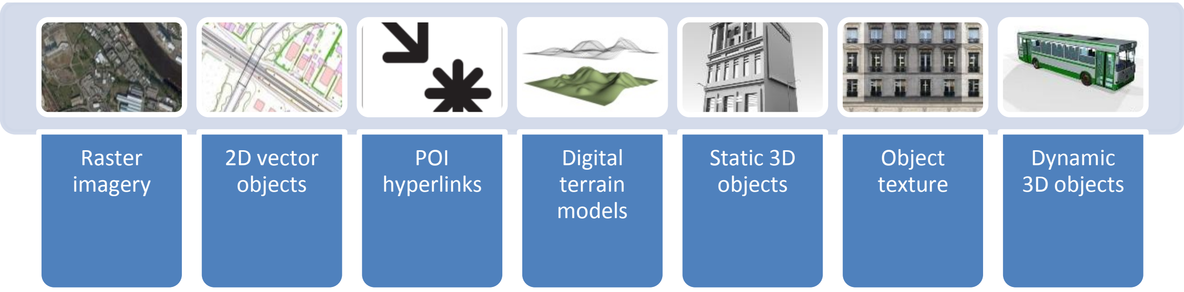


Figure 11: Components of a 3D landscape model (Nebiker, 2003).

Sources of data for generating geospatial and 3D models can come from a range of sensors, including film, digital image cameras, video cameras, camcorders, laser scanners, microwave sensors, ultrasound sensors, X-ray devices and a range of hybrid devices (Gruen, 2003). Capstick and Heathcote (2006) go further to say that no one data capture methodology would be used in isolation to capture 3D features (for OS' purposes). For example, aerial photography alone cannot capture all features due to obscuring objects that are seen in the aerial imagery.

Mapping agencies and GI data suppliers have recently begun practicing 'Integrated capture program' (Ordnance Survey, 2006), whereby a range of data is collected during a single flight. Capstick and Heathcote (2006) explain that an appropriate capture methodology can be achieved by a compromise between multiple end users and an economic data capture system. In other words, the creation of data that is fit for a range of purposes. Prandi and Brumana (2007) explain that the 3D modelling activity drastically increases the cost of data acquisition compared to 2D. Furthermore, combining 3D and 2D data from different sources can be problematic and the inconsistencies between different capture methods cause problems when attempting to produce a cohesive city model.

Assessing 3D data quality ensures the validity and tests the level of accuracy or tolerance. City models are essentially a product of 3D geometry, which in turn are derived from points measured by hand, by a laser or by analysing an image. Each of these methods will incur their own variation of inaccuracies due to the process itself (equipment) and by a human error contribution. These could be relative or absolute positional inaccuracies and vary in 2D and 3D. The value of city models increases as they become detailed, which is captured by more advanced analytical technology, such as LiDAR (Ichioka, 2008).

2.7.1 Remote Sensing

Remote sensing is defined as the "acquisition and recording of information about an object without being in direct contact with that object" (Gibson, 2000, p1) including satellite, airborne or ground-based photography and data capture (e.g. LiDAR). Remote sensing satellites marked the beginning of a worldwide drive for multi-sensoral, multi-spectral, multi-temporal and multi-polarisation (radar) data capture (Konecny, 2003). However, in terms of measuring and recording detailed building objects, more practical methods are generally found closer to the ground. Advances in 3D laser scanning and geometry capture from photography and images have had a profound effect on applications for the built environment, as models are being created from 'as-built' scan data, rather than CAD drawings that have been acquired direct from the designer. The versatility to observe both very small areas, as well as large ones, makes remote sensing techniques applicable over a wide range of disciplines (Gibson, 2000) and applications specifically designed for users in the construction industry are being developed (Whyte, 2002).

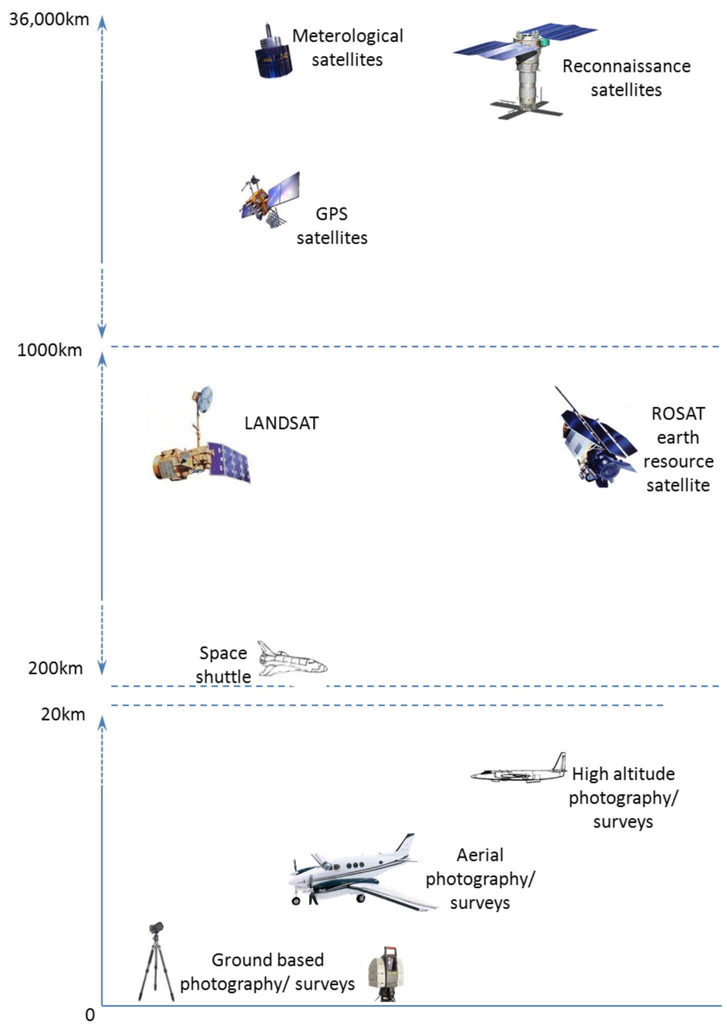


Figure 12: Remote sensing platforms and their relative operation heights (Gibson, 2000)

Digital photography has been exploited extensively in many aspects of remote sensing. Not only can a digital image record a greater spectrum of information, but there are many practical advantages. The storage and transmission of digital data is far more efficient than handling photographic film, which can also suffer from degradation that does not affect a digital medium. The ubiquity of computing has influenced the development into digital data and allows various image processing techniques and the management of large volumes of information (Gibson, 2000).

2.7.2 Photography

Gibson (2000) tells us that “the production of an image is virtually an instantaneous record of the conditions that exist in a particular location at a specific time”. A (colour) photograph is the simplest form of remote sensing, which can record information about colour, texture and spatial relationships (Gibson, 2000). This allows further information, such as building material, to be deduced by experienced modellers for reconstructing a city in 3D. Spatial information, such as dimensions, can be deduced from an image by taking specific measurements or relating to objects in the scene (e.g. vehicles, furniture). Information about colour is represented by a specific range within the spectrum of electromagnetic radiation. Certain remote sensing technologies obtain information that is invisible to the human eye, but nevertheless useful for a variety of applications. Objects that are obscured by cloud, water or heat signatures can be seen using special sensors.

In its broadest sense, aerial photography can cover any photographic capture that is not based from the ground, but the most common use for gathering raw data for modelling cities is from vertical photographs taken from aircraft. Satellite imagery is largely discounted for the purposes of accurate, detailed mapping or city modelling, as the spatial resolution is considered too coarse to meet the requirements of city modelling applications (Capstick and Heathcote, 2006). However, the variety of aerial (airborne) survey data is rich and increasingly affordable, offering a rapid and efficient method for capturing an entire city (Narushige, 2001). Certain systems can capture stereoscopic imagery that is used for 3D modelling (see Photogrammetry, p44). Scale distortions can be corrected with greater ease than oblique imagery, with a smaller margin of error. Aerial photograph that have been corrected of any distortions (e.g. radial, terrain) are known as orthophotographs(Gibson, 2000).

Figure 13: Oblique or ‘bird’s eye’ imagery (left) (Bing Maps, 2010); Orthophoto aerial imagery (right) (Microsoft Corporation, 2010)

The production of large ‘seamless’ aerial images are created by stitching overlapping adjacent images (see Figure 14). Oblique imagery has gained more interest in the last five years, with the huge success of web-based mapping services competing with different technologies. In some respects, this type of imagery can offer far more semantic information, offering a better sense of place and the topology in the scene and are being used increasingly for semi-automatic building modelling. However, geometric information is difficult to gather from single oblique images so photos from all directions are acquired sequentially to overcome objects overlapping and obstructions that occur in the data.

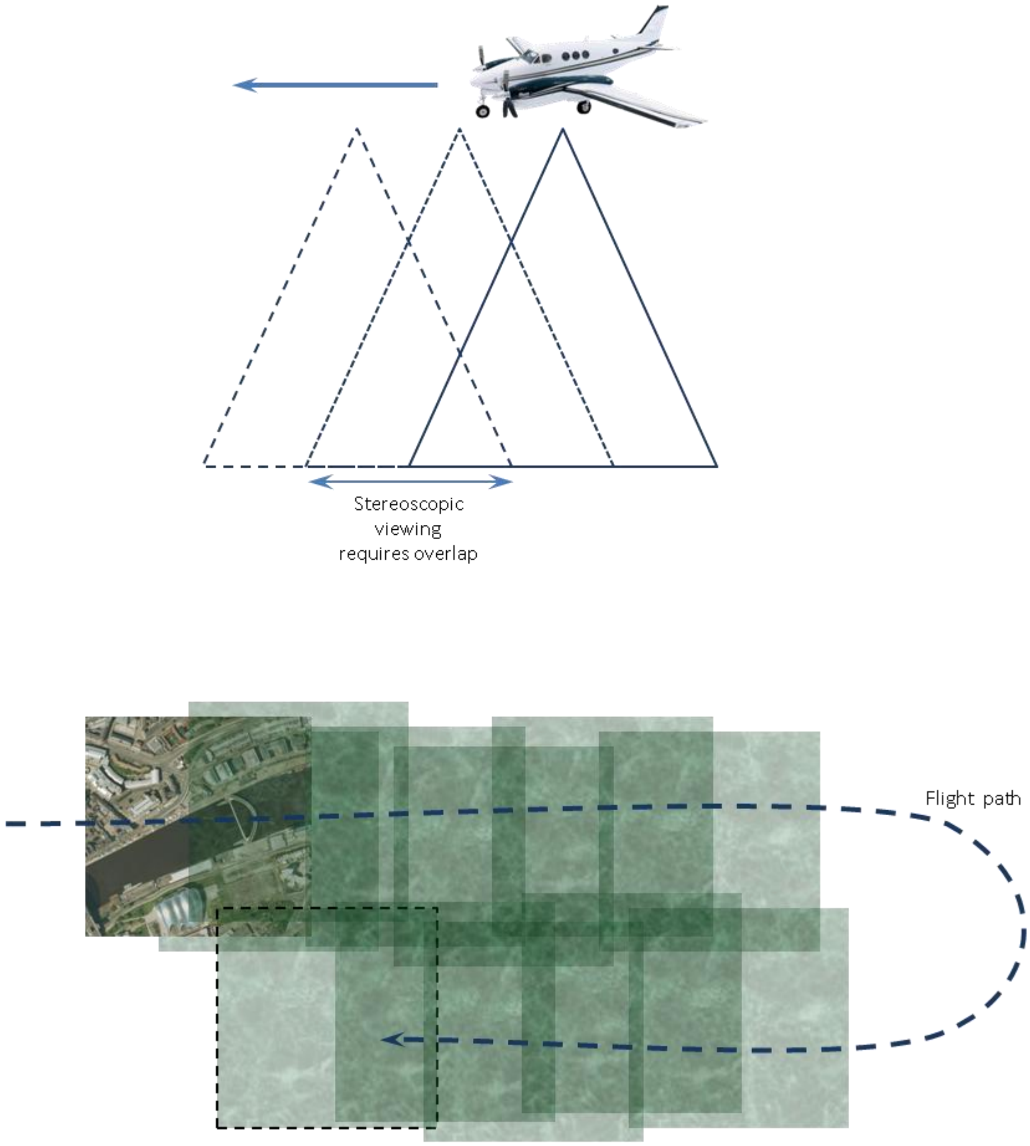


Figure 14: Production of large, stereoscopic aerial photographs requires a 60% forward overlap and 20% adjacent overlap (Gibson, 2000)

Unmanned autonomous vehicles (UAVs) were originally developed for military purposes, but commercially available systems have recently become available and are being used for a range of applications, including aerial photography. These are highly manoeuvrable machines that can capture a range of visual information in restricted spaces (Gruen, 2008). Currently, aerial imagery is a competitive market, but can have lengthy delivery time after a new set of imagery has been commissioned that demonstrates that 'existing' data can produce already out-dated results. Unmanned autonomous vehicles offer more control over the data acquisition process and avoids many of the impracticalities of flying light aircraft (e.g. weather conditions). Presently UAVs or small scale data capture vehicles (e.g. kites, balloons) are used for reconnaissance or monitoring of geographical features for a range of environmental applications (Marzolff and Poesen, 2009).

2.7.3 Surveying and Electronic Distance Measuring

Although many remote sensing techniques and modelling processes are heading for a high degree of automation, Gibson (2000) explains that ground-based verification data (survey) is an integral part of remote sensing. A ground survey provides an independent source of data and the identification of features detected by the previous remote sensing stage. However, in some city modelling processes, ground-based research is often minimal with research usually confined to very narrow disciplines and little cross-referencing. In many photogrammetric processes, for example, 3D representations are created from aerial photography without any ground survey being carried out. Modern photogrammetric processes use high resolution images and effective software to produce high levels of accuracy. The cost of an additional site survey can be expensive and unjustifiably so if it is merely for the purposes of verification. In any case, ground-based site surveys are still carried out in some cases. Photo modelling processes require additional geometric information from a scene so that an image can be properly scaled, rectified and calibrated. Most simple city models are based on 2D maps that contain building footprint geometry and other landscape features that are the basis of a city model. Surprisingly, the vast majority of these still employ site surveys to update and record the geographical information.

In the last century, a drive for detailed cadastral mapping has caused a range of developing technologies. Chains, steel measuring and compasses were eventually replaced with mounted telescopes for greater accuracy and range, thereafter developing into the first theodolites (or Transit Vernier Theodolite). The latest tools that are used by surveyors fall into the category of electromagnetic distance measurement or 'total stations' (see Figure 15: GPS Total Station (Testing Equipment, 2010), below). These highly versatile machines combine an electronic theodolite with an electronic distance meter (EDM) to measure angular, distance and height distances from the instrument to a particular point (Kavanagh and Glenn Bird, 1996). A microprocessor manages the information, surveying programs and storing of information (Kavanagh, 2008).

Figure 15: GPS Total Station (Testing Equipment, 2010)

Essentially surveyors measure distances, angles and positions. Surveys can be classed as either planar or geodetic, the latter considers that the earth's surface is ellipsoid and uses a different height reference than planar surveying (Kavanagh, 2008). Up until the 1990s, there existed clear disciplines of topographic (land), engineering, property and cadastral surveys. These boundaries have been blurred by advanced technologies and GIS (Bannister, Raymond and Baker, 1998).

2.7.4 LIGHT DETECTION AND RANGING (LIDAR)

Airborne LiDAR or Airborne Laser Scanning (ALS) have been used commercially since the mid-1990s and continue to be an active area of research and development (Liu, 2008). Similar to microwave or radar, LiDAR is an active remote sensing system that illuminates its target to gather information (Gibson, 2000). However, this technology emits laser pulses that reflect off objects, scattered and returned to a system receiver that measures the time of flight of the pulse so that the distance can be calculated. Each of these pulses effectively provides a 3D point, collectively known as a point cloud that is usually triangulated to create a digital elevation model (DEM) or digital terrain model (DTM) (see Figure 16 on page 40).

LiDAR capture statistics are generally impressive but difficult to rationalise, as scan quality and capacity can vary depending on the speed and altitude of the aircraft from which it is captured, as well as other factors (e.g. climatic conditions). Flights are generally carried out by helicopter or fixed wing aircraft at altitudes ranging from 30m–6,000m. Some scanners can collect up to 200 points per m^2 (at low speeds) and boast an accuracy of

2–30cm at similar speeds (Liu, 2008). Statistics on minimum detectable size of objects should also be considered with care, but on the whole the sensitivity that can be captured far exceeds the requirements for most built environment applications. For example, Lemmens (2007) explains that at a platform altitude of 200m power-lines that are just 8mm in diameter may be mapped; whereas at an altitude of 1,000m they need to be 3cm.

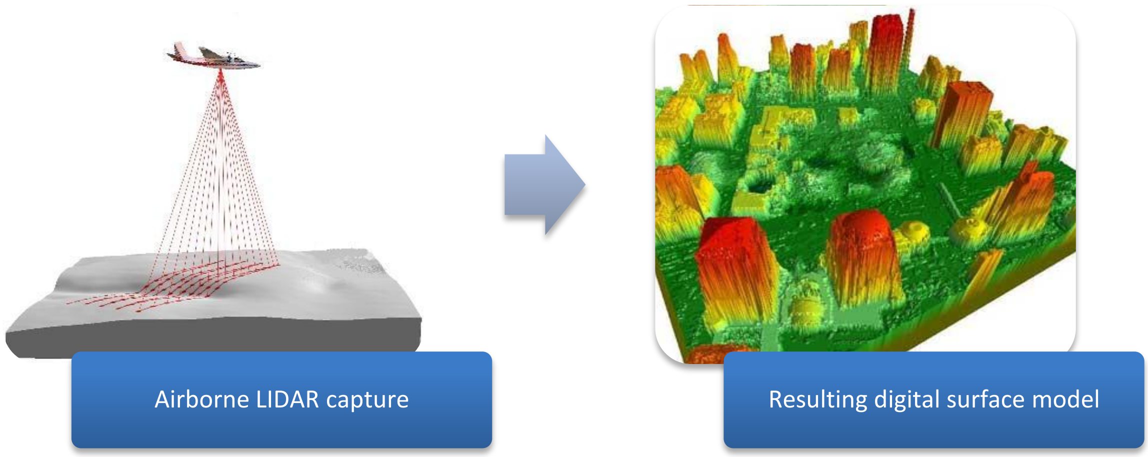


Figure 16: Airborne LiDAR data capture (Joint Fire Science Program, 2006; Laser Fest, no date)

Bodum *et al.* (2006) tells us that airborne laser scanners are one of the most widely used methods for acquiring 3D geometrical context today. The main challenge in handling laser scan data is the sheer volume of the datasets that contain vast amounts of 3D points and information and usually well above the capabilities of current graphics hardware (Hesina *et al.*, 2009). This output from scanning must be processed, ideally to reduce information to a lower level of entropy. The process involves removing noise, adding missing information, and removing the huge amount of redundant information present in the surface scan (Bodum *et al.*, 2006). Nonetheless, there are many algorithms and software that have been developed that hierarchically reduce the amount of points while preserving the full detail (Hesina *et al.*, 2009). Despite the large datasets, another alternative is to use LiDAR information as a basis for semi-automatic building or city reconstruction. This is beneficial over photogrammetry as the information is already digitised, as a set of 3D points that can be used to supplement additional building geometry, usually a 2D footprint. This has been a particularly popular method for creating large city models in Europe for urban planning or environmental simulation, which often have not required excessive building detail or façade texture (McKinley and Jung, 2008).

2.7.5 TERRESTRIAL LASER SCANNING

Ground based scanners work on the same principle as airborne LiDAR technology but use compact tripod mounted scanners for practicality. Laser scanners vary little in shape and form and usually require at least two users to carry and operate the equipment. One of the advantages of ground-based scanning is the ability to move a scanner around a site to gather point data from a variety of angles and thus avoiding blind spots. Hence, laser scanners are particularly useful for detailed models of building facades. Rutzinger, Elberink and Vosselman (2009) explain that the object representation in airborne and terrestrial scanning point clouds are rather different regarding point density, representation of object details (scale), and completeness, owing to the differing scan positions.

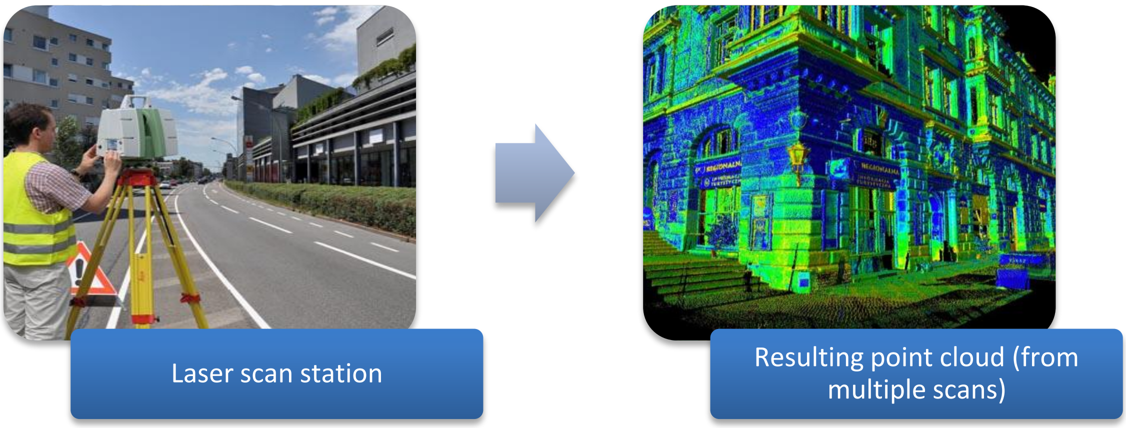


Figure 17: Laser scan data capture (GIM International, 2009; 3D Eling, 2009)

Undoubtedly, laser scanners offer a versatile and affordable method for gathering accurate 3D data, yet the processing of so much information still remains to be difficult. Reducing a point cloud to a suitable detail for modelling must first be carried out, followed by a laborious task of building reconstruction using the points as a reference. It is no surprise therefore, that great deals of research has gone in to investigating ways that this process can be automated (see Pu and Vosselman, 2009; Rutzinger *et al.*, 2009; Liu, 2008; Frueh *et al.*, 2005; Beck and Halla, 2007; Kimpton *et al.*, 2010).

Some city modellers have adopted mobile scanning units that are mounted on the roof of a specially adapted vehicle (see Figure 18 on page 42) and have proved to dramatically increase the rate at which large, city-wide scans can be carried out (Dursun *et al.*, 2008). Mobile scanning has the capability of greater capacity and range, thus they often combine laser scanning with GPS, inertial measurement, digital photography and video capture. This speed and variety of data is particularly useful for 3D building modelling and capturing façade textures.

Figure 18: Mobile laser scanning system and its captured point cloud

2.7.6 Global Positioning Systems (GPS)

GPS satellites have had increasing success since their introduction into civilian applications. In the 1980s, the US Navy introduced the Navstar GPS service, consisting of 24 orbiting satellites at an altitude of 20,200 km. At least four of these satellites are always in a direct line of sight from any observation point on the earth's surface throughout the day (Konecny, 2003). The satellites transmit two timed signals, one of which is a less precise carrier code for civilian/ public use that enable devices to calculate their position on earth.

GPS can be used for mapping purposing in a number of ways, but essentially involves recording positional information that refers to a geographical feature. They are often used in conjunction with another technology, such as an electronic distance meter (EDM)'total station' to provide positional information that relates to the gathered geometric data.

Figure 19: Kinematic GPS 'rover' gathering 3D surface data points (Kuker-Ranken Inc., no date)

GPS kinematic surveys are carried out in many city modelling processes, particularly for creating DTMs through surface interpolation (Kumar *et al.*, 2008). This usually involves gathering points along a route, such as a road or path, and is a simple but laborious process. One of the advantages, however, is that the surveyor has uncomplicated, manual control over the density of points gathered and the results.

2.7.7 Cadastral Information

As mentioned in the previous section, many of the earliest maps were produced to mark property boundaries and define land ownership (Kavanagh, 2008). Land mapping slowly developed into detailed cadastral maps, responding to government commission or drives from a global market. These detailed maps have proven to be extremely versatile, with applications in law, history, construction, planning, etc. There are many examples of city models that have been derived from 2D cadastral maps. Building footprints are used to define building geometry that is extruded to the correct heights – secondary information obtained from a different source (e.g. LiDAR). Bhunu, Ruther and Gain (2002) explain that in urban areas, where there is an intensive use of land, there is a growing interest in the use of space below the surface, hence a need for an integrated mapping system that can display underground features, as well as above street level.

The Ordnance Survey (OS) was officially formed in 1791 as the UK's National Mapping Agency (NMA). The Principal Triangulation of Britain project was carried out between 1783 and 1853 and was eventually superseded 150 years later (Seymour, 1980). In 1841, the Ordnance Survey Act gave the Agency a legal right to enter any land or property for survey purposes, to allow free access to almost anywhere in the UK. Since 1999, the OS was restructured as an Executive agency of the UK Government as a Trading Fund, whereby the business is required to cover its costs by charging for its products and services, or licensing others to use its copyright material. OS is funded by the UK Treasury, which receives a remit of any profits that are made. In this capacity, all OS material (data) is subject to Crown Copyright. The Ordnance datum was established as the mean sea level at a known point on the harbour wall at Newlyn, Cornwall. This was used from 1921 and is taken as a reference point for the height data on Ordnance Survey maps (Ordnance Survey, no date). In 1935, the erection of triangulation pillars, or trig points as they have become more commonly known, was completed alongside the establishment of the National Grid reference system (Owen and Pilbeam, 1992) that has since evolved to tie the OS datum to other measurement systems. The Second World War drove the development of more efficient mapping methods that could be measured remotely, which led to the adoption of aerial photography as a source of data collection and the introduction of photogrammetry in the OS. Satellite technology has been used since 1984, including the TRANSIT Doppler system, which was superseded by GPS. This enabled the OS to essentially capture 3D data for the first time, as the GPS framework provides height data as well as plan coordinates. Digitised maps were available from OS since 1971 when the coastline of Great Britain was available for sale on magnetic tape (Seymour, 1980). Advances in IT allowed the completion of the digitisation of approximately 230,000 maps in their collection by 1995 (Ordnance Survey, no date) known as OS Landline to its paying customers. Landline is essentially a digital version of a standard map, or cartographic tile for viewing on a computer. In order to produce a more intelligent, feature-based dataset, the OS re-engineered its maps into a topologically structured database (Walford and Armitage, 2007).MasterMap was launched in 2001 serving as a database of fixed geographical features in one continuous digital map. There are approximately 440 million features in this database represented by a Topographical Identifier (TOID) organised into specific layers. This complete system allows maps to be created depending on the location, area and layers, by filtering the required TOIDS depending on the request from the user or interface. The latest development by the agency was the launch of OS OpenData in 2010, which is a package of data sets that are free for use or re-use. These have already been adopted by many large online mapping services as an additional layer to enhance their existing services (e.g. MultiMap, Bing Maps).

2.8 3D Modelling Techniques

Virtual city modelling techniques use processes for image manipulation as well as building geometry in 3D. Figure 20 on page 45, outlines a city modelling process that utilises aerial imagery, cartography and street level photography.

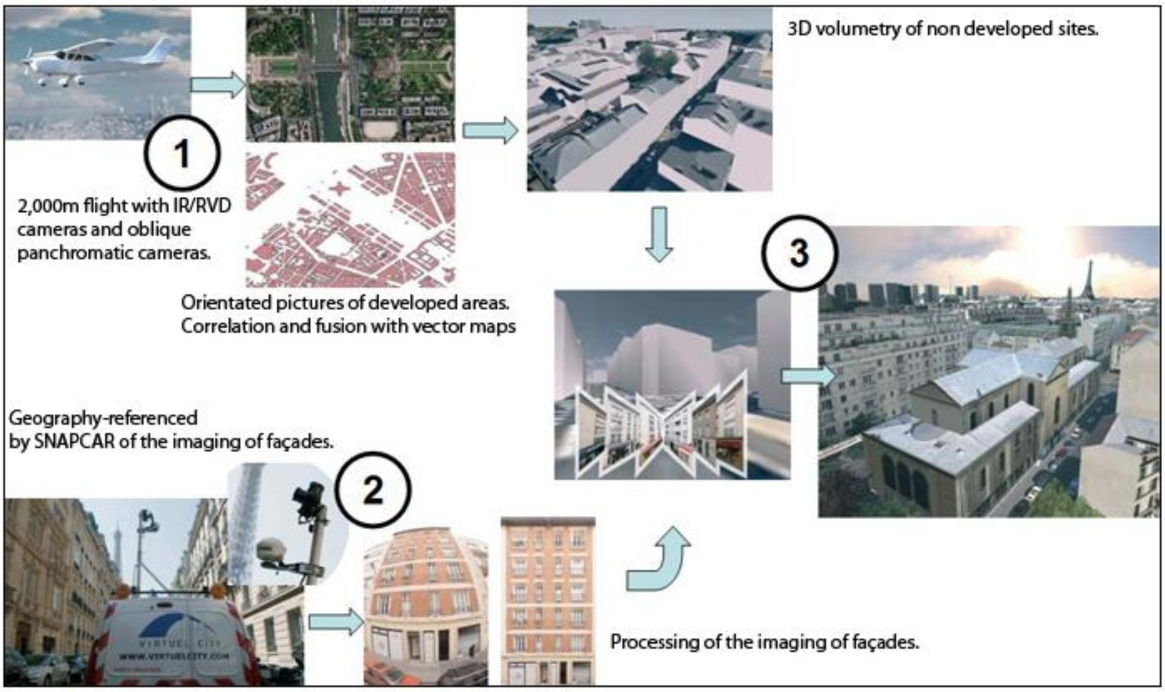


Figure 20: An example of a virtual city modelling process (Virtuel, 2009)

2.8.1 PHOTOGRAMMETRY

Reconstructing 3D objects using aerial imagery is a common method for many city modelling processes, due to the relative speed and cost efficiency. Fundamentally, geometric objects are traced over aerial photographs and accurate representations can be made if the scale is known. Stereo-photogrammetry requires pairs of aerial imagery that are captured simultaneously to create a stereo image, which allows the modeller to trace building footprints as well as elevation. This basic geometry is grouped to form representations of urban objects – buildings, land, roads or trees. The process can be facilitated by automatic point or object extraction, or to a lesser degree, by introducing object libraries (Gruen, 2008). Hence, photogrammetric techniques involve the extraction of both geometrical and semantic information from images. In other words, landscape and architectural features such as buildings, bridges, railways, trees and hedgerows can be distinguished and modelled appropriately. Temporary features, cars and people can also be discriminated. Certain semantic information is gathered by collecting a range of (aerial photography) information, such as infrared. Gruen (2008) illustrates a typical workflow of a photogrammetric or remote sensing process (Figure 21 on page 46).

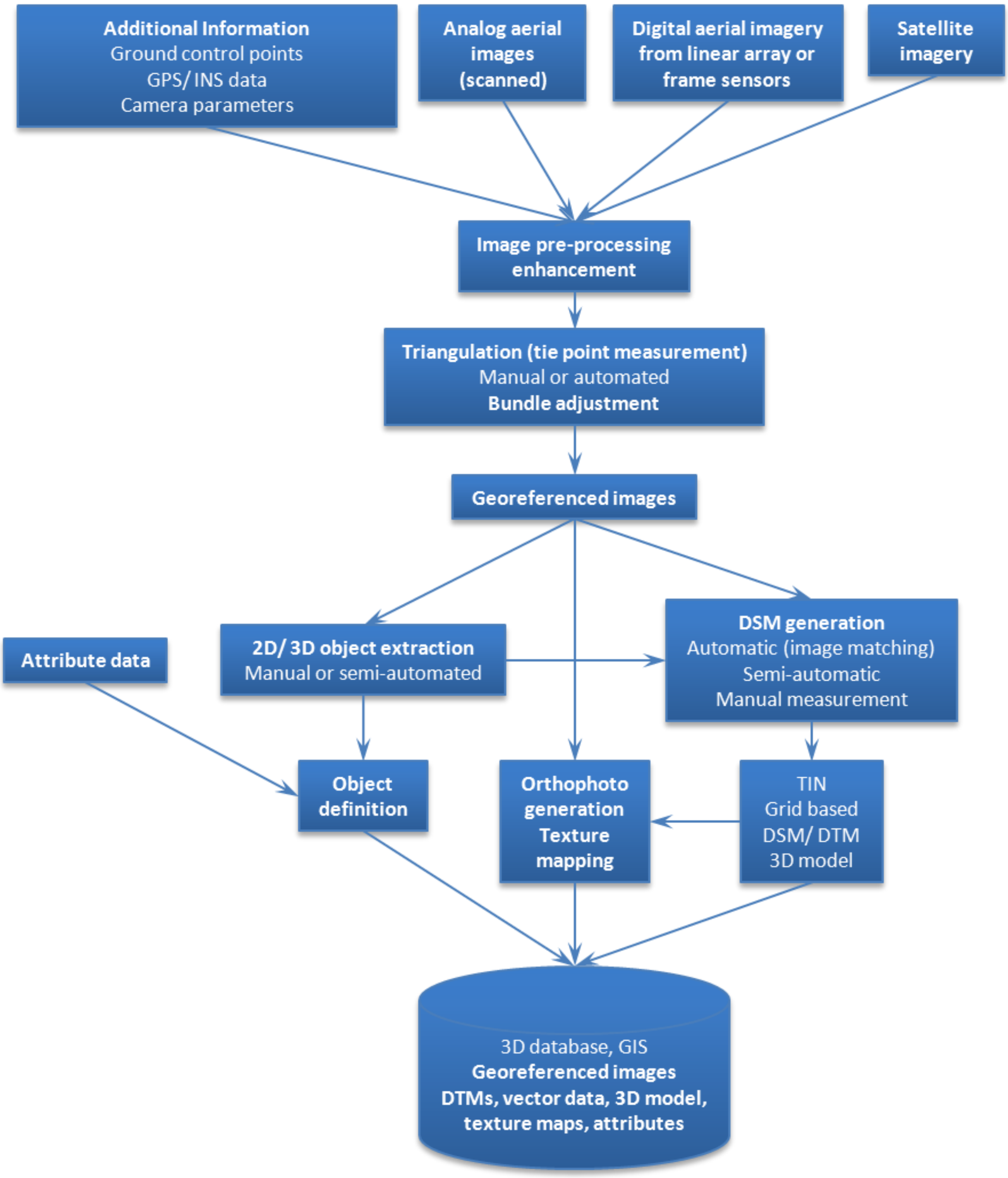


Figure 21: Photogrammetric/ remote sensing processes (Gruen, 2008, pp.88-106)

2.8.2 Image-Based Modelling

Image-based modelling (IBM) or ‘photo-modelling’ differs from other processes as they rely on standard terrestrial photography to reconstruct 3D buildings. Whereas earlier explanations of modelling processes describe orthophotos that are combined with height data, for example, to recreate 3D geometry, IBM software requires multiple images to create a 3D building wireframe that uses the images to apply textures to the completed model. Hudson-Smith (2005) suggests that IBM packages have been developed for creating models which are optimised in terms of file size but still retain a high degree of realism, which suits city models that are distributed over the web.

Historically, earlier examples of software fell short on speed, reliability and accuracy (van den Hengel and Dick, 2008). Wonka (2003) explains that IBM was a promising avenue for urban reconstruction in the early 2000s, with early tools producing excellent models with high accuracy despite the labour intensive process. Although advances have been made, the modelling processes is still fairly laborious and has only become a feature of many established 3D modelling packages, such as Blender, 3DS max, ZBrush and SketchUp (van den Hengel and Dick, 2008). The latest development in IBM produces similar results as scanning, whereby point clouds are produced from a set of images. Having calibrated the software to compensate for lens distortion, highly accurate 3D objects can be represented.

2.8.3 Parametric Modelling

Rather than relying on up-to-date visual information to reconstruct a building or city, another method is to define a building's form based on a description of its specifications or geometry. This uses the premise that all objects and in particular, buildings, follow set rules in their construction that allow a user to effectively program a 3D building model. Parametric or procedural modelling software use a pre-defined 'object grammar' for this effect. These products had been designed for use in urban planning (Wonka *et al.*, 2003), simulation, educational applications, etc., but there has been a significant demand for them in the film and game industry due to the low cost and expeditious method for creating realistic, complex urban environments (Dollner, 2005). Such extensive models or datasets can be created completely automatically, mimicking a particular architectural style or period.

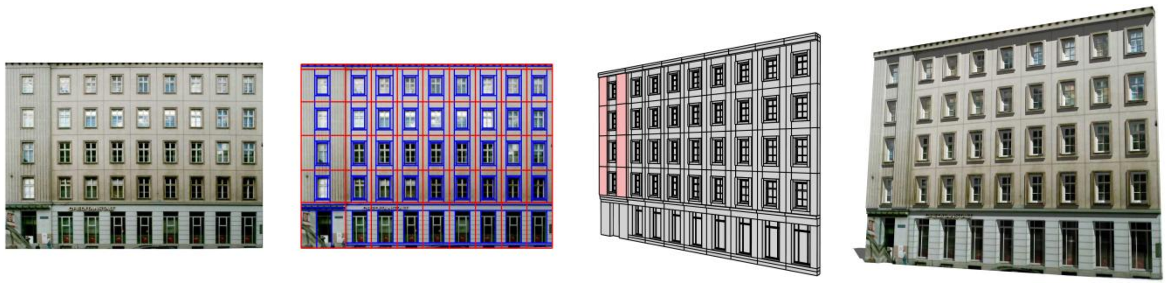


Figure 22: Parametric modeling (left to right): rectified facade image as input; facade automatically subdivided and encoded; resulting polygon model; a rendering of the final reconstruction (Muller *et al.*, 2007)

Another advantage of parametric or procedural modelling techniques is the ability to easily alter the LOD of the building or city model. This is particularly useful for city models that are used for a variety of applications, at varied levels of detail. Hence, parametric modelling can be used to simulate a building or to produce realistic building modelling reconstructions. Similar to IBM, the latter process usually begins with (orthorectified) photography that is used to reconstruct the building's geometry (see Figure 22, above).

2.8.4 AUTOMATIC MODELLING TECHNIQUES

Dollner *et al.* (2006) point out that virtual cities generated semi-automatically (or automatically) are required if they are intended to be managed in the long run. Large scale automation requires large quantities of aerial photography (including oblique imagery)or LiDAR point clouds to reconstruct geometry. Ground-based laser scanning processes are also in development that assists in the refinement of point cloud data and creation of building geometry. In some cases, parametric modelling techniques are applied to complete the modelling process. Digital (aerial) cameras have enabled a significant development in frame size, resolution and processing over the last decade. Although automatic building modelling is carried out after the data capture process, the quantity and quality of the data is the enabling factor for automation. An example of the most recent advances in full automation use Ultracam (Vexcel) hardware and applies ‘Multi-Ray Photogrammetry’ (Wiechert and Gruber, 2011), which relies on large amounts of overlapped images for the ‘dense matching’ of 3D objects (e.g. buildings) and terrain. The production of accurate (<10cm height accuracy with a point density of 50 points per m^2) DTM or digital surface models (DSM) was previously only possible using LiDAR data.

Figure 23: Dense matching of overlapping images to produce 3D geometry (Wiechert and Gruber, 2011)

Such techniques enable cities to be modelled more quickly than manual processes but are still restricted by the impracticalities of airborne data capture. A number of web-based mapping services, such as Nokia Maps, make use of automatic modelling techniques and have adopted a method of regular re-capture of their data rather than a gradual update process.

2.9 DATA STANDARDISATION

The standardisation of geospatial data is a key component to ensuring interoperability and successful city model ventures. Standards are required to prevent data duplication, access, retrieval and exchange problems (Wyatt and Ralphs, 2003). In geosciences, the creation of suitable Spatial Data Infrastructures (SDI) over the last decade has aimed at reducing the time and cost of geo-services (e.g. GIS) for internal uses as well as for public information services (Basanow *et al.*, 2008). Traditionally, virtual cities have been created by specialists, using specialist software: "They are used by a wide range of academic and technical disciplines, not because of the need for multidisciplinary interaction, but because they provide supposedly universal tools for handling spatial data." (Burrough and Frank, 1994, p2). By using standardised data, the information that incorporates city models has the potential to become discipline-independent. Geospatial Information (GI) can be particularly demanding data, containing many components and which the authors attribute to the general lack of an underlying theoretical basis for understanding spatial data:

> Conventional GIS are good at treating spatial data as exact objects (points, lines, areas) or discretised fields (pixels, voxels) but they have severe problems in dealing with certain forms of complexity, scale differences, generalisation and accuracy. We believe that people fail to appreciate that the inbuilt structures and assumptions in GIS technology may affect perception and the recording, storage, analysis and interpretation of data, thereby leading to distortions and misunderstanding. (Burrough and Frank, 1994, p.102)

Brunnermeier and Martin (1999, cited in McHenry and Bajcsy, 2008) explain that there are several common problems with data exchanges related to 3D data format conversions. These errors during conversion are due to software or hardware incompatibility, as well as product data quality. Some examples include:

- missing, collapsed, or inverted faces;
- models that do not form closed solids (surfaces and edges do not connect);
- models with incorrect feature orientation;
- lines that do not meet at corners or that cross at corners;
- curves or lines drawn as many short line segments;
- multiple occurrences of the same feature at the same location;
- lines or surfaces coincident with other lines or surfaces;
- surfaces that do not meet at lines;
- some or all of the geometry not translated;
- geometry, dimensions, and notes not correctly separated into different layers;
- planar features drawn out of plane;
- geometry of features not drawn to scale.

Compatibility or file exchange allows various applications to extract or view datasets from one another, but despite the many efforts to allow such compatibility, information loss is still common (Gerbino, 2003 cited in Wang *et al.*, 2007).

2.9.1 International and European Standardisation

The International Alliance for Interoperability (IAI) was established in 1994 to develop standards to support computer-integrated construction and which aims to "provide a universal basis for process improvement and information sharing in the construction and facilities management industries" (Hassan and Ren, 2007). This was in response to a widespread uptake and development of CAD in industry and ensures the transfer of files between different CAD packages (Whyte, 2002). The group created the Standard for Exchange of Product model data (STEP) initiative, which was adopted by the International Organization for Standardization (ISO) as a formal standard, but not widely implemented in CAD packages. Industry foundation classes (IFCs) were also being developed by the IAI, with the intention to specify the objects that could materialise in a constructed facility (e.g. windows, doors) should be represented electronically. The resultant specifications represent a data structure that is useful in sharing data across applications – without concern over which software was used to generate the data, or which software is reading and processing the data (Hassan and Ren, 2007).

In 2007, the INSPIRE directive was introduced by the European Parliament to create a European Union (EU) spatial data infrastructure. The aim is to establish an extensive distributed network of databases. Consequently, these must be linked using common standards and protocols to ensure compatibility and interoperability of data and services (INSPIRE, 2009). The end result will be a Spatial Data Infrastructure (SDI) of electronic data and services that can be accessed across EU administrative borders. Practically speaking, the INSPIRE Directive states that 'Legally Mandated Organisations' (LMO) are required to keep informed, review INSPIRE deliverables and submit reference material (INSPIRE, 2009). Through a hierarchy of international, national and regional contact points, local authorities and other Government organisations are required to submit electronic spatial data (related to any of 34 specified themes) to the INSPIRE Geo-portal. This also applies to some third party data providers or stakeholders. In order to standardise the data and ensure interoperability, Implementing Rules (IR) have been adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). This has meant that many Government bodies have been obliged to update and convert data, replenish datasets and many other tasks to conform to the Directive.

Although the European Commission is enforcing extensive undertaking and demands, the key principles that underpin the INSPIRE directive could have a profound impact on the GI industry and access to information:

- Data should be collected only once and kept where it can be maintained most effectively.

- It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.
- It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.
- Geographic information needed for good governance at all levels should be readily and transparently available.
- Easy to find what geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used (INSPIRE, 2008).

Despite the imminent enforcement of the handing over of information, the UK government initially lobbied against the lack of pricing structure (Cross, 2006). Member States were given until May 2009 to bring their own laws and regulations into line with the Directive – a process known as transposition. The Directive has had an extensive effect on the business models of many agencies, such as Ordnance Survey, who have begun to respond to the changes by amending their license structure and access to data.

Much progress has occurred over the last five years in the standardisation of city model data, such as the recognition of the CityGML (City Geography Mark-up Language) data standard. In 2008, the KML (Keyhole Mark-up Language) language was officially recognised as an ISO standard, establishing Google's position in the Geographic Information (GI) industry. This is also in line with the development of industry foundation classes and building information models which have the potential to further improve data-rich city models. The uptake of BIM in practice could present information rich, accurate geometric models for larger 3D virtual city models (Kohlhaas and Mitchell, 2007). Beside the technical issues of these large complex models (Wang *et al.*, 2007), it has been reported that the lack of high level commitment by key participants in both the construction and software industries hinders the standardisation efforts in the architecture, engineering and construction industries(Behrman, 2002). Various levels of detail of the same city model have to be taken into account as an important requirement in the system specification, as well as the ability to create and call up different variants and versions.

2.9.2 3D Data Formats

Suitable methods for storing and representing 3D information have responded to advances in available IT and the software applications adopted by professionals. Software companies have produced bespoke file formats for a number of reasons, often with varying levels of acceptance in industry. Coupled with the large variety of available data types is a gamut of problems related to 3D data acquisition, representation, storage and retrieval due to the lack of standard definitions of 3D data content, data structures in memory and file formats on disk, as well as rendering implementations (McHenry and Bajcsy, 2008). Essentially, city model data can be handled as 3D model information or as Geographical Information. Some larger models were intentionally stored this way in order to preserve the highly detailed models that may lose some of its integrity in other (GI) formats.

One such data format that was designed specifically for geographical features is Geography Markup Language (GML), which is based on XML grammar. Not only does it function as a modelling language for GI, but it serves as an open interchange format for geographic transactions on the internet (OGC, 2008).Other commonly used 3D data formats include:

- X3D (the extensible 3DFormat (x3D) is an ISO approved extension to VRML introduced in 2005).
- 3DS (the original native file format for Autodesk 3D Studio until 1996 but still in use)
- W3DS (OGC implemented draft standard to deliver SDI's that can be managed over the web).
- COLLADA
- OBJ
- O3D

Although CityGML does outline thematic methods of representing digital building models ('Level-of-detail 0-3'), established recommendations are necessary for quality levels and methods of depicting the content of a building proposal (Bourdakis, 2004). This is essential for better understanding of a planning scheme and a democratic aspect of city planning decision-making (Sunesson *et al.*, 2007). Furthermore, different stakeholders involved in the development process require to see the model from different perspectives and qualities (Brown, Knight and Winchester, 2005).Bodum (2005) points out that the modelling of virtual environments is not a standardised process, without common rules regarding building geometry. Some software has begun to address this, such as parametric modelling, but common semantic rules that underpin these varying solutions are needed.

2.9.3 CityGML

Principally, schemas are extensions to existing data languages that describe the document that contains the actual data. The CityGML is a GML application schema – a multi-purpose representation for the storage and interoperable access to 3D city models (Kolbe, Groger and Plumer, 2005). More specifically, CityGML is an XML-based application schema of GML version 3.1.1 (GML3) that represents the basic entities, attributes, and relations of a 3D city model. The OGC (2008) elucidates that CityGML models both complex and geo-referenced 3D vector data along with the semantics associated with the data. Another feature is a method for differentiating five consecutive levels of detail (LOD):

- LOD0: regional, landscape
- LOD1: city, region
- LOD2: city districts
- LOD3: architectural models (exterior), landmarks
- LOD4: architectural models (including interior features)

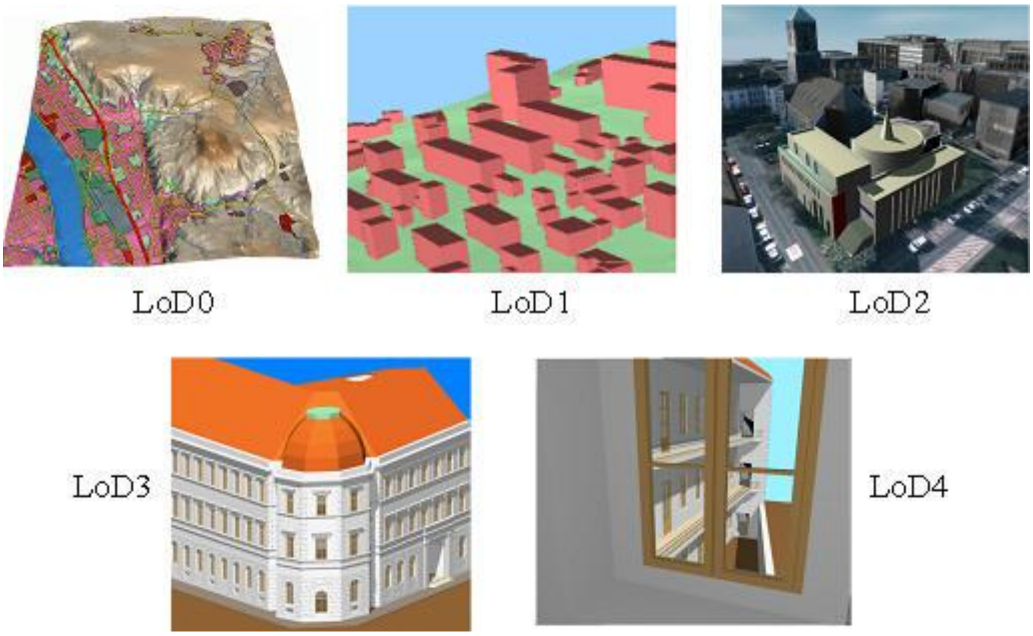


Figure 24: CityGML consecutive levels of detail (OGC, 2008)

The thematic model of CityGML employs the geometry model for different thematic fields such as Digital Terrain Models, sites (i.e. buildings), vegetation, water bodies, transportation facilities, and city furniture (OGC, 2008).

2.9.4 VRML

The Virtual Reality Modelling Language (VRML) was conceived in 1994, responding to a need for a common language for specifying 3D-world description and WWW hyperlinks. In essence, VRML is a file format for describing 3D interactive worlds and objects, which may be used in conjunction with the world wide web (although VRML is not an extension to HTML). This presents a relatively low-cost and practical method, as the VRML browsers are generallyfree software that allowthe distribution of 3D models over the web (Hudson-Smith, Dodge and Doyle, 1998). In order to create a 3D model from 2D data, the conventional 2D GIS database is used to map the desired spatial information and a program or script generates a VRML format output from the 2D geometry and attributes. This output can then be loaded into a suitable VRML browser for viewing and interaction. The virtual reality modelling language (VRML) last release was VRML97 and is still widely used for many commercial city modelling applications (Capstick and Heatchote, 2006). The data files are text-based which aids human authorship, characterising a modelling language or environment for creating 3D scenes (McHenry and Bajcsy, 2008). The subsequent development of GeoVRML was designed by an official working group of the Web3D Consortium in order to create an extension for VRML specifically designed for representing geographical data. The majority of software developers have simultaneously developed bespoke file formats for their native modelling packages.

2.10 Application and Communication

It is suggested that 3D 'geo-virtual' environments that encompass 3D virtual city models, should "serve as the interactive interface between city model contents and users" (Dollner *et al.*, 2006). Konecny (2003) explains how surveying and mapping has emerged from individual disciplines, such as geodesy, surveying, photogrammetry and cartography into a "methodology oriented integrated discipline of geo-information based on GPS positioning, remote sensing and digital photography". These are all methods of data acquisition that GIS uses for data manipulation and data output. Figure 25 (on page 55) highlights the variety of applications for city models that were found during this review.

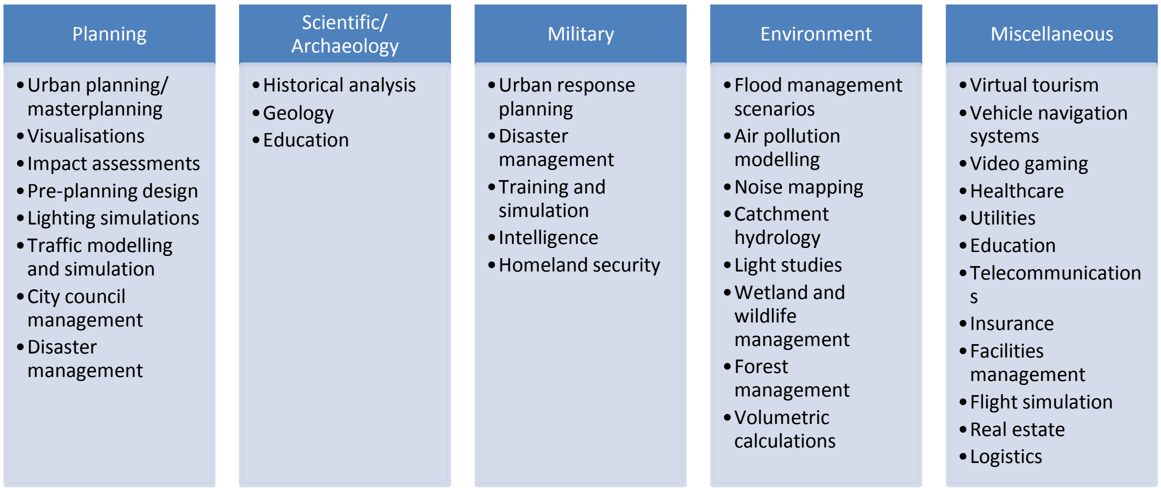


Figure 25: Applications for virtual cities

According to Gigante (1993), 'traditional' VR applications emerged in the fields of:

- operations in hazardous or remote environments
- scientific visualisation
- architectural visualisation
- design
- education and training
- computer supported cooperative work
- space exploration and entertainment.

Applications in mobile communications was one of the earliest use of commercial 3D urban models, often used to model radio wave and signal propagation and for siting new masts to improve service. More visual applications could be used in these situations and particularly in utilities management, whereby the complex maze of various pipes and cables could be mapped in 3D and also in relation to surrounding buildings and features (Bhunu, Ruther and Gain, 2002). Bourdakis (1997) highlights two levels of engagement that a VR urban model can fulfil, the first of which, as a presentation and evaluation tool and secondly, as a planning support analytical tool.

Batty *et al.* (2000) explain that developing systems which can query and extract subsets of information easily are often a part of these tools, as in GIS, but it is in visualisation that these new digital tools have the widest appeal. However, Dollner *et al.* (2006) argue that the array of applications that can be used should not be neglected and a virtual city model should be able to carry out thematic queries, analysis tasks or spatial data mining. Bhunu, Ruther and Gain (2002) explain that planners could use VR to assess the impact of new housing schemes, for example, in relation to transportation, local facilities and amenities. Uncertainty and lack of consistency in the design process has been blamed on the communication difficulties between planning authorities and designers (Hall, 1996). Altmaier and Kolbe (2003) tell us that certain users require immediate data access, tools for 3D analysis and data processing, as well as solutions for interactive visualisation and presentation. This highlights two distinct methods for use, namely real-time use and non-real-time visualisation. Real-time users of city models require far more advanced computing for navigating, editing and creating city models. Typically, desktop PCs are used for these tasks, with a range of secondary peripherals to aid modelling and simulation, such as 3D navigators and graphics tablets. Non-real-time use is typified by city model navigation, which can be carried out on almost any devices, including the latest mobile phones. Web-enabled services have dramatically increased the availability of city models in recent years. Furthermore imagery and videos that have been prepared by city modellers are used extensively for a range of purposes and even decision-making roles. This type of media delivery has the advantage that they can be processed and rendered in advance for greater detail or realism that real-time viewing will allow.

Many city model hosts have adopted large 'decision theatres' for greater collaboration (Allen, 2009), which also come in a variety of screen sizes and types that run on desktop computers. The city of Berlin's city model is presented at their Business Location Centre which is described as a 'showroom' with a large screen projector for effective presentation of the model (Dollner *et al.*, 2006).

2.11 Geographic Information Systems and planning Support Systems (PSS)

GIS is the union of cartography and database technology, created for the purposes of attaching socio-economic information to 2D plans (Ichioka, 2008). Its use has become integral in many Local Governments across the world, albeit the extent of its use is varied. GIS is often used to refer to a variety of related applications and disciplines, but dedicated GIS software is designed for the collection, retrieval, analysis and display of spatial data (Burrough and McDonnell, 1998) and has become an important part of environmental modelling technology for managing and analysing complex data (Yassemi, Dragicevic and Schmidt, 2007). Furthermore, Ozidilek and Seker (2004) suggest that the "creation of a GIS database almost always represents the most significant investment" and therefore the data management becomes the most important part of GIS. The primary role of GIS technology in the planning system is for environmental applications, as the use of data can be easily layered onto maps.

GIS have been described as a particularly 'data hungry' resource, often containing poorly managed data bounded by a strong sense of data secrecy that inhibits data sharing between organisations and individuals (Wyatt and Ralphs, 2003). The technological progression from paper to digital mapping to GIS created a myriad of interoperability issues across datasets at an organisational level that hinders immediate operational use. The UK Traffic Management Act 2004 revealed that some information was shared across utilities, contractors, Local Highways Authorities, The Highways Agency and some other stakeholders, highlighting concerns of both a broad lack of responsibility of the data and interoperability between users (Ordnance Survey, 2006).Nebiker (2003) warns that originally a number of major GIS vendors simply added 3D visualisation support to their existing 2D GIS products. This presents many issues for the representation of 3D objects within the platform and generally produced unsuitable results.Regardless of such issues, GIS have become integral in many more than just planning or geography departments, due to the high demand for spatial information. This underlying use of spatial information causes some confusion with global visualisation engines, planning support systems' (PSS) and other geo-information tools. Whereas GIS is a way of accessing a spatial database in a mapping context, the latter are generally visualisation engines that use a 3D map as a base that can then have spatial information overlaid on this. GIS are chiefly specialist software that requires trained users.

Geo-information tools that are used for simulation in the context of landscape planning may be categorised as Planning Support Systems (PSS) (Geertman & Stillwell, 2004). The authors conducted an internet-based survey aimed at identifying the existence and use of PSS for purposes of landscape planning worldwide and make some recommendations regarding the future of PSS development and application:

1. PSS should be integral to the planning process;
2. PSS should fulfil the key requirements of interactivity, flexibility, adaptability and maintainability demanded by modern participatory planning processes, as opposed to traditional planning practices;
3. PSS should be appealing and tailored to user capability;
4. The user-interface should be tailored to the needs of participants (Geertman & Stillwell, 2004).

Paar (2005) explains that responses from a survey carried out regarding software requirements from 3D simulation software, respondents cited in particular: ease of learning; integration into the respective software environment (interoperability); and a large 3D object library. Furthermore, low investment costs, navigation and orientation tools were also considered important. In terms of software features, responses from users varied: database-assisted visualisation and low hardware requirements were considered more important by environmental (planning) authorities than by private consultancies. The latter, however, were more concerned with user-specific customisation and a wide palette of representation styles. Other features such as real-time rendering or photo-realistic representation were not considered to be particularly important (Paar, 2005).

2.12 Data Management

The physical storage of data and access by its users involves key decisions that ensure a city model's continued use and performance. This section highlights current hardware for storing large datasets including desktop hard-drives and mainframe servers. Accompanying storage software is a link between the data and the end user but can also act as a storage entity in itself, such as virtual private servers (VPS).

The opportunities for sharing city models are limitless using modern technologies and network capabilities. City models are generally kept secure to a range of core users, with read-only access to the public via the web. This is often the case with city council hosts. The maintenance of this data involves software choice, file protocols, user access and permissions, data security, update and enhancement procedures. Hamilton *et al.* (2005) points out that the broad tasks involved in city planning employ a variety of tools that requires a consistent database management to ensure GIS and CAD model libraries (geo-located) remain consistent.

Evidently, much research has been carried out on the process and application of virtual city models, but little work has been carried out on the theoretical organisational and management issues that these technologies encounter (Podevyn, Horne and Fisher, 2009). Hamilton *et al.*(2005) verifies this notion that, in general, the ability to manage urban planning data leaves much to be desired and that practical aspects such as the management of 3D city models and how they can be sustained must be addressed (Dokonal and Martens, 2001). Bourdakis (1997) highlights the issues of managing a shared resource such as urban databases that are created by different teams, with data that needs constantly updating and synchronising. However, some research has been focused on developing data management and system architecture for city model data. Doller *et al.* (2006) have developed such systems, suggesting methods for administrative workflows for multi-user applications and datasets (see Figure 26, below).

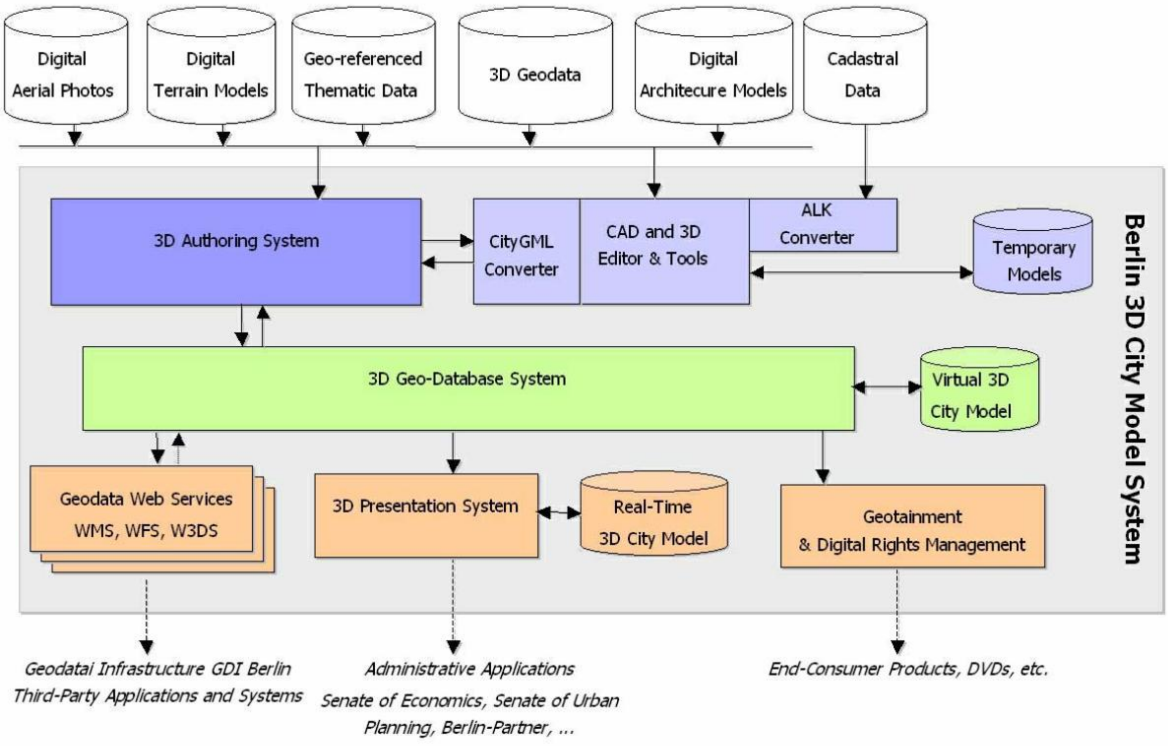


Figure 26: System architecture of the Berlin virtual city model (Dollner *et al.*, 2006)

Gruen (2008) tells us that the generation, administration, analysis, representation and manipulation of 3D models that utilise Virtual Globes are essential tasks that require the attention and input of all geo-related sciences.

ESRI products have dominated GIS for a number of years, offering software solutions as well as the data to carry out a range of tasks. ArcGIS (10) is the latest version of the popular software that is available for desktop computers, servers, mobile IT and cloud-based applications, all of which support 3D components for representing virtual cities. Most recently, ESRI Cityengine 2011 uses parametric modelling techniques (see section 2.4.2) for simulating detailed urban environments. However, there is a number of software or middleware designed specifically for urban planning and design, notably Citygrid, Autodesk LandExplorer 2009 or Infrastructure Modeller 2012. Middleware is a key component as they provide an interface between 3D modelling software and GIS within the software.

2.12.1 Data Storage Hardware

As with many aspects of virtual city models, software considerations are not unique to the field. They are, however, closely linked to 3D CAD (architectural modelling) and GIS fields. Both of these areas have an established user base and therefore an experience base to that lends itself to this relatively newer field of city modelling. Vitter (2008) points out that the data sets in such large applications are usually far too big to fit completely inside the computer's internal memory, which causes a major performance bottleneck when the machine must communicate between the fast internal memory and slower external memory (such as disks). The physical storage of data is one of the major components of any IT system, past or present. Temporary data storage in a computer's memory is referred to as random access memory (RAM), which is classed as volatile storage as these lose the information when not powered. This primary storage medium is present on all modern computers and is the fastest method for storing information due to its physical proximity to the CPU. However, large quantities of data are rarely held permanently in the RAM, relying on other secondary, tertiary or off-line storage. Secondary storage is most commonly associated with the modern computer's hard disk drive. They include flash memory, CD or ZIP drives. Tertiary storage typically uses robotic mechanisms to access large arrays of memory devices, such as standard hard drives.

Off-line data storage has many key advantages for large data-sets, notably improved security. Off-line storage is described as any medium that is not under the direct control of a processing unit, or the machine that is accessing it at the time. This also means that if other computers that use this information are destroyed, the data is safe. Furthermore, off-line storage can introduce improved protection from computer-based attacks. Solid state drives are non-volatile memory that contains no moving parts, previously used solely for the purposes of RAM. However, in recent years, it is evident that flash memory based solid state disks are replacing hard drives in some machines, particularly laptop computers.

2.12.2 Data Storage Software

Although bespoke file structures can be designed and implemented for almost any application, there are a variety of off-the-shelf products that will provide all of the necessary features that a city model scheme may require. They are used to assist the file management, provide complex access systems and backup schedules as well as other tasks. Essentially, storage software functions for managing the necessary databases, a solution that is by no means ubiquitous in city modelling or a characteristic of it. Dollner (2006) explains that the creation and maintenance of virtual 3D city models is based on a number of independent data sources. The sustainable management of 3D city models requires tight links to existing administrative work flows and databases that can include cadastral, digital terrain models (DTM), aerial imagery, building models and GIS databases.

Upgrading (or updating) a traditional non-geographic CAD databaseto a database that supports geospatial objects could achieve a higher degree of interoperability (Bodum *et al.*, 2006). A GIS platform performs as "like a catalyst it permits changes to occur, providing the material it acts upon is in a certain form" (Burrough and Frank, p102, 1994). Where a spatial data infrastructure (SDI)has been adopted, powerful databases are needed to manage and administer 3D data efficiently, such as PostGIS or OracleSpatial (Basanow *et al.*, 2008). The majority of current 3D city models are stored in either relational or object-relational Database Management Systems (DBMS), due to their proven reliability in both conceptual and commercial solutions. More recently, strategies use object oriented DBMS, which can store both geometry and attributes in the same structure, which gives more possibilities for visualising information within the geographic objects (Kjems and Kolar, 2006). Middleware must then be utilised to provide a link between the database and the user. As is the case of GIS middleware, it provides a facility for functionality of data. There are a number of products that have been developed for the purposes of city modelling and differ from GIS as they are developed with a greater capacity for 3D navigation. Other features generally include CAD, GIS and BIM data integration and the ability to carry out measurements, data querying, create videos and images, as well as distribute the 3D city model to numerous different viewers (Niemiec, 2009). Typically, middleware consists of a 'modeller', 'viewer' and 'manager' application in which the necessary tasks can be carried out. Another advantage is their ability to rectify 3D data and thus reduce the amount of storage it requires. For instance, a data structure can be based on lines rather than faces, which is the normally the case in architectural modelling, whereby the faces are generated 'on the fly' during navigation. This also allows better performance when viewing large datasets that is characteristic of city modelling.

2.13 Data Update Methods

Dollner *et al.* (2006) reveal that weak integration of maintenance and update processes in administrative workflows represents a major barrier in developing virtual 3D city models. In developing a city model of Berlin, the authors suggest that model generation and updating processes should be seamlessly integrated into administrative workflows so that the model's quality does not lack with respect to its legal correctness, completeness, and remains up-to-date. Ross *et al.* (2010) explains that one of the main conflict of interest arises between the cadastre and the planning department, which can also involve other departments (e.g. city marketing). Cadastral departments have a public mandate to maintain geo-data to a specific standard, although the planning department will regularly need to modify, change and update the 3D city model that relies upon the former for its underlying data. A study by Voigt, Linzer and Schmidinger (2004) suggested that the main processing methods that their auditees required were:

- archiving of information
- looking up both current and historical information
- modifying and updating
- supplementing (adding/ editing) information
- measuring (geometry)
- visualisations
- generating simulations (e.g. noise, energy or wind)
- presentation

Concepts for 3D change detection and automatic/ semi-automatic updates of city models have developed steadily over the last two decades. These concepts however, generally focus on the comparison of temporal information (e.g. remote sensing imagery) to identify discrepancy so that areas for re-modelling can be detected and carried out (Song and Deren, 2003). Holland and Tompkinson (2003) describes the process as the comparison of two sets of imagery that require some manual intervention from a user who must interpret and prioritise all change illustrated in the graphical display that is adopted. Gruen (2008) tells us that artificial intelligence, through image understanding algorithms for automatic image interpretation, has not delivered the promised performance since its inception. Voigt, Linzer and Schmidinger (2004) suggest a dataset update cycles of three years, as the different age of the datasets and the response times (from request to processing) are measured differently, making a more frequent update challenging. For large sets of 3D geometry (as in city models) and most forms of geospatial data, update can be carried out by either re-acquiring or revising the original data. The decision must then be made depending on the extent of work to be done (Song and Deren, 2003) and therefore the cost of the procedure. Research on model update is rapidly converging on complete automation (Holland and Tompkinson, 2003, Song and Deren, 2003). However, this approach is still costly and time-consuming, where data must be periodically reacquired for data comparison.

Image resolution plays an important role in automatic extraction of 3D geometry. Potentially, the smaller the scale the more successful automation will be (Gruen, 2008). Currently, the following is possible:

- Orientation and geo-referencing can be done in parts automatically. In other words, 3D points can be located automatically from imagery.
- Digital surface models (DSM) generation can be done automatically, but requires some manual input.

- Ortho-image generation is a fully automatic process, such as texturing a digital terrain model (DTM) or building surface.
- Object extraction and modelling can be semi-automated.

Capstick and Heathcote (2006) explain that the initiation of an update process of the OS' databases is event driven for 2D information. The events that drive these changes include 'significant change', quality improvement programs or corrections. Such event triggers may or may not be applicable for 3D. Furthermore, field survey tools that are currently used by the OS are not considered suitable for modifying 3D objects due to the complexity of the required editing.

2.14 Virtual Cities and Planning

Planning systems were introduced for a number of purposes depending on location, including noise and privacy, infrastructure and sanitation or military defence. In essence, planning is defined as the considered design of the built environment in urban areas – places with a higher density of buildings. The last two decades have seen shifts in paradigms of urban planning, where architectural consideration has attempted to coordinate the aesthetic and organisational layout of urban centres. It has been suggested that urban design "acts as the interface between planning and architecture" (Bhunu, Ruther and Gain, 2002, p201).

Hall & Tewdwr-Jones (2011, pp4-7) illustrate that planning theory and education was based on the study of making physical plans, rather than planning methods. They tell us that this attitude changed during the 1950s, led by American business schools and their science of decision-taking in complex situations. These were taken from concepts in philosophy and politics, while recognising the social sciences of economics, sociology and psychology (Hall & Tewdwr-Jones, 2011). Planning is considered as a complex iterative process, consisting of problem definition, collecting and processing of complex information, exploration and evaluation of potential designs according to set objectives (James, Fernando and Hamilton, 2004). This complex process must consider the physical nature of city alongside the economic, social, environmental and cultural factors (Hamilton *et al.*, 2005). Hall (1996) identifies at least four distinct groups involved in the whole process: the planners working for the local authorities, the architects/ planners working for clients, the clients themselves and the general public. In the 1960s, the development of computerisation in management and planning led to the development of sophisticated control systems (Hall & Tewdwr-Jones, 2011) but Barrett and Leather (1984) explain that planning departments did not consider the use of computing in the planning system until the lead up to the 1968 Town and Country Planning Act. This Act led planners to examine the application of computer modelling and forecasting techniques to formal planning and organising information to support the new planning system (Hudson-Smith, 2005). So the primary concern during this time was system organisation to support the “value neutral process of rational planning” (Klosterman, 1995) utilising early main frame computer systems. However, the use of computers in these pioneering local authorities was mainly limited to their financial departments (Hudson-Smith, 2005). Subsequent studies that examined the implications of computers in the planning system were carried out and were aimed to encourage the use of computers in spatial planning and design. One of the most influential of these was the joint local/central research project on the information needs of the new planning system, which resulted in the influential 'General Information System for Planning' report by the Department of the Environment in 1972 (Barrett and Leather, 1984).

Computer generated photomontages became established in the UK planning system in the 1980s, where perspective views were generated from 2D/ 3D working drawings and related to the site through photomontage (Maver, 1987). Hudson-Smith (2005) explains that the web is leading to an emerging toolkit for digital planning, a toolkit that is not aimed exclusively at the planning profession. The dramatic rise in popularity for global visualisation engines and their associated software (particularly SketchUp) describe a shift away from high end VR technology in recent years. Although VR has been considerably researched and applied in many cases, its impact in the urban planning and building design process has not happened as predicted (Roupé, 2009). Studies have also shown that planners themselves are reluctant to travel from their workplace to view a 3D city model in a VR environment (Sunesson *et al.*, 2007).

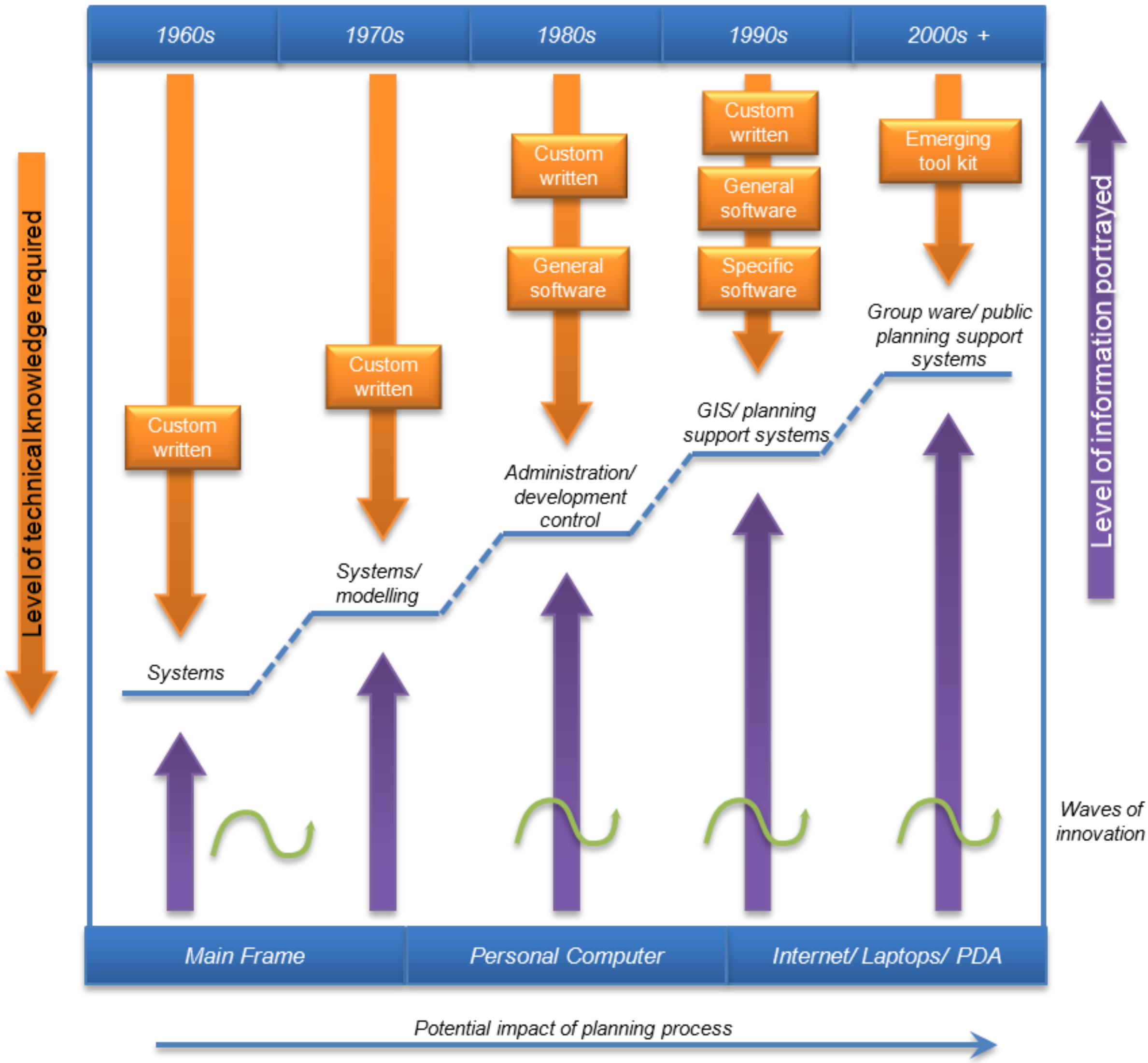


Figure 27: Computing, software, information and technical knowledge in planning (Hudson-Smith, 2005)

Levy (2011, p4) states that "the deciding factor on the use of 3D virtual models will rest on issues of integration into the planning process", as the added value that 3D models present must be proven in order to become a part of well-established planning processes. Bhunu, Ruther and Gain (2002) tell us that the way urban planners think about and communicate their ideas about urban problems and their solutions is strongly, although not exclusively, visual. This visualisation of urban planning and urban design can be based on three assertions (Dodge, Hudson-Smith and Doyle, 1997). Firstly, to understand nearly any subject of consequence it is necessary to consider it from multiple viewpoints, using a variety of information. Secondly, understanding complex information about urban planning and urban design may be greatly extended if the information is visualised. Finally, visualisation aids in communicating with others. Thus, communication and visualisation are at the heart of the planning system, traditionally as maps and 2D plans are accepted as the norm (Bhunu, Ruther and Gain, 2002). Doyle, Dodge and Hudson-Smith (1998) explain further that planners have often employed the use of physical models or large-scale plans for three aims:

1. To aid the decision-making process
2. To democratise the planning process
3. To assist in the conveyance or dissemination of ideas.

More specifically, 3D or physical scale models are used to assist in spatial planning – a component to all planning tasks, but not an exclusive task in itself. Levy (2011) suggests that an interactive environment, as created by the integration of CAD and GIS, enables a new scope of design factors that include scale, density, public access, open space, zoning, viewscapes, sun and shade (Batty, 1998; Helda, 2007, Howard and Gaborit, 2007 cited in Levy, 2011, p2). There are many assumptions that digital representations of these physical scale models pose as a suitable alternative. James, Fernando and Hamilton (2004) outlines that testing is needed to assess this assumption that 3D visualisation will lead to improved communications and participation, compared to 2D maps and static 3D models. Hence, an increasing amount of data and available data is putting a strain on those who are responsible for its use but Wang *et al.* (2007) agree with Harris and Batty (1993) that there is an increasing requirement to “seamlessly integrate” these datasets at a range of scales or details.

Bhunu, Ruther and Gain (2002) explain that 2D presentations (e.g. maps) need a complex system of layers to fully describe an urban environment, which normally requires professional training to be able to manipulate and interrogate the software. Hence, it is believed that a 3D VR system could overcome such limitations and would also reduce the need for site familiarity. Another distinct advantage of virtual city models is its ability for interaction. This broad term is often used when referring to virtual environments and can cover a range of tasks involving a city model and its user or users. Typical interactive activities involve navigation around the virtual model or taking measurements (Hesina *et al.*, 2009) and Batty *et al.* (2000) categorises the applications for which a 3D city model can be created:

1. Emergency services
2. Urban planning
3. Telecommunications
4. Architecture
5. Facilities and utilities management
6. Marketing and economic development
7. Property analysis
8. Tourism and entertainment
9. E-commerce
10. Environment
11. Education and learning
12. City portals

Although there are many examples worldwide of VR technologies and 3D city models being used to assist the planning process, the issue of how VR functions as a means of communication for planning applications is insufficiently researched (Sunesson *et al.*, 2007). Not only are there various technical barriers to the inclusion of various stakeholders in the planning and design process, but current methods for communicating development proposals to the general public are difficult to understand and do not give appropriate opportunities for participation (Mantle, Jenkins and Jiang, 2007), contrary to the publication of 'The Draft Town and Country Planning Regulations' (ODPM, 2005) (now Department for Communities and Local Government). Strobl (2006) explains that historically, calls for comments, statements and general public opinion on regional development plans, environmental impact assessments or zoning changes typically attract very low turnout at traditional planning discussion meetings. In some ways this had a detrimental effect on the process, as many Local Authorities were led to reassess their commitment to public consultation and to carry out only the minimum necessary to meet the requirements of the planning acts (Royal Town Planning Institute, 2003). On the other hand, some planning authorities stayed committed to the principle of participation and devised new strategies to overcome the barriers to engagement.

As Lange (2005) explains, computer-based visual simulations can potentially function as the link between the classic top-down approach in planning, i.e. experts providing information to the general public, and the bottom-up approach, i.e. the general public being consulted and participating in decision-making. However, a major problem that faces the hosting and management of city models is the issue of merging those involved in the participation, planning and the development processes together within a common framework of understanding (Brown, Knight and Winchester, 2005). Furthermore, the various stages in a cyclic or successive design process need to be communicated to a wide variety of affected parties (Batty *et al.*, 2000). Bishop and Forster (2007) explain that the many technological and organisational barriers that affect the use of VR in collaborative planning may be overcome by thoroughly designed model implementation and use. Much research has been carried out to explore the barriers and perceived barriers to adopting VR in various stages of the planning process (Hudson-Smith, 2005; Fu *et al.*, 2005; Bourdakis, 2004; Firmino, Aurigi and Camargo, 2006; Appleton and Lovett, 2005), which reveal that cost and time for training are major opposing factors to its use (Mantle, Jenkins and Jiang, 2007).

It is suggested that computers cannot decide the outcomes of social-based decisions; they can only present information and ease the processing of large amounts of data (Hudson-Smith, 2005). Batty *et al.* (2000) explains that the design process begins with the definition of a problem, informed by data collection, and supported through analysis. Hence, Dollner *et al.* (2006, p1) explain that the Berlin city model was developed in order to extend the city's existing geo-data infrastructure using the latest technology. In this way, current workflows and administration were not disrupted by adding this extra service, but it was seen as improving an already existing process. The increased use and implementation of ICT through e-government processes has been a key target of the UK Government. In planningterms, this will require full development control, enforcement and policy services to be made available in order to improve the overall service byimproving sharing of information (James, Fernando and Hamilton, 2004). This strategy was implemented through the Planning and Regulatory Services Online (PARSOL) National Project, which was originally funded as part of the Government's Local e-Government initiative to help support local authorities implement e-planning and e-regulatory solutions (Communities and Local Government, 2008). The UK Planning Portal was launched that provides a range of services including planning application information and submission, access to development plans, regulations and guidance notes.

Other secondary applications have been well documented – engineering and telecoms planning, but not necessarily attached to the formal Urban Planning process. Sheppard (2001) and Paar (2005) are both sceptical about the extent to which 3D simulations have been, and will continue to be adopted – exact numbers of which are even more difficult to ascertain. Although architects and some town planners construct and use 3D models as a matter of routine (Paar, 2005), the scale of city models is a far more technical and organisational burden. Furthermore, those who routinely use the city model and benefit the most from the superior spatial analysis that is on offer, are found mostly at the strategic level of the planning process, rather than IT backgrounds. Thus, Dollner *et al.* (2006) explain some of the key requirements for establishing a virtual model of Berlin:

- Supporting the integration of varied sources for administrative geo-information.
- Acquiring and evaluating 3D geo-data of the city.
- Developing interactive systems for presenting and communicating the virtual 3D city model to a variety of target users and application areas.

The use of free software, coupled with extensive 3D terrain data that is typified by Google Earth and SketchUp has enabled the extensive uptake of 3D modelling and design, as Levy (2011, p4) notes that one of the barriers to the development of urban models has been the accessibility to data on roads, buildings and terrain. However, the author notes that this type of data is not sufficiently accurate for use in a "formal city planning hearing", but does provide a great deal of context to a design or decision-making process (Levy, 2011, p4).

2.14.1 Public Participation

Thompson (1999) points out that participation in both the planning process and design processes dates back to the 1970s. Although there are several different ways to conduct public participation in planning and design, the following methods are more common ones: Charrette, workshops, planning-for-real, design games, public meetings, steering groups, focus group(s), and community forums (Thompson, 1999). In all these types of involvement designers and planners refer to some sort of a visual aid in order to disseminate their ideas and engage the public in the development. Lange (2005) believes that so far, visualisations in planning are mainly seen as a tool that allows visualising a certain pre-defined proposal. Visualisations are not seen as an integrated part of a participatory planning process leading towards a proposal (Podevyn *et al.*, 2008). In recent years the use of new types of visual aids in participation process are slowly becoming common practice. As Lange (2005) explains, computer-based visual simulations can potentially function as the link between the classic top-down approach in planning, i.e. experts providing information to the general public, and the bottom-up approach, i.e. the general public being consulted and participating in decision-making. It has been noted that 2D architectural plans or maps are difficult to understand for non-professionals hence the role of VR in public participation has been the subject of much research (Bhunu, Ruther and Gain, 2002). Bourdakis (1997) suggests that citizens' votes and opinions could be either used as a trend indicator and subsequently only considered in the final meetings as recommendations, or could play a more substantial role in decision-making. For instance, Al-Kodmany (1999) used three different types of visualisation tools in different types of involvement models in a participatory planning in Chicago. In different levels of design workshops they introduced an artist using an electronic sketch pad, Geographical Information Systems and computer photo-manipulation process. Al-Kodmany (1999) suggests that these techniques, visualisation through digital technology, provided a common language for the participants and could be an important contribution to the evolution of the participatory planning and design. Bishop (2005) suggests that visualisation is important for certain public participation objectives, but either not possible or not important for others. Schroth *et al.* (2005) suggests with evidence-based research that 3D landscape visualisations applied as tools for participatory workshops in planning do benefit from interactive features.

Current lack in public participation is often due to physical access to information. Solving some of these issues can come from these new global visualisation engines that provide mainstream geospatial visualisation and interaction environments and are particularly useful tools for participative frameworks (Strobl, 2006). The process and relative value of participation has been extensively researched in academia (see Strobl, 2006; Mantle *et al.*, 2007; Bourdakis *et al.*, 2004; Knapp, Bogdahn and Coors, 2007; Lange *et al.*, 2005).

James, Fernando and Hamilton (2004) explain that improved understanding of human-computer interfacing to develop more intuitive and easy to use services is an important area of research.

2.14.2 The UK Planning System

According to the UK's Planning Portal (2011), (planning) control is the process of managing the development of land and buildings for the purposes of preservation and improving the infrastructure. Each local planning authority is responsible for deciding whether a development should go ahead and each authority must prepare a local development framework – a comprehensive agenda that outlines how the planning system will be managed locally. Hall & Tewdwr-Jones (2011) explain that the traditional 'linear' process that consisted of 'survey-analysis-plan' has been replaced by a new planning sequence that is more akin to a continuous cycle with "goals; continuous information; projection and simulation of alternative futures; evaluation; choice; continuous monitoring" (Hall & Tewdwr-Jones, 2011, p6). This structure is similar to many planning systems worldwide, beginning with the formulation of objectives and goals for the area concerned (Local Development Framework) that are continuously refined and verified, as with other stages of the model.

Organisationally, the planning system in England consists of two main parts – a framework of plans and development control. James, Fernando and Hamilton (2004) describe a third element as the role of the Secretary of State in determining planning policy, deciding planning appeals and some important applications. Until 2004, the system relied completely on a plan-led framework, whereby development plans were produced by county authorities (structure plans), district councils (local plans) or unitary authorities (unitary development plans) (James, Fernando and Hamilton, 2004). These development plans were written within the context of Regional Planning Guidance. Since the introduction of The Planning and Compulsory Purchase Act 2004, the system of Local Plans and Structure Plans was replaced with Local Development Frameworks (LDF). These are based on spatial planning; a broader approach focusing on integrating and delivering economic, social and environmental objectives (Hill, 2004). Uribe-Sandoval and Prosperi (2009, p542) correspond to this, suggesting that the key to considering issues on a larger, metropolitan scale (such as those tackled by LDFs) is to "understand the implications of a project beyond its immediate boundaries. There is a need to move from 'project thinking' to 'project impact thinking'". The 'Planning Policy Statement 12 (PPS12): Local Spatial Planning', published in 2008 sought to address similar concerns and outlined "creating strong safe and prosperous communities through local spatial planning" and established the national policy framework for creating local development frameworks.

LDFs are also required to include Development Plan Documents (DPDs), which are more directly related with decisions on individual planning applications. Independent planning inspectors must look at all DPDs that local authorities in England prepare for an examination. The examination is described as the last stage of the process for producing a DPD, which should have involved everyone who has an interest in the document (Planning Portal, 2011).

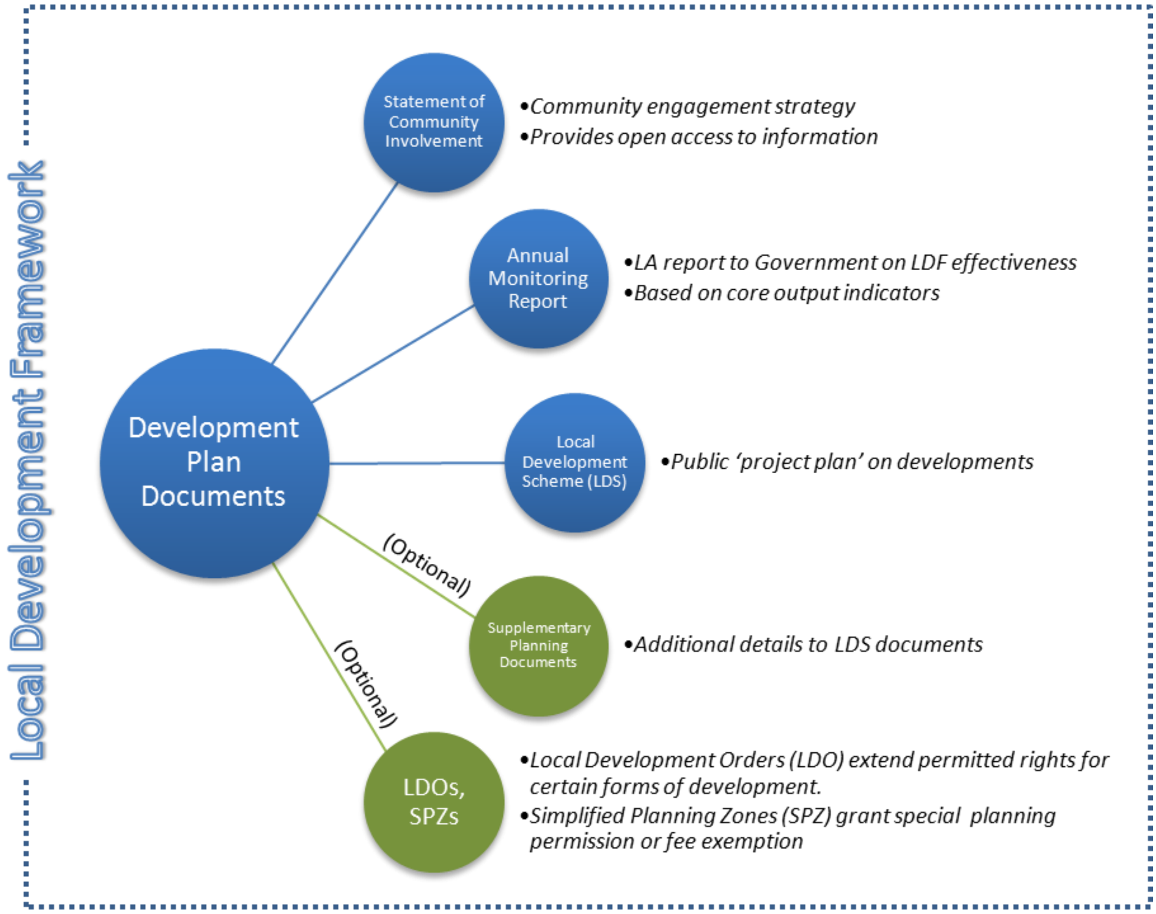


Figure 28: The Local Development Framework (Planning Portal, accessed 17/4/2011)

Planning Policy Statement 12 (PPS 12) sets out the UK Government's policy on how to prepare these Local Development documents.

The broad objective of land use planning in the UK system is to "regulate the development and use of land in the public interest", although in 2004, a much wider purpose was added by the Planning and Compulsory Purchase Act (s. 39.) to contribute to the achievement of sustainable development (Cullingworth, 2006). Development control authorities, usually at District level (see Figure 29 on page 72) are responsible for putting local plans into place and decide on applications to develop land or buildings.Recent updates to the development framework include the Localism Act in 2011 that enables local communities to establish forums for the purposes of preparing neighbourhood plans.

Participatory planning aims for a more democratic planning process and is carried out in varying degrees of involvement (Rowe and Frewer, 2004). This ranges from a one-way (top-down) flow of information to an engaging dialogue between a number of parties (Hoogerwerf and van Lammeren, 2005). Public, often practically speaking commonly consists of community organisers and social workers (Forester, 1987). Participate in public consultation periods for Local Development Frameworks or contacting the local authority on planning applications (Planning Portal, 2011).

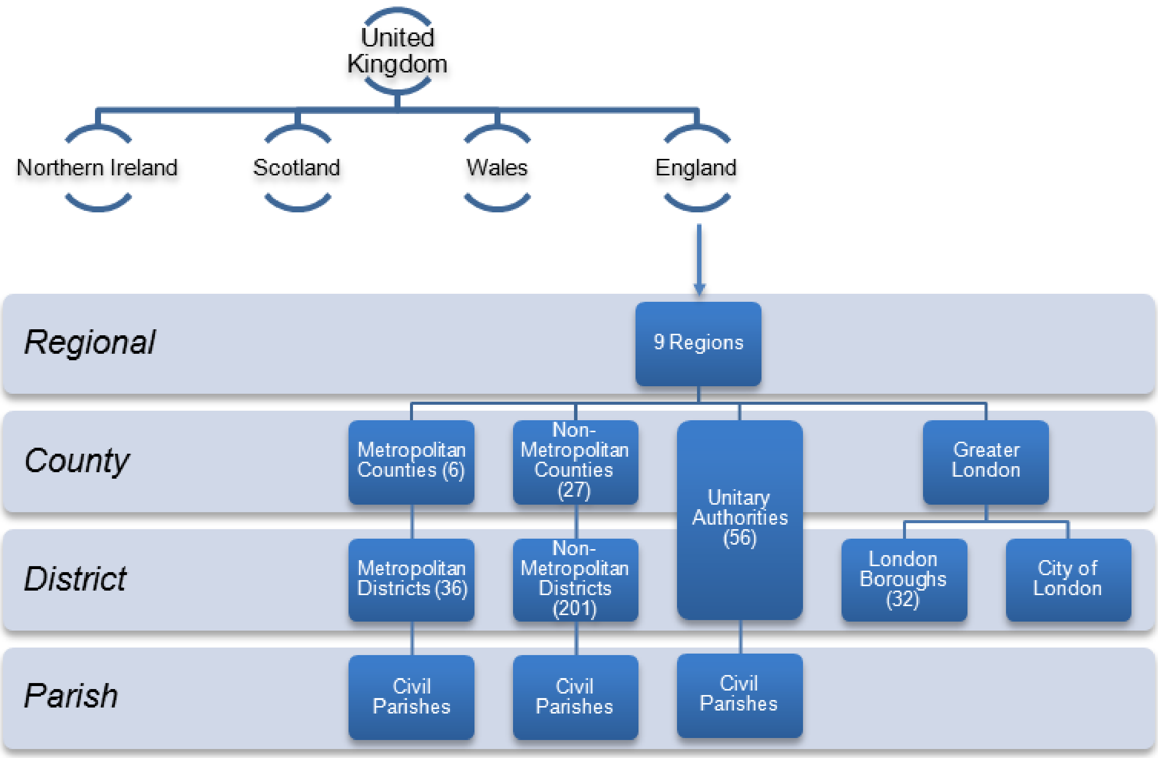


Figure 29: Local Development Structure

Jones and Evans (2006) tell us that a recurring theme in the literature on planning practice is the inability of government to act, either because too much emphasis is placed upon policy tools or due to the difficulties of achieving cooperative action. The latter is central to autonomous urban development in the UK.

Those parties that are involved in the spatial and environmental planning process consist of people and organisations from the civil, private, and public sector (Ross *et al.*, 2010). In the UK, Planning Officers are those employed to prepare plans and deal with applications. They either work for local councils or private consultancy firms on behalf of developers or individuals (private). For certain planning decisions or guidance, Planning Committees are meetings of elected councillors of the local councils, generally politicians. Local Planning Departments have also been referred to as 'Development Control', 'Environmental Services', 'Environment Directorate' or 'Regeneration' departments.

Despite the complex nature of the planning system, Devische (2008) suggests that the tools that planners rely on need to be addressed, rather than the roles of the planners themselves. These tools "should allow for a "more process orientated type of planning, involving a variety of stakeholders, that is geared towards communication as well as experimentation" (Devische, 2008, p210).

Large urban developments rely on a number of Supplementary Planning Documents (SPD) and official guidelines depending on the circumstances or stipulations of the local authority. For instance, 'Tall Buildings Guidance' (Newcastle City Council, 2005) or environmental impact assessments may be followed. Originally, the accuracy of the required 'redline' photomontages for planning applications relied on the skill of the architect/ designer/ visualiser to properly judge the position and aspect of the design proposal. Emerging methods aim to improve this process and at the time of writing, verifiable views are required in London, whereby evidence must be shown that the process has been carried out to a reasonable level of accuracy, although this is not required in other parts of the UK. However, some visualisers or architects are choosing this method as common practice. Predefined viewpoints are used, so that designers do not choose those that would be most beneficial to their design. Secondly, the photography should follow strict guidelines, which is why many outsource this stage of the process. Finally, the photomontage must use (and evidence produced to show this) appropriate software to identify the correct scale and position of the inserted 3D proposal.

2.15 Legal Considerations

Cross-discipline city model projects involving multiple stakeholders, financiers and users can have complex ownership and financial structures. It falls upon the virtual city host to control how the data is used (see 2.16, below). The legal issues that concern the host involve the rights to the digital data and the responsibility that this ownership entails. Kemp, Hinton and Garland (2011) suggest that data itself is effectively inert of legal terms, but more accurately spoken of in terms of the legal rights in relation to data. There are two areas that concernthese legal rights. Firstly, the rights to the city model data itself. Broadly speaking, protecting the legal rights of the owners of the source data requires meticulous caution. The second issue involves protecting the rights to privacy and security of individuals that could be affected indirectly by others viewing the 3D data. Gleicher and Hwang, (2008) highlight the fundamentals of protecting certain geospatial information, explaining that unauthorised access could endanger users' safety, "whereby harassers, stalkers, thieves, a snooping government, and even terrorists" could put such information to a wide range of objectionable uses (Gleicher and Hwang, p77, 2008). Ross *et al.* (2010) explain that the exchange of planning information is regulated by law, whereby plans have to be signed and exchanged by planners and members of the civil administration to ensure their legal validity. Previously, this process could not be solved through digital processes, but new technologies and methods have been developed to enable authentication, secure data transfer and digital rights management (DRM). Much debate that concerns 3D city models can be associated with the data acquisition and how this is managed. Data acquisition for constructing 3D models is often sourced from third party aerial imagery or specialist city modellers. This can restrict the communication, distribution and intended use as the necessary Intellectual Property Rights (IPR), security or privacy laws may be applicable. It has been noted that the lack of proper copyright protection or digital signature stamping in 3D geometry, coupled with the relative ease at which file can be transferred across the internet is hindering the development and availability of urban models (Bourdakis, 2001). Furthermore, architects or designers who submit 3D models can state confidentiality or copyright restrictions to their data, not solely for IPR purposes, but for fears of misrepresentation, particularly during the course of planning proposals. For these reasons, more recent examples of city models have acquired data using laser scanning technologies to avoid legal restrictions and produce 'as-built' 3D geometry, rather than relying on architects' drawings (e.g. Glasgow, Westport) (Pritchard, 2007).

One of the characteristics of modern web-based, open sourced platforms is the apparent lack of ownership in their early stages. In the example of OpenStreetMap, data was principally owned by the contributors until a foundation for the project was established (in Great Britain) for both legal responsibility and a base for hardware infrastructure (Wasserburger, 2009). Hassan and Ren (2007) point out that there is a lack of a solid contractual basis that governs the electronic exchange of information and documentation within and between design participants in the context of 3D building modelling.

Confidentiality can also be an issue in relevant data. Kemp, Hinton & Garland (2011) explain that unlike copyright and database right, which are solutions to protecting the way in which information is displayed, the law of confidence can protect the substance of the information itself. Practically speaking, the authors suggest that consideration is given in an organisation's system of contracts, website and any other notices to ensure that any 'data' is expressly stated to be confidential, which may involve modifying contractual definitions of 'Confidential Information' to be sufficiently broad as to cover computerised data.

2.15.1 Copyright and Intellectual Property

Hassan and Ren (2007) explain that copyright protects the creations of human intelligence which are endowed with originality. This long-established doctrine dictates there should be two distinct legal contents. Firstly, a moral decat that expresses the relationship between author and work, which is non-transmissible and cannot be prescribed. Secondly, there is an economic facet, consisting in the exploitation of the work for making profit. This constitutes the very object of an ownership (and can therefore be sold, etc.). Copyright agreements protect any original work against copying without licence or permission (Kemp *et al.*, 2011). Batty *et al.* (2010) explains the prevalence of copyright whereby, there is little map data available on the web or in other remote digital format that is not without some copyright restrictions on who is able to use such data. Wyatt and Ralphs (2003) explain that the law does not regard that individual data items are 'ownable', but it is the creative effort spent in selecting and recording data that is recognised and protected. Therefore, the producer of a set of information has rights associated with its use, such as the right to buy and sell information or the right to be identified as the author of a data set. ICT law is still an emerging area of research and development that is undergoing a rapid evolution. It has a transversal nature, as it ranges across all legal sectors, from trade law to IPR, from data protection to criminal law, to commercial law and IPR (Hassan and Ren, 2007).

Legal rights for derived data concerns virtual city data that has used external 'input data', such as building footprint information. Questions frequently arise about the extent to which a user or licensee may use any input data to create derived data and then who owns what rights in the derived data, particularly whether the supplier of the input data has an interest in the derived data (Kemp, Hinton & Garland, 2011). Furthermore, co-mingling data is similar to deriving data, but with the user taking input data from more than one supplier or licensor and creating something different. Once again, contractual agreements should cover expressly a solution, although that could present practical difficulties. For the supplier or licensor who wants to claim an interest in the commingled data in the absence of an express entitlement, the problem is that copyright, as a formal solution, is unlikely to help, although confidentiality may provide some assistance (see Privacy on page 76). Analogously, existing Enterprise Rights Management (ERM) or Digital Rights Management (DRM) systems, such as those used in media, aim to control who accesses data and the usage of data, even after the data has been disseminated to recipients. However, once the data has been used there is no control or protection of the information created as result of its use (Scalavino, Gowadia and Lupu, 2010).

Thus, the legality of the use, ownership or distribution depends on the source of the data and therefore the contract terms which all parties have agreed to. Normally, consent is given to use and edit the data for a range of applications. Re-sale and commercialisation of the data further complicates any agreement and can be restricted. Similarly, distribution of the data (including gratuitous distribution) can carry restrictions, although not always explicitly. Another conflict that arises is the question who owns the 3D models or representations that are integrated into 3D city models during different stages of the planning processes (Ross *et al.*, 2010). These concerns are the driving force behind much research on this subject, particularly as there is an increasing emphasis on public participation and transparency in the processes or services by which the public are governed.

2.15.2 Privacy

Privacy issues and definitions varies from country to country, reflects on tradition, but changes with culture as we struggle with the notions of ‘public’ and ‘private’ (Kada *et al.*, 2009). Due to the prevalence of personal information of the web and ease of access (legally or not) the boundaries of privacy are slowly fading. For instance, mobile phones already continuously provide some location data to telecommunications companies, with or without the users’ knowledge and illustrates the privacy implications of such information being broadcast by devices when a user has a reasonable expectation of privacy (Gleicher and Hwang, 2008).

Information can be classed as geospatial data if it contains “any data with a direct or indirect reference to a specific location or geographical area” (directive 2007/2/EC of the European Parliament and Council). Kada *et al.* (2009) illustrate this case, whereby photos or photo-realistic models of spatial objects, such as a building, could be easily located by geo-coordinates and therefore easily matched to its owner or residents, in such a situation geospatial information becomes personal data that may be considered an intrusion of privacy (Siemoneit *et al.*, 2009). Google Street View has come under heavy scrutiny since its launch in the US in 2007 (UK launch 2009). The program blurs individual’s faces and license plates and users can request additional distortion of images that contain homes, cars or other private content. The company assert that “Street View contains imagery that is no different from what you might see driving or walking down the street” (http://maps.google.com/help/maps/streetview/privacy.html, no date). The service is criticized for having a “privileged view” on the spatial object as images are taken at a height of 2.5m above ground level, which is not at the height of the eyes of a pedestrian and allows users to look inside a property or home (Privacy International, 2009). Objections are raised against the extent to which this information is now being put in the public domain, particularly from where privacy and data protection laws are stricter than in the United States where the company originates (Siemoneit *et al.*, 2009). Similarly, 3D laser scanners allow some data capture of interior layouts and features through windows, which would not normally be visible to the naked eye. Altmaier and Kolbe (2003) illustrate that although public web maps like city maps can be accessed freely, users usually do not have the rights to get the original spatial data from which these maps were derived. Similarly, no municipality would offer unrestricted access to its 3D city model on the feature (or detailed) level, but may provide public 3D portrayal services that deliver images or a simplified version of the model. Such detail could raise security concerns, whereby increasing levels of detail accrue greater security implications, such as LOD3 city models that display the interior of buildings and room layouts.

Gleicher and Hwang (2008) summarise that despite the obvious privacy risks, any new regulation that could constrain these factors risk eliminating the very characteristics of GI that make it so valuable and "reducing the quantity, quality, or frequency of data gathered could fatally handicap [GI] services. Instead, regulations should focus on how this information is exchanged and retained, and how much control users have over it." (Gleicher and Hwang, 2008). Many of these issues that arise for GI are shared with city models hosts, where the 3D data is used as PSS or to enhance GIS. In this sense, it is the occupation of the data that will encounter the legal concerns, but in many ways the 3D data, or in particular, the geometry may be scrutinised.

2.16 Virtual City Hosting and Stakeholders

Although virtual cities have been developed by a range of users, from educational establishments to private urban modellers, Le Heron (1999) highlights the importance of the careful hosting of a city model for specialist applications. This is necessary to ensure that information is secure and to protect certain individuals' rights, as well as the need to control the information so that it does not become a commercial and/ or marketing tool. Furthermore, the risk of enfranchisement or disenfranchisement raises obvious concerns to most of the stakeholders in the urban planning decision-making process (Bishop and Forster, 2007). Hosting a city model presents significant legal and security responsibilities. Bodum *et al.* (2006) explain that if a 3D city model is required for a local initiative, the normal procedure is to contact companies that specialise in 3D city modelling. Ross *et al.* (2010) suggest that amongst the reasons that hinder the broader utilisation of 3D city models are 'high relevance' organisational issues. Problems can begin at these early stages, as it can be a very complex task to understand and communicate a 3D city model, which becomes a complex task for the local administrators to define the requirements for such a model:

> Instead of thinking in terms of context and interoperability, they often become fascinated by the fact that the companies are able to present a very visually convincing solution to them. The issues that are discussed are typically linked to the traditional understanding of a mapping situation, where issues such as absolute geometric accuracy and completeness of the model would be important. But in a 3D reconstruction of a city model, the interesting discussions are not how close to reality you can get or the fidelity of the details in the model. The interesting subjects are topology, relative accuracy and interoperability of the model in relation to other information systems (Bodum *et al.*, 2006, p2).

In situations where a city model has been introduced to enhance an existing service, Sargent, Harding and Freeman (2007) verify this notion, explaining that the majority of GI (Geographical Information) users do not yet know what they require from 3D building data.

It has been noted that the host can be responsible for ensuring that a city model does not deviate towards a marketing tool and become a commercial benefit to certain paying individuals (Le Heron, 1999). This situation is evident in many off the shelf products, such as Satellite navigation systems, which are partly-funded by certain chains of hotels or fast-food restaurants that are featured on their maps. However, it is a fact that most city budgets are tight and a 3D city model can become an attractive prospect when, besides the diverse internal applications for use within the city or host, external interests can be additionally served (Ziele *et al.*, 2005). Leem *et al.* (2007) point out that the facilities infrastructure (e.g. electricity) are built, supplied and maintained by a variety of service providers and it is often the case of these providers to record the information of where these services are located.

Originally, architecture and academia were the driving factors for the creation of city models, but followed by users from telecommunications, surveying, programming and GIS, all of whom are driving the development of city models for a variety of applications (Dokonal 2008). Thus, there have been few city model enterprises that have been established for a single purpose, rather as an extension or project to an existing business or department. Bourdakis (1997) anticipated that city councils or possibly especially formed speculative departments could be responsible for maintaining, storing and handling the centralised databases that would contain city model data. Wang *et al.*(2007) suggest that the insufficient integration and interoperability between software applications have caused considerable barriers to communication between the stakeholders. A key aim of virtual city models is to assist communication between its users and stakeholders highlighting the importance of appropriate software and data management from the outset. Hall (1996) categorises four relevant parties in the urban planning process: city planners, architects working for clients, the clients and the general public, all of whom are seen as legitimate ‘stakeholders’. Ross *et al.* (2010) outline that the stakeholders in spatial and environmental planning consist of people and organisations from the civil, private, and public sectors. Moreover, the civil sector is typified by a planning department, coordinating plans with environmental, transport, social and economic departments and agencies on local to national and sometimes international level.

The communication environment itself is also an important forum, as research shows that many VR environments or ‘Decision Theatres’ do not boast many returning visitors, once an initial project has been completed (Kobayashi, 2006). Cases such as Berlin’s Business Location Centre and Glasgow School of Art are examples of established city model developers who have a high frequency of users and returning users for planning, architectural visualisation and real estate interests and who have a robust framework to attracting users (Kobayashi, 2006). Altmaier and Kolbe (2003) suggest that interoperable 3Dgeo-information systems show market, economisation and refinancing potentials as there is a strong demand on the market by certain users.

2.17 Virtual City Audit

An audit of virtual city projects that were identified from a desk-based investigation was carried out to gather qualitative research data from a sample of current European virtual citiesbetween September 2008 and January 2009. Although the literature review displayed trends, origins and issues in city modelling, the audit was a means to investigate which organisations were hosting models and the details of their project. The process would also assist in identifying participants for the following interview stage (see Chapter 5.5: Interviews). In order to establish boundaries for this data collection, only virtual cities that represent European Cities were considered. Information gathered from the literature review indicated that there are many common issues pertaining to hosting and managing city models within this group, such as software, applications and legal issues. Secondly, the accessibility of the audit participants was an important factor for the purposes of the research and the subsequent interview stage, where issues such as language barriers and time differences could hinder the research.

Details of the audit are presented in Table 2(on page 80) and outlines 49 on-going virtual city projectsin European cities, their hosts and functions (see Appendix for more comprehensive details). They are projects that demonstrate extensive andsustained use, rather than virtual city 3D data that has been created for a single use or application (e.g. architectural visualisations). Furthermore, certain countries produce 3D mapping functions of their entire regions, which are consequently available to its citizens, such as the case with Sweden’s Lantmäteriet (Hallebro, 2006). Denmark-based Blom ASA began an initiative to model every building in the country (2.2 million buildings approximately), which can be achieved using recent advances in automated city modelling technologies Hence, this audit focused on the cities that had been adopted by a ‘host’ that did not include mapping agencies on a national scale.

Table 2: Virtual city audit – host and functions

City	Host	Primary Function	Secondary uses
Salzburg	Cybercity, for Client ViewTec Inc.	General public information	Tourism
Vienna	City Council	Planning	Emergency planning (Euro Cup)
Birmingham	City Council	Planning	
Glasgow	Digital design studio, Glasgow School of Art	Planning	Public participation, consultation aid
Manchester	Arup	Planning, master planning	
Newcastle	Northumbria University	Research/ planning	Heritage, transport simulations, emergency planning, GIS
Nottingham	City Council	Planning	
Liverpool	GMJ	Planning (visualisation)	
London	CASA (UCL)	Planning (visualisation), public participation	Planning, GIS research
London	Cybercity	3D data provider	
London	ZMapping	3D data provider	
London	GMJ	Planning (visualisation)	
Newport	GMJ	Planning (visualisation)	
Sheffield	City Council	Planning	
Stockport	City Council	Planning	
Brno	Europoint Brno	Planning (relocation)	Transport simulations and visualisation
Helsinki	Fontus	3D data provider	Tourism
Bezons (Paris)	Archivideo	Planning (transport)	
Dijon	Archivideo	Planning (transport)	
Nantes	Vectuel	3D data provider	
Paris	Vectuel	Planning	
Paris	Cybercity	Planning,3D data provider	Tourism
Vierzon	Vectuel	Planning	
Berlin	Berlin Senate and Berlin Partner GmbH	Planning, business development	Research
Bocholt	GTA Geoinformatik GmbH	Planning	
Bochum	Realcity	Planning	Media and marketing animations

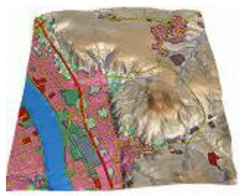
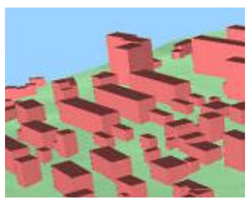
Chemnitz	Virtual City Systems	Planning	
Coburg	GTA Geoinformatik GmbH	Planning	Tourism
Dortmund	Dortmund Economic Development Agency	Planning, business development	
Frankfurt	Realcity and Frankfurt City	Planning	Marketing
Hamburg	Cybercity	3D data provider	
Hamburg	GTA Geoinformatik GmbH	3D data provider	
Hannover	Leibniz Universität Hannover	Research	Planning
Heidelberg	GDI 3D (various contributors)	Research	Planning
Munich	Cybercity	Planning	
Neubrandenburg	GTA Geoinformatik GmbH	Tourism	
Stuttgart	State Capital of Stuttgart and GIS-AG of Stuttgart	Planning, research	
Weimar	GTA Geoinformatik GmbH	3D data provider	Planning
Wiesbaden	Wiesbaden and GTA Geoinformatik GmbH	Planning, 3D data provider	
Westport	AMT 3D	Planning, heritage	Virtual tourism (Google earth)
Florence	Cybercity	3D data provider	Planning
Lucca	GeoSIM systems	3D data provider	Planning
Milan	GeoSIM systems	3D data provider	Planning
Parma	Compagnia Generale Ripreseaeree S.p.A. (CGR)	3D data provider	
Venice	Compagnia Generale Ripreseaeree S.p.A. (CGR)	3D data provider	
Bratislava	Comenius University	Planning	Tourism, media
Maribor	CityGRID	Planning	
Gothenburg	Department of Architecture at Chalmers University	Planning	Visualisation
Geneva	COWI	Planning, GIS	GIS

There are examples of cities that claim more than one model. London, for example, has at least four virtual cities of varying sizes, coverage and LOD. Two of these serve the architectural and planning consultancies with 3D geometry (ZMapping, Cybercity). A third (GMJ) was established to capture laser scanned (LOD4) 3D data that the practice would also own outright. This subsequently developed into a research project to develop an automated modelling process from point cloud data. In contrast to this,the Berlin 3D city model has received much collaboration from its built environment community to create a virtual city 'master model' that includes 3D geometry and GI data from a range of sources. Moreover, clusters of detailed city models are evident in some countries for two apparent reasons. Firstly, they follow clusters of established 3D GI data providers that offer city modelling services for large parts of their country (e.g. GTA Geoinformatik GmbH in Germany, ZMapping in the UK and Vectuel in France). Secondly, recent EU legislation has encouraged their use, such as the Environmental Noise Directive (2002). Many cities in Germany have been modelled, partly for this reason, but also due to Germany's approach to the city modelling technology and an established GIS underpinning that have been driven by research and academia in the country.

From the sample list, no current virtual city models were found that existed before 2001, despite evidence in the literature review of their use in urban planning for almost 20 years. This explains a lifespan of less than a decade for many virtual city projects. The sample data collected ranged from 4 to 2,500 km^2 in representative model size, boasting anywhere between 185 and 300,000 buildings. Generally speaking, more extensive virtual cities also showed a lower level-of-detail. However, many models created in the last three years have used automatic or semi-automatic modelling processes from oblique imagery, display facade textures. However, this does not affect their level-of-detail according to CityGML standards, as their positional accuracy and architectural detail remain fairly simplistic. Generally speaking, the audit sample displays an increased LOD than examples of virtual cities from a decade ago (e.g. Bath, Edinburgh) where simple urban block models (LOD1) were used. The most common applications were tabulated and analysed with respect to their minimum useful LOD according to the auditees (Table 3, below).

Table 3: Urban Planning related applications and minimum LOD

Type	**Application**	**Min detail (LOD)**
Urban Planning	Master planning/ plan making	1
	Visualisations	3
	Visual Impact Assessments	1
	Pre-planning design	1
	Lighting simulations	2
	Traffic modelling and simulations	1
	Project management	1
	Disaster management	2
Environment	Flood management/ catchment hydrology	1
	Air pollution modelling	1
	Noise mapping	2
	Light studies	2
	Wetland and wildlife management	1
	Forest management	0
	Volumetric calculations	3
Tourism and	Video gaming	3

CityGML Guidelines	
	**LOD0:** regional, landscape
	**LOD1:** City, region
	**LOD2:** City districts

Media	Virtual tourism	2
	Vehicle navigation systems (Sat nav)	1
Science	Historical analysis	2
	Geology	0
	Education	1
Military	Urban response planning	2
	Disaster management	1
	Training and simulation	1
	Intelligence	4
Other	Healthcare	1
	Utilities	2
	Education	1
	Telecommunications	2
	Insurance	2
	Facilities management	4

	**LOD3:** Architectural models (exterior), landmarks
	**LOD4:** Architectural models (interior features)

The more modern examples of virtual city projects analysed for this study display a more unified set of data. CityGML standards are evident or were at least considered by many of the hosts and interoperability issues have been addressed that hindered earlier virtual cities. The results also highlight an increasing list of established hosts and data providers who specialise in virtual city modelling. There is also evidence that modern city modelling has reacted to the rapid development of virtual globes, as almost half of the auditees mentioned that their data was also available on Google Earth (or it was at least a future consideration). However, these were used for secondary applications, such as virtual tourism rather than more detailed planning related activities. Many projects exist beyond their original planning function by their extension into other applications, typically virtual tourism.

There was limited evidence to suggest that (3D) data update and enhancement has been tackled, so this will be an important part of the on-going research. As mentioned earlier in the chapter, technological approaches are still an expensive option and not feasible for most applications. The cost of data acquisition and large scale modelling is gradually decreasing so that often the simpler and cheaper option is to re-commission and purchase a more up-to-date model.

This process identified current virtual city projects in Europe that are used for urban planning functions. Clusters of detailed city models are evident in some countries for two main reasons. Firstly, established GI data providers that boast 3D modelling services can offer city model data for large parts of their resident country (e.g. GTA Geoinformatik GmbH in Germany, ZMapping in the UK and Vectuel in France). Secondly, recent EU legislation has encouraged their use, such as the Environmental Noise Directive (2002). Many cities in Germany have been modelled, partly for this reason, but also due to

Germany's approach to the city modelling technology and an established GIS underpinning that have been driven by research and academia in the country. Furthermore, some European countries carry out strategies that enable their cities to be modelled virtually and in 3D. For example, Sweden's national cadastral and mapping agency, Lantmäteriet, collects and publishes 3D data that is freely available for its citizens (Hallebro, 2006). However, despite this compelling 3D GIS benefit, there are few examples of more detailed city models evident from the literature investigation. Denmark-based Blom ASA began an initiative to model every building in the country (2.2 million buildings approximately), which has been achieved following developments in automated city modelling technologies and suitable data acquisition.

The audit highlighted an extensive list of established city modellers and data providers who specialise in city modelling. Dokonal (2008) explains that early attempts at modelling cities were expensive and time consuming tasks were carried out by a handful of academics with limited results, whereas the audit reveals an increasing number of specialist city modellers or 3D data providers who are delivering cost effective products by outsourcing their modelling.

The lack of virtual city projects from before 2001 indicates theabsenceof model update procedures by many hosts, although this investigation does not explain whether or not this is the cause or effect of their decline. On average, the period between data acquisition and its completed modelling process using photogrammetric techniques are 2 years apart. This is due to a number of factors, primarily being the practicalities and costs of capturing aerial photography. Although the modelling time is far greater to reflect the higher LOD, terrestrial laser scanning has a shorter development time for creating the models (typically 2–6 months) for the audit sample. This also reflects the in-house process of 3D data collection and modelling compared to an outsourcing approach that is favoured by many current hosts. This lengthy stage between data capture and final model for many of the city models can be extremely problematic, as a model can effectively be a number of years out-of-date 'straight out of the box' and their reliability for certain activities is immediately questionable.

The sample data collected ranged from 4 to 2,500 km^2 in representative model size and containing between 185 and 400,000 buildings. Of the cities of greatest coverage, these generally represent a lower LOD, although there appears to be no other relationship between the size of city models and their LOD in less extensive models. An increasing amount of models, particularly since 2006, have been created using automatic or semi-automatic modelling processes from oblique imagery and are fully textured. However, this does not affect their LOD according to CityGML standards, as their positional accuracy and architectural detail remain fairly simplistic. This follows a homogenised approach in the GI industry to capture a range of information during the same flight so that both imagery and LiDAR data, for instance, are captured at the same time (Ordnance Survey, 2006). Generally speaking, the audit sample displays an increased LOD compared to a decade ago as revealed in the literature investigation, when simple urban block models (LOD1) were used widely to visualise the landscape. Roof-scape and façade details are evident in most cases, as well as photorealistic textures and building details (LOD3, providing suitable positional and height accuracy), mostly due to technological advances in data storage and capture techniques.

The latest set of city models around Europe highlight a shift in trends towards more unified, interoperable data. CityGML standards are evident in many of the data and previous interoperability issues have been addressed in many cases. Older examples of city models for urban planning functions were often setup using experimental techniques of data capture and modelling processes, with piecemeal results. Although some of these early models generally showed high levels of accuracy, they were usually of such a low level of detail to create any lasting practical application for urban planning.

2.18 DISCUSSION

The use of computers in large organisations has evolved from sizeable central mainframes to desktop/ personal computers, distributed data processing and the 'networking of networks' (Burg and Di Iorio, 1989). More recently, the emergence of the network-based computers means that data and software can be stored on server computers and accessed over the internet (or an organisation's own intranet) as needed. Although this will dramatically reduce the investments in the purchasing and maintenance of PCs, it introduces other concerns such as data security.

Emerging technologies in the fields of visualisation and web-based GIS applications are beginning to converge due to their cross-compatibility and advances in Web 2.0. There are some recent examples where applications such as Google Earth have been used for urban planning activities and the two disciplines are becoming increasingly connected in terms of ICT.Although advances have been made in many areas to improve standardisation of 3D geometry, many of the integration problems occur well before the modelling stages, in the data capture. For example, multiple datasets that have been derived from aerial photography do not always align, particularly when combining 2D and 3D information.

Lange (2005) explains that computer-based visual simulations can potentially function as the link between the classic top-down approach in planning, i.e. experts providing information to the general public, and the bottom-up approach, i.e. the general public being consulted and participating in decision-making. However, a major problem that faces the hosting and management of virtual city projects is the issue of merging those involved in the participation, planning and the development processes together within a common framework of understanding (Brown *et al.*, 2005). Much research has been carried out to explore the barriers and perceived barriers to adopting VR in various stages of the planning process (Hudson-Smith, 2005, Fu *et al.*, 2005, Bourdakis, 2004, Firmino *et al.*, 2006, Appleton and Lovett, 2005), which reveal that cost and time for training are major opposing factors to its use (Mantle *et al.*, 2007). Wang *et al.* (2007) suggest that the insufficient integration and interoperability between software applications have caused considerable barriers to communication between the stakeholders.

Various 3D data suppliers exist who can provide stand-alone, off-the-shelf 3D city models. Evidence from the literature review suggests that these stand-alone models often lack geographic extent or context and are not maintained (Capstick and Heathcote, 2006), yet their use is increasing throughout Europe. Updating their data often relies on a complete re-modelling process, rather than modification, which can be extremely problematic if the virtual city data has since become interlaced with other data or models.

Virtual cities have emerged in two disparate strands of software specialism – CAD and GIS. More recently, virtual cities are starting to display common features of both disciplines, hinting that database technology, compatibility issues, 3D modelling and data capture have matured as more productive resources. Despite the technological advances, evidence shows that there are still certain technical barriers to inclusion of various stakeholders in the planning process. Furthermore, evidence suggests that current methods for communicating development proposals are not only difficult to understand but lack appropriate opportunities for participation (Mantle *et al.*, 2007). The problem exists when bringing together those who are involved in the various planning, participation and development processes within a common framework of understanding (Brown *et al.*, 2005). These can be both technological and organisational barriers that may be overcome by a thoroughly designed business model, implementation and application. Much research has been carried out to explore the barriers or perceived barriers to adopting VR in various stages of the planning process (Hudson-Smith, 2005, Fu *et al.*, 2005, Bourdakis, 2004, Firmino *et al.*, 2006, Appleton and Lovett, 2005). It has been recognised that the majority of GI users are not always sure what they require from 3D building data (Sargent *et al.*, 2007) and can be misled by high expectations from VR and video games.

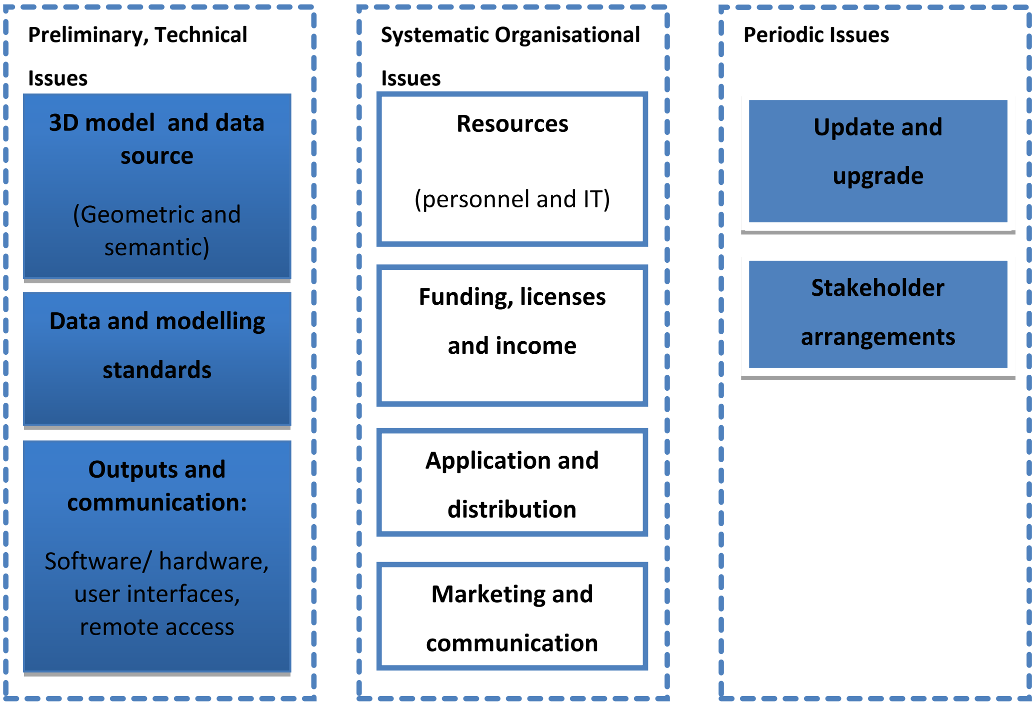


Figure 30: Key considerations for virtual city modelling revealed in the literature investigation stage

Hall (1996) categorises four relevant parties in the urban planning process: city planners, architects working for clients, the clients and the general public, all of whom are seen as legitimate stakeholders. The communication environment itself is also an important forum, as research shows that many VR environments or 'Decision Theatres' do not boast many returning visitors, once an initial project has been completed (Kobayashi, 2006). This is not necessarily due to the shortcomings in these facilities, but the relative power of modern desktop PCs and the breadth of freely available software and interconnected information. Originally, it was reported that architects and academia that have been the driving factor for the creation of city models for spatial analysis, but this has shifted towards a variety of users from surveying, programming and GIS. The growth of virtual globes and advanced mapping technologies has created a broad user base in geospatial information that has in turn assisted the development of data capture techniques, 3D modelling and in particular automatic modelling processes.

Progress has occurred over the course of the research in the standardisation of city model data, such as the official ISO recognition of the CityGML and KML data standards. Latest developments of Industry Foundation Classes (IFC) and Building Information Modelling (BIM) are reported to have much application in data-rich city models, despite the lack of high-level commitment by key players in construction or software industries that have hindered the standardisation efforts in the Architecture, Engineering and Construction (AEC) industry (Behrman, 2002). It has also been reported that the eventual uptake of BIM in practice will present information-rich, accurate geometric models that can be integrated into large 3D virtual city models when the technology is suitably developed to support it. Although CityGML does outline some thematic methods of representing digital building models, established recommendations are necessary to enhance this structure for methods of depicting the content and quality (accuracy) of a building proposal (Bourdakis, 2004).

Le Heron (1999) highlights the importance of the careful hosting of a city model for specialist applications, which is necessary to ensure secure information and protect appropriate individuals' rights, as well as the need to control the information so that it does not become a commercial and/ or marketing tool. Legal issues concerning 3D city models can be linked to the data acquisition and distribution, which can be restrictive of the communication, sharing, ownership and various stipulations to its use, as the necessary IPR security or privacy laws may be applicable. It has been noted that the lack of proper copyright protection or digital signature stamping in 3D geometry, coupled with the relative ease at which file can be transferred across the internet is hindering the development and availability of urban models (Bourdakis, 2001).

Dollner and Buchholz (2005) explain that virtual 3D city models serve to present, explore, analyse and manage geo-referenced data yet evidence from the literature investigation shows that this is a difficult accomplishment which often fails to deliver. High expectations and lack of understanding of the processes involved were some of the reasons revealed by the investigation. Evidently, many VR technologies and subsequently, city models, have been instigated on an exploratory basis, responding to advances in IT and technology. These have created a ‘technology push’, rather than responding to the needs or shortcomings of the planning process (decision support). Thus, technological developments in this area have been ignorant of how practitioners and planners actually work. Furthermore, there are inconsistencies in the required detail from the stakeholders in the urban planning process for their various activities. In some situations, it is thought that detailed and accurate models are needed, whereas other practitioners explain that simple block models suffice. The issues typify early adopters of city models and their purpose: 3D models have been used primarily to assist in visual spatial planning tasks. Physical models only have this capacity, but with the new global visualisation engines and GIS, there is an assumption and expectation that they should also assist in other decision-making roles.The audit exposed a level of clarity that was otherwise contradictory in the literature investigation. The levels-of-detail that were required from the city models by their users was relatively low, even though this was clearly one of the most conspicuous features of a city model. Whereas academic literature cited many references to highly detailed models as being one of the most useful factors for city model analysis, in practice models that are used for various urban planning activities display relatively low LOD and this trend has continued for over a decade.Bourdakis (1997) explains that the role of VR is not to imitate reality but to aid in communicating ideas, designs, teaching, etc. whereby multiple levels of resolution is vital. Similarly, the content of a city model should be balanced, whereby ‘abstraction’ is often more applicable or useful than ‘photorealism’, as a simple model can be enhanced with other forms of information. However, there is also a requirement for 3D data to be accurate and credible if it is to be used as a decision-making tool for the planning process. If data accuracy could be preserved on freely available web-based applications they afford a way for the communication of 3D models remotely.

The concepts for 3D change detection and automatic updates of city models have evolved over the course of the research, whereby ambitions are leading improved automation in the field. Some level of manual intervention is needed in almost all of the processes, such as refining automatically generated 3D models. City model data update, as with almost all forms of geospatial data, can be carried out by either re-audit or revision, depending on the extent of work to be done (Song and Deren, 2003). Although current research (Holland and Tompkinson, 2003, Song and Deren, 2003) suggests the update of city models is converging on complete automation, the cost and prolonged time-scale of this approach is still high and spatial data must be periodically re-acquired by remote sensing (aerial photography in most cases).

The literature investigation and audit revealed a great number of technical solutions and their related organisational issues, but there was no clear indication of a pattern in their management methods. Despite the focus on virtual cities that are used for planning related applications, their users, stakeholders and hosts can have broad circumstances and requirements. Hence, the organisation of their processes will not only require a focused investigation in their use from key practitioners, but an analysis of common methods or business models that have been used in similar enterprises.

CHAPTER 3: LITERATURE REVIEW II – BUSINESS MODELS

3.1 INTRODUCTION

After establishing the background and environment in which virtual city models may be created and used, this chapter aims to investigate the ways in which they can be organised and supported by appropriate business models. Fundamentally, this review investigates an area often avoided in previous city model projects, yet which should be considered a key component of any organisational framework designed to sustain a city model. Hence, the objective of this chapter is to explore the ways that business processes may be structured and what tools are available to help develop these structures that will ultimately assist in the decision-making activities that are encountered. The chapter begins with an overview of the ISO methods that have been adopted throughout the world, followed by an analysis of appropriate business models.

Particular focus is placed on (business) models, policy or strategies that are appropriate for small businesses, as well as those that are suited to small-scale IT-based activities that involve high levels of technical ability, data management and complex stakeholder arrangements. Models are examined that are suitable for both public bodies and private organisations. An overview is provided of the components, or models that could be employed to support an organisational framework.

There is an extensive amount of literature on business theory and business modelling (Kijl and Boersma, 2010, p1). This covers business strategy, business policy, business modelling, business process and many other connotations that explain the methods of running an organisation according to a set of goals, for the purpose of increasing a profit, improving a process, quality or customer satisfaction. Business modelling has been described as the managerial equivalent of a scientific method, with the formulation of a hypothesis that is tested in action and revised when necessary (Margretta, 2002, pp5-6). An organisational framework describes an over-arching structure, or a set of heuristics that is used to gain an understanding of, or guidance on a particular matter; a general methodology for defining a business process. Business models are usually specific to their field or area of business, so their creation usually requires much customisation. Although the most important characteristic is that it provides a holistic view of the enterprise, a balance should be sought between a technical infrastructure and agile business processes (Lankhorst, 2009). Organisations and their managers developbusiness models in which people and business partners can work efficiently and effectively, both individually and collectively, and succeed for mutual benefit.

Business processes involve a reflective analysis that requires continuous validation and modification. Among many other concerns, the process needs the observation of the product (or service) quality, personnel, technology, market analysis, etc. Hence, a variety of models may be employed in an organisational framework as each virtual city host will have unique circumstances, yet based on similar defining features. City modellers, for instance will have a different 'value discipline' (see below) than a city council who host a virtual city model.

3.2 International Standardisation

One of the most recognised standards is the ISO 9000 family that concerns quality management of an organisation. Fundamentally, it aims to guide a business towards achieving customer satisfaction by fulfilling their requirements and carrying out continuous performance improvements. ISO 9001:2008 sets out a set of standardised requirements for a quality management system that can be applied to almost any organisation (ISO, 2011).

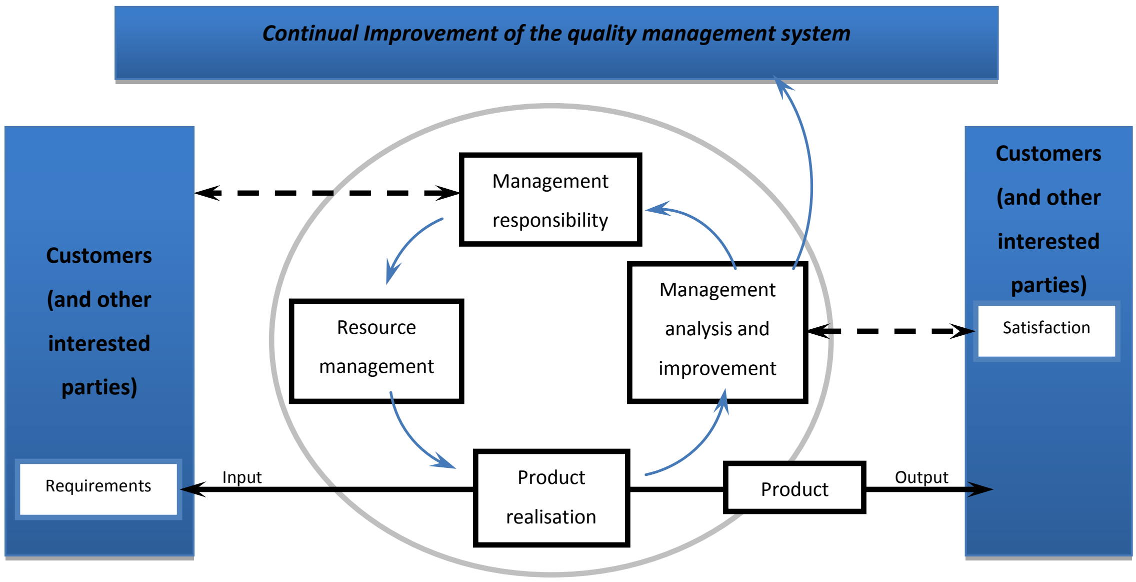


Figure 31: An overview of the ISO 9000 process (ISO, 2011).

The standard demonstrates a customer focus but this can be extended toward general users or clients of a service or product. At the end of 2009 there were 1,064,784 certified companies globally (ISO, 2009). However, a number of studies have debated the actual impact of introducing ISO 9000 has on company performance (Terziovski *et al.*, 1999; Naveh and Marcus, 2005; Benner and Veloso, 2008, in Martinez-Costa, 2009).

3.3 Business Models

Business management models have been designed to create order in certain business processes, analyse strategies and improve performance, described as an organisation's core logic for creating value (Linder and Cantrell, 2000, cited in Fuller *et al.*, 2010, pp96-97). They attempt to establish a sense of order to reduce the complexities and uncertainties involved in organisational problems. (ten Have, ten Have and Stevens, 2003). The generic notion of a business model "implies a number of anticipations", hence it refers to a replicable process, at its core, that produces revenues and profits (Fuller *et al.*, 2010, pp96-97).

There are no definitive models for any one organisation, although some prove to be more popular or effective than others according to the area of business. For the purposes of any organisational framework, these are integral to their design and essential to every successful organisation (Magretta, 2002). The author elaborates that one of the critical issues that organisational models do not comprise is competition, which is tackled by a proper business strategy.

What follows is an overview of some of the many management models that exist, with a particular focus on those that are more appropriate to small, technology-based services. Hence, many models will be analysed for their relevance towards anorganisational framework for city modelling, but it is expected that only a minority of the models will be adopted or used to make up the sum of its parts. Many of these models are referred to as frameworks by their theorists, such as the Five Forces model (Porter, 2008), Capability Maturity Model (Paulk *et al.*, 1994) and Core Competencies, which all give rise to more strategic frameworks. They are embodied or represented by relatively simple models that indicate a more extensive explanation, often with a variety of interpretation. Table 4, on page 94, highlights 50 models that are described in depth by ten Have, ten Have and Stevens (2003), which were chosen based on the results of an interview process. This list was then analysed for their suitability to the area of city modelling. The refined list of business models that follows has been chosen for their adaptability or relevance to the type of organisations that host city models. Others have been included due to their extensive use or notoriety in business literature so that key principles could be extracted. Although this is a broad subject, some models are designed solely for their application in complex supply chains, global product markets, financial markets and stocks, risk management, etc. Therefore, many of these limited models were discounted for the purposes of this investigation. Secondly, certain models that follow a rigid workflow and do not allow for customisation could also be disregarded from the review, for the reasons mentioned above. Fuller *et al.* (2010, p96) explain this rationale when analysing models for 'creative industries':

> The generic notion of a business model is well understood by investors and business managers and implies a number of anticipations; chiefly that it is a replicable process that produces revenues and profits. At its heart is some replicable process, artefact or proposition around which the everyday practices are formed.

Hence, there are a number of reasons why this conception is weak, particularly for 'non-goal oriented' activities (Fuller *et al.*, 2010, pp96-97). The remaining models were explored in more detail to extract key principles that could make a contribution to an organisational framework.

Table 4: Key management models (ten Have, ten Have and Stevens, 2003)

Action Workflow (3.3.1)	**Hofstede's cultural dimensions**
Activity-based costing	**Just-in-time (3.3.10)**
Adizes'PAEI management roles	Kaizen
Ansoff's product/ market grid	Kay's distinctive capabilities
Balanced scorecards (3.3.2)	Kotter's eight phrases of change
The BCG matrix	**Kraljic's purchasing model (3.3.11)**
Belbin's team roles	Levers of control
Benchmarking (3.3.3)	MABA analysis
Berenschot project management model (3.3.4)	The Malcolm Balridge award
Business process redesign	Marketing mix
Capability maturity model (3.3.5)	Maslow
Change quadrants	The 7-s framework
Chaos model (3.3.6)	Mintzberg's configurations
Competing values of organisational effectiveness	Mintzberg's management roles
Competitive analysis: Porter's five forces (3.3.7)	The Neurotic organisation
Compliance typology	**Nolan's IT growth stages (3.3.12)**

Core competencies (3.3.8)	Overhead value analysis
Core quadrants	Parenting analysis
Covey's seven habits of highly effective people	**The purposive change model (3.3.14)**
Customer marketing and relationship management	**Risk reward analysis (3.3.15)**
The Deming cycle (or PDCA cycle) (3.3.13)	Scenario planning
The EQFM model	Schools of strategy synthesis
Eisenhower's effective time management	Seven forces model
EVA (economic value added)	Sociotechnical organisation
The fifth discipline	**SWOT analysis (3.3.16)**
Four competencies of the learning organisation (3.3.9)	Value-based management
Generic competitive strategies	**Value chain (3.3.18)**
The gods of management	**Value disciplines (3.3.19)**
Greiner's growth model	

The final criteria for business model selection were for those that frame an on-going enterprise, rather than a single project. There are many business models that are used to structure a single activity, such as contractor procurement (for purchasing third party data, for example). Arguably, a city model enterprise will carry out a number of project-based activities, but should rather be considered as an on-going process if it is to be sustained. An overview of the set of appropriate models follows, after which more encompassingframeworks are presented.

3.3.1 Action Workflow

A service-oriented business model describes this method for establishing a process aligned with delivering a product or service to its customer. The workflow is characterised by "the identification and construction of atomic 'loops' of action in which a performer completes an action to the satisfaction of a customer (internal or external)" (Medina-Mora *et al.*, 1992, p281). Action workflow is described as a generic methodology for the design of a workflow management system, as well as the name for a supporting software tool (Kethers and Schoop, 2000, p152), a characteristic that is evident in many of the following business models. Furthermore, it is focused on the communication that takes place within a process and was developed in response to the increasing use of IT in business processes, facilitating a way of improving the interface between the users and the technology. Or as Goldkuhl (1996) explains, human actors and their actions must also be considered when designing information systems, rather than focusing solely on the data objects and data flows.

3.3.2 Balanced Scorecards (BSC)

This performance management tool is used to monitor the execution of activities or the performance of an organisation and adjust business strategy accordingly. Modern variations of balanced scorecards use top-level objectives as a benchmark by which secondary objectives can be measured cumulatively towards this goal. Strategy maps are used to visualise the relationship between these objectives. In other words, the design of a BSC begins with the identification of the financial, as well as non-financial measures. Targets are then given to each of these measures so that they can be reviewed and determined whether or not current performance meets expectations. Although BSC frameworks come in many different forms, Kaplan and Norton (1992) suggest that they should be organised around a company's vision into implementation from four perspectives:

1. Financial perspective
2. Customer perspective
3. Business process (organisational) perspective
4. Learning and growth (Internal) perspective

Balanced scorecards have been widely adopted by a range of users from corporate units, education, government and even the military (Kurtzman, 1997). As with many management methods, it is widely believed that a great deal of the benefit of the balanced scorecard comes from the design process itself.

3.3.3 Benchmarking

The comparison of a business process is used in many models, but benchmarking differs as it compares performance (typically quality, time and cost) with other industries (Camp, 1995). There are many areas of a business that can be measured in this way, such as its processes, financial, performance or even energy consumption. Moriarty and Smallman (2009, p484) explain that "the locus of benchmarking lies between the current and desirable states of affairs and contributes to the transformation process that realise these improvements". Consequently, 'best practice' companies must be identified or surveys of similar organisations carried out for a proper comparison. Benchmarking networks exist in many forms around the world, highlighting the extent of their use in business practice.

However, Huggins (2010, pp640-655) suggests that although benchmarking exercises inform policy adaptation and innovation, they can be constrained by political and financial factors. Regional benchmarking involves the comparison within a specific region, with the intent on improving regional development or focus.

3.3.4 The Berenschot Project Management Model

The four key components of Berenschot's model consist of:

1. The **lifecycle**
2. The **project hierarchy**, whereby sub-projects are identified to correctly prioritise tasks.
3. **Project fundamentals** that establish the objectives or key questions on the purpose of a project.
4. The management cycle describes a continuous process of re-examination after carrying out the various tasks (see also The PDCA Cycle, below).

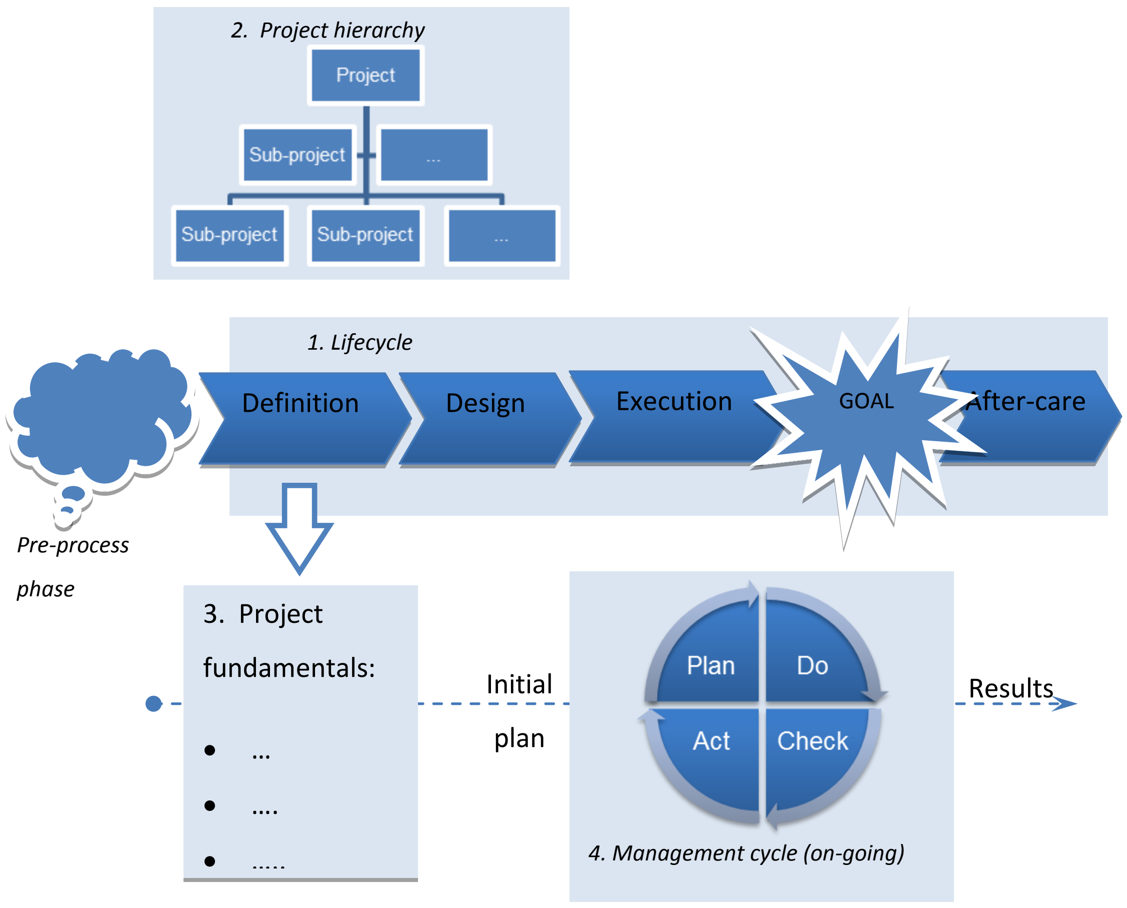


Figure 32: The Berenschot model and the four key areas (ten Have, ten Have and Stevens, 2003)

It has also been noted that the stakeholders should be considered during the process, how they can affect the project and what they will gain from its outcome (van Assen, van den Berg and Pietersma, 2008). Evidently, this model connects a number of disparate business models for the purposes of creating a more extensive framework.

3.3.5 The Capability Maturity Model

The Capability Maturity Model (CMM) describes the key elements of an effective software development process from an ad hoc, immature process to a more disciplined structure (Paulk *et al.*, 1994). Its design reflects that of a similar maturity model outlined in five stages:

1. Initial: ad hoc or chaotic management, the starting point for the process.
2. Repeatable: established project management tools are introduced to track cost, schedule and functionality (Paulk *et al.*, 1993).
3. Defined: organised or defined processes.
4. Managed: processes measured quantitatively and controlled.
5. Optimised: Continuous improvement through process feedback.

Within each of the maturity levels there are key process areas that further contain the goals, commitment, ability, measurement and verification process for that particular level. This rigorous, structured strategy has been applied to other disciplines, such as project management, planning, construction, engineering and e-business, despite its origin in software development (Perera *et al.*, 2006).

3.3.6 The Chaos Model

The locus for the chaos model is within the fluctuating conditions of the progress of an organisation. The model leads to self-organisation and structure if it is properly controlled, by allowing an evolution of a business' organisation and regressing back to a chaotic, self-organising process when necessary. This model is particularly applicable as it does not try to make explicit use of (business management) theory in the face of anticipated obstruction. Hence, it is useful for dealing with technology industries and areas with high risk of shifting legislation. Understandably, this model is often used or implied in many business processes and often suffers from incomplete use, where the model is used as a metaphor to refer to a more unintentional resultant process (Raccoon, 1995).

3.3.7 Competitive Analysis: Porter's Five Forces

Although the core of this model looks at competition from external threats, it encourages its users to look beyond such competition and the threat of substitute products or services that can lure away customers.

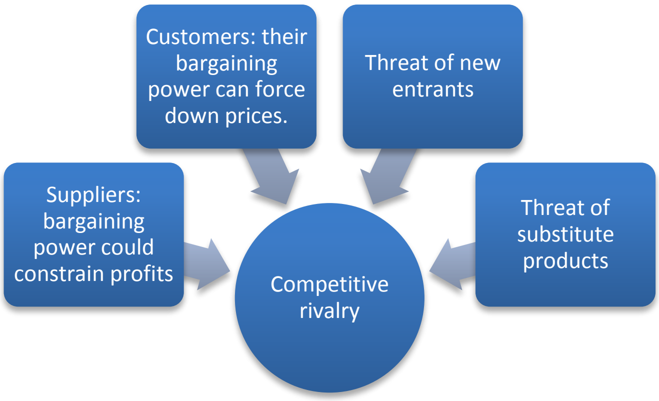


Figure 33: Five force analyses focused on competitive rivalry in industry (Porter, 2008)

By analysing each of these five forces, Porter (2008) explains that an organisation will gain a complete picture of what is influencing profitability, anticipate new trends for exploitation and work around any constraints. This process is described as 'reshaping the forces' to an organisation's best advantage. Porter's models have been used extensively by both managers and academics, but it is suggested that they only tackle the 'what' of strategy, or the strategy content and ignore the questions of 'how', 'who' and 'when' that relate to the strategy process (Mann *et al.*, 2009, p2).

3.3.8 Core Competencies

A basic ontology that can often be overlooked, core competencies are specific factors that a business or organisation identifies as being central to its performance. In mapping an organisation, its managers must not see it as a collection of strategic business units, but as a portfolio of core competencies (Prahalad and Hamel, 1990). These are found by asking important questions about the function, customer and future direction of the business. Having established these core competencies, a strategic architecture can be written up, which outlines a framework for the future of the company.

3.3.9 Four Competencies of the Learning Organisation

Sprenger and ten Have (1996, cited in ten Have, ten Have and Stevens, 2003) suggest that successful knowledge management requires four learning competencies to manage the knowledge flow in an organisation.

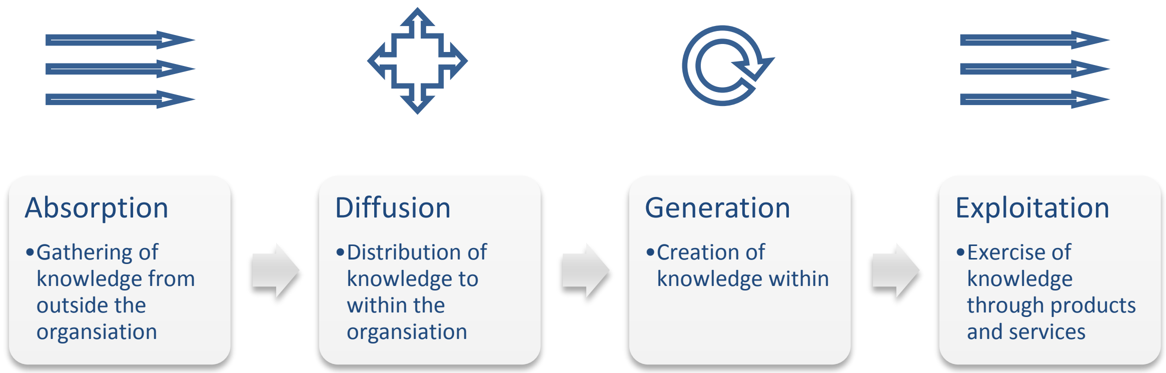


Figure 34: The four competencies

It is deemed particularly useful when overcoming poor performance, such as problem-solving or budget overruns. The 'knowledge' that is referred to in the model can represent both expertise (social knowledge) and systems knowledge (data) (Sprenger and ten Have, 1996).

3.3.10 Just-in-Time (JIT)

This highly recognised model is most commonly associated with mass production vehicle manufacturing lines where it originates. Since its inception in the 1970s, its general method has been adapted to improve upon a breadth of industries. JIT is used for minimising inventories, minimising waste and reducing complexity. Quality control is also a key part of the process. Customer-managed inventories are evident in many IT related services, such as 3D modelling. They also reveal some degree of a lean manufacturing strategy, which is a derivative of JIT and also consist of tools that assist in the elimination of waste (time as well as resources).

3.3.11 Kraljic's Purchasing Model

Evaluating risk and cost is the purpose of Kraljic's model, outlining a systematic approach to decision-making in purchasing and supply management. The model follows analyses of profit impact against supply risk, with regard to four key factors: leverage, strategic, non-critical and bottleneck items. Kraljic argued that the purchasing function should transcend the 'back office' to take the strategic role for improved purchasing management (Mitchell, 2008). More recent studies have expanded on the model to reveal how purchasing portfolio analyses are carried out in business practice (Geldermanan Van Weele, 2003).

3.3.12 Nolan's IT Growth Stages

"Nolan's model reflects one of the major problems associated with the development and deployment of IT in an organisation: varying expectations, different levels of maturity and lack of coordination between users and providers of IT (ten Have, ten Have and Stevens, 2003, p158)." Although it has been suggested this out-dated model is overly complex (Gottschalk, 2002) and difficult to implement (ten Have, ten Have and Stevens, 2003) its usefulness was publicised for its practical, evolutionary introduction of IT into an organisation, consisting of the following steps:

1. Initiation
2. Contagion
3. Control
4. Integration
5. Data administration
6. Maturity and de-concentration

Adopters of Nolan's model must first identify which stage they currently reside in so that the appropriate measures can be introduced. In this way, this theoretical model is more of a reflective information resource than a strategy, but many organisations recognise its continued validity.

3.3.13 The PDCA Cycle

Also referred to as the Deming cycle or PDSA cycle, this consists of the logical sequence of plan, do, check (or study) and act.

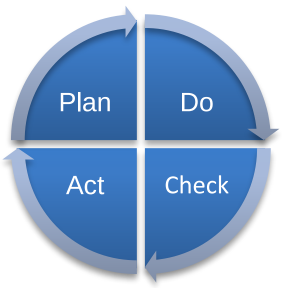


Figure 35: PDCA cycle (Walton and Deming, 1986)

The cycle aims to properly manage improvement initiatives (Walton and Deming, 1986), similar to Kaizen thinking. Each stage requires some planning and reflection when applying the model to a specific activity, ensuring that the predefined key questions are answered during the process. Hence, PDCA cycles are tools for quality control or TQM (Total Quality management) that shows evidence of a simple, scientific process.

3.3.14 The Purposive Change Model

The active discipline of changing the direction of an organisation, rather than allowing passive change lies at the core or the purposive change model. This type of activity has also fittingly been compared to business policy and strategic management. Bower (2000) explains that purposive behaviour in a complex organisation can have intellectual, economic, organisational and emotional components. Ten Have, ten Have and Stevens (2001) tells us that the Purposive Change Model introduces the key concept of 'integrated congruency', whereby all of the issues, components and disciplines within a business are organised in harmony, working towards the same goals.

3.3.15 Risk Reward Analysis

Put simply, risk reward analysis is to compare the expected returns of an investment to the amount of risk that is undertaken to gather the returns. This analysis can take the form of a descriptive matrix or a more precise ratio. Such a scalable model that can be substantiated mathematically has understandably shown much approval in investment banking, trading and other finance related practices. The model is also referred to as the risk-return spectrum, as there are a variety of classes within an overall spectrum that describes the level of risk compared with the reward.

3.3.16 SWOT Analysis

Dyson (2002) describes the SWOT analysis as an established method for assisting the formulation of strategy, by identifying the relative strengths and weaknesses of an organisation and the opportunities and threats in its environment. Hence, a SWOT analysis has been described as a deceptively simple tool (Weihrich, 1982) for an extremely complex process. Similarly, a TOWS matrix is used to visualise comparative strategies with respective to internal and external factors.

Table 5: The TOWS matrix

	Strengths	**W**eaknesses
Opportunities	SO strategies	WO
Threats	ST	WT

Various strategies can be tested using a SWOT analysis, with a further scoring system to organise these for added precision. Organisations that focus on particular areas within the matrix can be duly defined, charged with offensive or defensive strategies, for example.

3.3.17 VALUE DISCIPLINES

Teacy and Wiersema (1996) argue that there are three fundamental strategies or value disciplines that describe an organisation:

1. Operational excellence: the pursuit of the best cost position. They offer relatively high quality at relatively low price, following the market's direction with a streamlined, efficient business process (ten Have, ten Have and Stevens, 2003).
2. Product leadership: defined by innovation, invention and market leadership. This is a high risk strategy with often unknown markets, whose operations focus on research and development, design and market exploitation.
3. Customer intimacy: a strategy focused on customer satisfaction.

The theory of value disciplines states that a company can only successfully exist if it identifies which discipline it lies in and adjusts its strategy accordingly. Although hybrid models of combinations of the above disciplines have been used, this is not recommended as it can give rise to confusion and conflict within an organisation.

3.3.18 VALUE CHAIN

A value chain represents a business as a linked set of value-adding activities (Caisse, 2002) and is described as one of the most well-known frameworks in business literature (Porter, 1985), albeit existing in a variety of increasingly complex forms. The most common model for the value chain is organised into five primary and four secondary activities whereby advantage or disadvantage can occur.

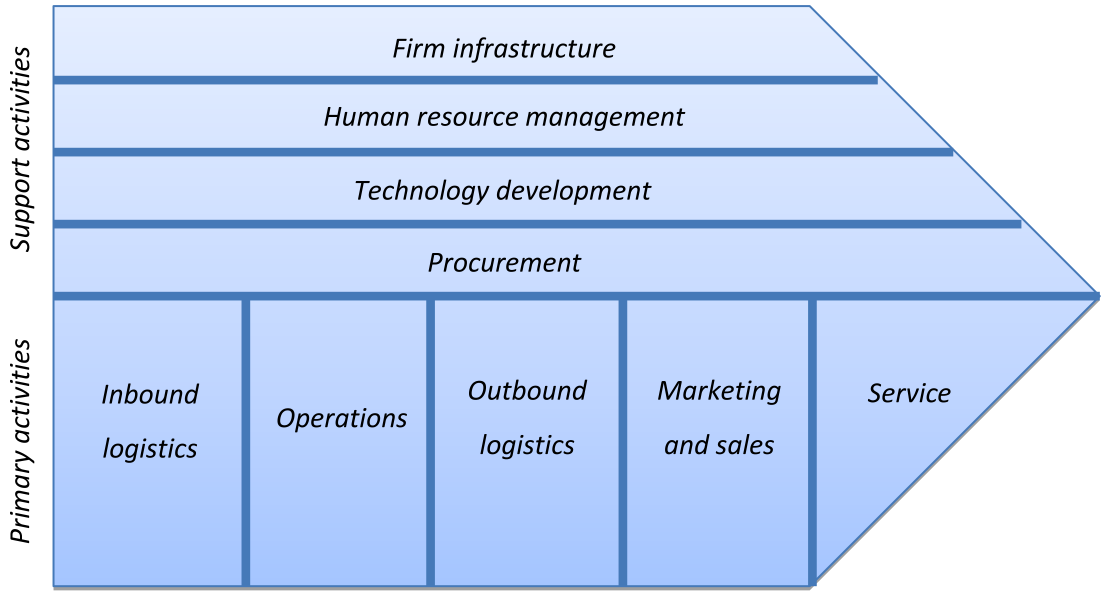


Figure 36: The Value Chain (ten Have, ten Have and Stevens, 2003)

Kaplinsky and Morris (2001) explain that the value chain describes all of the activities that are required to bring a product or service from conception to disposal. They can be complex and limitless, as supply chains can have extensive external factors that affect delivery (of any particular item in the chain). Each activity in the chain can vary in importance and aim to give any user an overview or framework of how a particular process works.

3.4 TECHNOLOGY ROADMAPPING

Described as a plan that enables the organisation of a new technology or product, a road map aligns business goals with specific technology solutions to enable the goals to be met. They represent a more complete framework than some of the models mentioned above, as they are also usually designed to assist the decision-making processes. Roadmaps can take various forms, but Phaal, Farrukh and Probert (2003) conclude that the most common approach is encapsulated as a time-based chart, made up of a number of layers that include both commercial and technological perspectives. Garcia and Bray (1997) explain that the plan should identify the critical system requirements, performance targets, technology alternatives and milestones for meeting those targets (see Figure 37 on page 105). Technology is defined in this situation as a specific and applied type of knowledge, often relating to (although not implicitly) a physical object or product (Phaal, Farrukh and Probert, 2003). Phaal and Muller (2009) emphasise that the development of good roadmaps require the involvement of key stakeholders and groups representing different perspectives and from a range and diversity of input, in terms of disciplines, functions, levels within the organisation, including external perspectives where feasible. The identification of appropriate participants is an important step in the planning phase. As is the case with other business models, it is claimed that the process of developing a roadmap is more valuable than the roadmap itself, due to this associated communication and consensus generated between stakeholders and their functions (Phaal and Muller (2009).

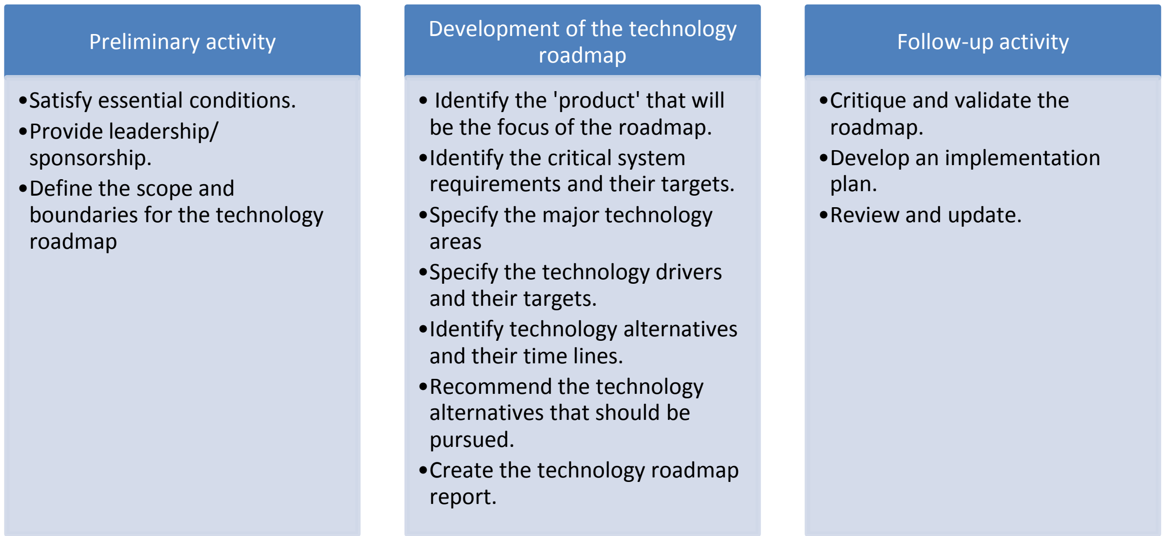


Figure 37: Technology roadmapping (Garcia and Bray, 1997, p7)

Yasunaga, Watanabe and Korenaga (2009) studied the differences in public and private sector roadmaps, highlighting that government-based roadmaps often do not have clearly defined goals as they are not usually directly engaged in actual business or manufacturing. Instead, the authors suggest that these bodiesmay set goals by formulating a “common understanding (or common visions) through intensive discussions with business people and researchers in academia” (Yasunaga, Watanabe and Korenaga, 2009, p63). In this way, roadmaps combine descriptive goals and strategy with specific details for tackling circumstances and aiding the decision-making process.

3.5 Business Plans

The UK Government funded advice service Business Link describes a business plan as “a written document that outlines a business and its objectives, its strategies, its market and includes financial forecasts (Business Link, 2011)”. There are many purposes for this type of document, such as focusing objectives or measuring success within an existing business. However, the most common purpose of the BP is to raise finances, often by securing external funding as a BP is the minimum document required by any financial source (Kuratko and Hodgetts, 2001 cited in Mason and Stark, 2004, p227). Hence, a BP can be drawn up at any stage of a business' lifespan. Ultimately, a business plan explains a strategy – just one of the components of a framework.

(Generic)

- **Executive Summary**
- **Introduction and Background**
- **Content- Management**
- **Content- Market**
- **Content- Product/ Service**
- **Content- Business Operations**
- **Financial Projections**
- **Appendices**

eg. HSBC UK Business Plan (2010)

- Executive Summary
- Overview
  - Introduction
  - Current position
  - Competitve advantage
  - Growth plan
- Strategy
  - Tactics
  - Strategic issues
  - Core values
- Marketing
  - SWOT and critical success factors
  - Market research
  - Distribution channels
  - Strategic alliances
  - E-commerce and technology
  - Tactical promotion plan
  - Marketing budget
  - Credibility and risk reduction
- Team and management structure
  - Skills, experience, training and retention
  - Advisors
  - Management systems
- Financial budgets and forecasts
  - Profit and loss forecast
  - Cash flow forecast
  - Balance sheet forecast
  - Capital expenditure budget
  - Break-even analysis

eg. Business Link (2011)

- Executive Summary
  - Business Details
  - Key Personnel
- Vision
  - The Business idea
  - Business goals
  - What the Business does
  - What makes the Business different
  - Legal requirements
- Marketing
  - Market research
  - Profiling customers
  - Profiling competitors
  - Managing market risks
  - Pricing
  - Promotion and advertising
- Running the Business
  - Staff
  - Premises
  - Suppliers
  - Equipment
  - Managing operational risks
- Finance
  - Start-up costs
  - Profit and loss forecast
  - Sourcing finance
  - Managing financial risks
  - Cash flow forecast

Figure 38: Contents of common business plan

Barrow *et al*. (2008, p6) suggest that the most important step in launching any new venture or expanding an existing one is the construction of a BP. A business plan not only includes details about a business' introduction, outlining growth and maturity, but also its eventual decline. Although the primary objective of this research is to develop a sustainable business framework, some consideration should be given to the fact that the lifecycle of some city model projects may be intentionally limited. In this way, the business framework must anticipate on-going use of its underlying data or even the delivery of the model itself can continue to adapt under, say a dramatic advance in technology. Andrews *et al.* (2009) suggest that public organisations are increasingly required to produce business plans, yet they may be "cosmetic exercises which bear little relation to the actual way in which decisions are made" (Llewellyn and Tappin, 2003, cited in Andrews *et al.*, 2009, pp735-736). Conventional business plans are formulated around a specific product or service, which is outlined in a linear, predictable growth structure. Contrary to the importance and prevalence of business plans, Mason and Stark

(2004, p228) explain that much of the literature on writing a plan adopt a 'one size fits all' approach, whereby the plan should satisfy a range of audiences, even though they will certainly have different interests or perspectives on the business. Regardless of the complications with financers, Brinckmann, Grichnik and Kapsa (2010, p29) report that scholars suggest that written business plans are more important for an organisation's performance than the process of business planning as the "written documentation legitimises the new organisation and enables better communication between the entrepreneurs, internal and external stakeholders".

3.6 Enterprise Architecture (EA)

Jarvis (no date) explains EA as a comprehensive set of cohesive models that describe the structure and functions of an enterprise. EA is a growing area in business planning, with the formation of many international associations, academic courses, research and EA consultancies specialising in this subject. The term 'enterprise' is favoured in this topic as it can include both public and private sector organisations, smaller business units up to entire organisations and incorporating the people, information and technology within the system. In this context 'architecture' surpasses the typical meaning as a formation or coherent form, but is simply defined as the establishment of a shared vision (Perks and Beveridge, 2003, p2).

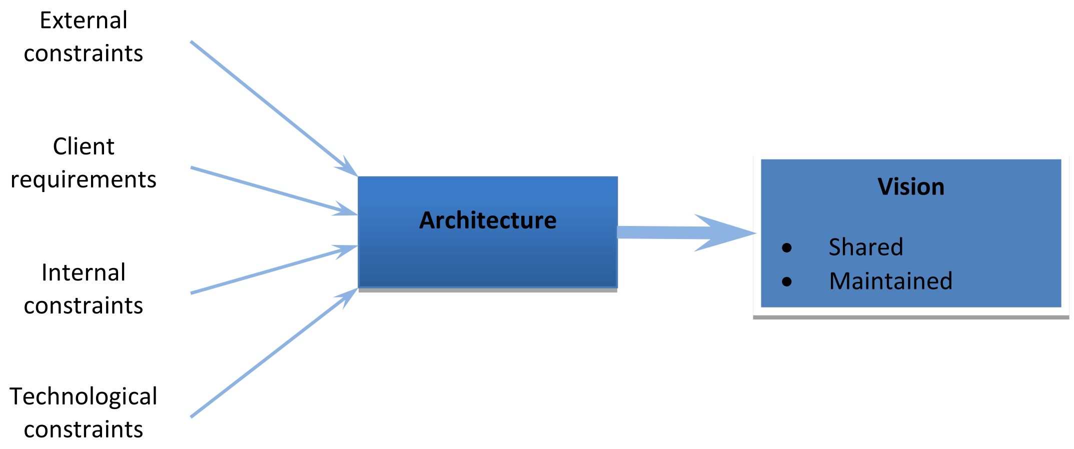


Figure 39: Influences on Enterprise Architecture (Perks and Beveridge, 2003, p2)

It is also evident that some authors describe enterprise architecture as the organisation of business processes and IT infrastructure (Ross, Weill and Robertson, 2006). Lankhorst (2009) defines enterprise architecture (EA) as a coherent set of principles, methods and models that are used in the design and realisation of an enterprise's organisational structure, business processes, information systems and infrastructure. As the core values of a business are more stable than specific solutions, a good EA helps to establish the essentials of the business, while allowing for flexibility and adaptivity (Lankhorst, 2009). Different types of stakeholders will have their own viewpoints on the architecture that rely on existing methods and techniques from disparate domains. Hence, an integrated approach is needed for the specification, analysis and communication that fulfil the needs of the various stakeholders.

Similarly, enterprise engineering describes the discipline that focuses on the design of enterprise systems, which in turn describes the information system an organisation uses (Giachetti, 2010). Such a design should incorporate the processes of the system it supports, the people who work in the system and the information content. Longépé (2003) uses a metaphor of a city to the use of IT systems, comparing the synchronisation of enterprise architecture with urbanisation:

> "The metaphor of the city, and more specifically the vocabulary, rules and principles of the urbanism of towns has been widely used in the IT systems field because of the similarity of the initial set of issues: how to overhaul, modernise and judiciously profit from technological advances without erasing the past, within the cost limits set, and do so while continuing to live in the city while the work is carried out?" (Longépé, 2003, p13)

Although it is uncommon for a commercial organisation to publish the details from their enterprise architecture descriptions, there are many examples of certain generic aspects of EA available. Due to the nature of EA and their adaptation in business organisations, high levels of customisation are needed during the process of restructuring this type of framework.

3.7 Discussion

Having analysed a range of business strategies, models and plans, an over-arching framework should comprise of no less than the following:

- goals and strategies
- policies
- organisation and culture
- relationship contracts and arrangements

- business processes
- roles
- tools
- systems
- objectives
- measures and incentives

Such a framework should create an organisational environment in which “people think and act for themselves, yet collaborate to achieve common goals and objectives” (Stratege, 2011). The methods for delivering, disseminating, communicating and presenting a business framework to its stakeholders depend on many factors. (This is not to be confused with communication strategy, which can be a part of the business framework itself).

Figure 40: Common EA domains and components (The Open Group, 2009)

EA, technology roadmapping and other business models (e.g. action workflow) are available as software from various software suppliers. Users of such software can customise these models according to their specification and produce a number of outputs, such as documents or spread sheets. The separate models in an EA are organised in a logical manner that provides an increasing level of detail about the enterprise it describes, including its objectives, goals, processes, systems and data. Evidently, various business models and methods are used to piece together an overall framework. In the context of enterprise architecture, the architects produce lists, drawings, documents and models which are referred to as artefacts. Margretta (2002) highlights the advent of the PC and the subsequent use of spread sheets as a major milestone in the use of business models, hinting at how models and their frameworks are stored and used.

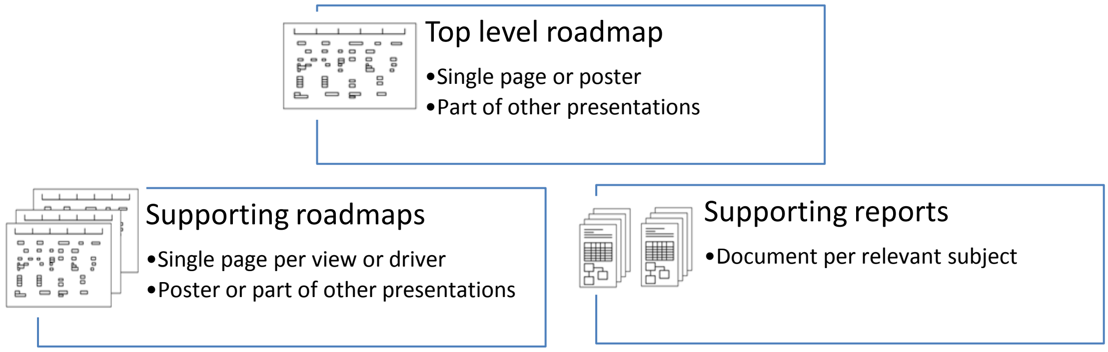


Figure 41: Increasing levels of detail of a roadmap (Muller, 2010, p2)

This type of business plan is a document that is generated by the technology roadmapping process (Bray and Garcia, 1997, pp25-28). This structure is indicative of the multi-layered approach to many types of frameworks. Shi and Manning (2009, pp54-57) propose a framework that is made up of four basic related sub-models: the exchange model, the organisational model, the resource model and the financial model. The authors explain:

> The exchange model describes the added values a firm offers to the other economic actors in a market, including customers, suppliers, and competitors. The organisational model incorporates the roles and responsibilities, the activities, and the business processes, which allow the flow of product, information, and money to actualise the exchanges between the firm and its exchange partners. The resource model encompasses the firm's variety of resources required to mobilize and energize the organisation. The financial model defines the firm's objective functions that collate the other three elements of the business model (Shi and Manning, 2009, p46).

Hence, the various models, frameworks and business plans outlined in this chapter are generally presented as anything from a single diagram to extensive sets of documents. The complexity of the business and its processes dictate how much detail is needed to be communicated, but the underlying notion is that an organisation must first base its processes on an underlying structure. Osterwalder and Pigneur (2010) refer to this structure as a business model 'canvas', which includes nine essential 'building blocks': customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partnerships and cost structure. Hence, the canvas is customised by its adopting organisation to form a business model, which is completed in more detail to form an overall plan or framework. Such an adaptable model would the most suitable for the purposes of this research, where a generic framework is required that can be modified and completed with specific detail

Enterprise architecture (EA) is defined as the establishment of a shared vision, with the overall objective as a coherent set of principles, methods and models that are used in the design and realisation of an enterprise's organisational structure, business processes, information systems and infrastructure. The term 'enterprise' is favoured in some business literature as it can include both public and private sector organisations; a range of business sizes and incorporates the people, information and technology that are contained within it. Action workflow models aim to manage the communication in an organisation, particularly for IT in business processes for facilitating a way of improving the interface between the users and the technology. Goldkuhl (1996) explains that human actors and their actions must also be considered when designing information systems, rather than focusing solely on the data objects and data flows. Nolan's model for IT growth expands on this with a model that attempts to resolve the issues of varying expectations, different levels of maturity and a lack of coordination between users and providers of IT.

Technology roadmaps emphasise that the development of effective frameworks requires the involvement of key stakeholders and groups representing different perspectives and from a range and diversity of input, in terms of disciplines, functions, levels within the organisation, including external perspectives where feasible. The identification of these appropriate participants to be involved is an important step in its development. In this way, roadmaps combine descriptive goals and strategy with specific details for tackling circumstances and aiding the decision-making process. Similarly, Berenschot's project management model introduces a method of combining many models for outlining a broader framework. The key concept of 'integrated congruency' is introduced with the Purposive Change Model, whereby all of the issues, components and disciplines within a business are organised in harmony and working towards the same goals. Such a framework should create an organisational environment in which "people think and act for themselves, yet collaborate to achieve common goals and objectives" (Stratege, 2011).

Despite the widespread recognition in commercial organisations for analysing the concepts of value, product quality and customer satisfaction for internal processes, collaborative measures across unrelated organisations are reported to be relatively rare. Benchmarking allows for comparisons to be made of these external methods, without presenting an added external threat.

As well as the identification of the correct models, the recognition of the precise goals is also an important process in business modelling. It is reported that Government or public sector enterprises often do not have clearly defined goals. Instead, the literature investigation revealed that these can be established by formulating the common visions through discussions with contemporaries, stakeholders and from academia. The theory of 'Value Disciplines' explains that a company can only successfully exist if it identifies which discipline it lies in and adjusts its strategy accordingly. The three fundamental strategies that exist concern either the operational excellence, product leadership or the customer intimacy. Hybrid models of combinations of these disciplines are not recommended as it can give rise to confusion and conflict within an organisation. This is reflected in the formation of most modern business plans, whereby key objectives must be outlined from the outset. Methods such as the value chain bring to light the methods by which these objectives are delivered, by emphasising the processes or stages that bring value it.

The investigation showed that the creation of an organisational framework is specific to its business environment and require much customisation if adapting an existing model. Lankhorst (2009) explains that although it should provide a holistic view of the enterprise, a balance should be sought between a technical infrastructure and an agile business process. However, one of the few underlying notions throughout business literature suggests that the process of creating a business model, or overall framework, is a more valuable exercise than the resulting process that it proposes. This infers that a reflective process that analyses the participant's business environment carries a great deal of importance and suggests that anorganisational framework designed as a 'one size fits all' for city model projects should be avoided. The framework should encourage its host to analyse their own circumstances and adjust the process accordingly. It should allow for flexibility, while assisting the decision-making process with evidence of established practice. The reflective analysis or process is one that requires consistent validation and modification. The investigation showed that the process needs the observation of the product (or service) quality, personnel, technology, market analysis, etc.

Hence, one of the most challenging aspects for this research investigation is that a suitably robust and flexible organisational framework should be designed that suits a variety of city model host, based on their relatively unique circumstances. These circumstances could range from hosts with free access to 3D data, complex stakeholder agreements or architectural diversity. A common feature of many of the explored business models and frameworks was a focus on customer or client satisfaction and the proposal of user-centric approaches to delivering a product or service. Therefore, further investigation was needed through the semi-structured interviews to determine whether there was, or could be, a single city model 'type', or set of types, that could be used for the most effective use of planning and other applications.

Chapter 4: Research Methodology

4.1 Introduction

The purpose of this chapter is to provide a précis of the various methodologies available for undertaking research and establish the correct methodology for the purposes of this research project. It begins with a look at the ontological and epistemological issues that are raised by the research hypothesis, project aims and objectives. This is followed by a review of the appropriate methodologies that are employed in the field of research, highlighting their relationship or suitability to the research project. Finally, a summary of the research project methodology employed will outline the mixed method approach for identifying best practice in virtual city modelling.

In order to properly design a suitable methodology for the research, it was necessary to revisit the aims, objectives and hypothesis to provide context for this stage of the investigation. The conclusions drawn from preliminary work and the literature review indicate that the research encompasses many disciplines, technologies and business principles. Hence, a variety of research methods will be considered for an overall framework. In doing so, certain research questions have been proposed in order to attain a suitable organisational framework for on-going virtual cities:

- Why do earlier examples of virtual city projects have limited lifespans?
- What are the issues involved in hosting a virtual city for the purposes of applications in planning?
- What tools can be used to improve this process?
- What are the most effective ways to manage and maintain a relevant and self-sustaining high quality virtual city?

4.1.1 Research Aim

To formulate a sustainable organisational framework that outlines best practice and recommendations for the process of 3D virtual city modelling, focusing on virtual cities that are used for urban planning related activities.

The research aim was deduced from the research questions and subsequent review of the literature. The supposition that a virtual city model project can be sustained, based on a few examples of virtual city projects from around the world, of successful projects that are continually developing or adapting their methods to meet the challenges of such a project (or enterprise) and its environment. Consequently, the methods by which a virtual city enterprise can be self-sustaining are explored during the following stages of the research. Regardless of the inevitable technological advances, this research proposes a framework for the organisational structure that supports the technology and data and is designed in such a way to ensure a virtual city's long-term use.

4.2 Research Ontology

Fundamentally, research methods are processes by which society creates and maintains meaningful knowledge (Cooper, 2004, p85). Epistemology, the philosophical theory of knowledge that underpins all research, seeks to identify and establish the limits of different kinds of knowledge (Bullock, Stallybrass and Trombley, 1988). Regardless of the arguments of what constitutes knowledge, it is noted that different views on the construction of reality (ontology) leads to different ways of establishing what it considered to be 'real' (epistemology) (Cooper , 2004, p85).

Hence, choosing a technique for collecting data and employing particular strategies for validating and communicating the findings will inevitably influence the quality of the knowledge derived from the research. Although objective, explicit assumptions can be made regarding the course of the research, Adam and Healy (2000) outline the main inquiry paradigms in Table 6.

Table 6: The basic beliefs of the main inquiry paradigms (Adam and Healey, 2000)

Question	Positivism	Interpretivist
Ontological	Naïve realism, 'real' but conceivable.	Relativism, local and specific constructed realities.
Epistemological	Dualist/ objectivist; Findings, etc.	Transactional/ subjectivist Created findings.
Methodological	Experimental/ manipulative Verification of hypotheses, chiefly quantitative methods.	Hermeneutical/ dialectical, mainly qualitative with support from quantitative methods.

Berger (1991) suggests that research methods fundamentally rely on the premise that knowledge can be systematically uncovered. Cooper (2004, p87) explains the terminology that being systematic not only refers to the organisation of individual research tasks, but more profoundly to the relations that give meaning to the smaller fragments of information that are uncovered during the course of the project. The complexity of research can be organised if patterns of reference are recognised and concepts are formulated in order to organise this knowledge (Preece, 1994). It is therefore integration, or the systematic questioning, inquiring and scrutinising of knowledge that is a key function of research, as Hart (2000) notes: “Integration is about making connections between ideas and theories and experience.” Hence, solutions can lie in a synthesis of methodologies of theories, or it might be the connections between particular knowledge and a broader framework of knowledge. Either way, the identification of the underlying, existing patterns within phenomena, or the implications of creating new patterns of data, is one of the key factors in understanding the systematic nature of knowledge (Cooper, 2004, p87).

Naoum (1998) defines research as a careful search or inquiry, the endeavour to discover new or collate old facts by scientific study of a subject, or a course of critical investigation. Hence, there are various research methodologies available to the researcher, which are categorised in a variety of ways (Yeomans, 2005). Difficulties arise in the classification of the work that is carried out, not only due to the use of ‘fuzzy’ definitions but, more importantly, because work can occur across a variety of methods (Fellows and Liu, 2005). However, Dainty (2002) explains that research methodologies can be classified by three distinct perspectives or approaches:

- *Positivist (scientific):* the research looks to discover laws and generalisations that explain reality allowing for some prediction, explaining events or phenomena through knowable facts, real causes that have a law-like regularity (Woods and Trexler, 2001) and measurement.
- *Interpretative (phenomenological):* the focus of research is based upon understanding and interpreting occurrences and social structures to provide a meaning to a phenomenon (Woods and Trexler 2001).
- *Critical:* the questioning of truths about subjectivity, experience, and the way the world is combined with recognition of the cultural, political and historical factors which shape experience.

Leming (1996) recommends that deciding on a methodology should be influenced by the nature of the research hypotheses, the body of existing knowledge, as well as the expertise in a given methodology and the resources available to the researcher. When considering the research project and initial hypotheses in relation to the above issues, the following were distinguished as key factors in taking a decision on the most appropriate methodologies (Yeoman, 2005, p45):

- The nature and boundaries of the research problem were classed as 'open' and complex. The issues associated with virtual cities were not immediately identifiable, which required a dynamic and fluid approach at the early stages of the project.
- The existing body of knowledge on the subject of managing a virtual city was not easily recognised or identifiable.
- The body of existing knowledge surrounding organisational frameworks and business modelling was far more comprehensive, represented in general terms or in their application to large scale enterprises, supply chains, market analysis, etc.
- The resources that were available to the research project included:
    - Northumbria University's academic supervisors, comprehensive library, electronic resources as well as extensive IT expertise and resources.
    - Virtual NewcastleGateshead, associated stakeholders and expertise. Including contacts within Gateshead City Council (GCC), Newcastle City Council (NCC), various Regional Development Agencies (One NorthEast, Bridging NewcastleGateshead) and local industry professionals (Ryder, Eyelevel).
- Constraints included having a limited amount of time and budget.

Furthermore "the selection of a research design is also based on the nature of the research problem or issue being addressed, the researchers' personal experiences and the audiences of the study" (Creswell, p3, 2009). Ultimately, the latter point has had much bearing on the design of the research as any other; in order to advise any current or prospective virtual city host, the research needs to establish what is currently being carried out in this field. Having reviewed the literature, it was evident that this research is interdisciplinary in nature, which poses additional challenges:

- Contextualising the research from a range of research paradigms and delivery of the results in a suitable manner.
- Understanding the different languages or terminology of various disciplines.
- Creating a systematic process and integrating the findings effectively.

Specifically, this research investigation involves business modelling, project management, urban planning, Information systems (IS) and computer science. These disciplines intersect several research paradigms including the physical sciences, social sciences and design.

The broader subject of research in the 'built environment' can utilise both qualitative and quantitative methods depending on the research area. Analytical-based research, such as materials testing, would normally follow the 'traditional' quantitative methods that are particularly suited for circumstances where there is no involvement of a 'thinking participant'. However, the level of human participation within the built environment and this research project usually requires the use of more qualitative research methods. Debates exist within information systems (IS) research regarding research methodologies (see Mingers and Stowell, 1997; Mumford, *et al.* 1985). Alavi and Carlson (1992) reported that the advent of IS research focused on the technical aspects and resulted in the adoption of quantitative research methodologies. More recently, however, a recognised shift has been made towards more qualitative approaches, which was justified in some early research that explain the difficulties in getting IS to work effectively within organisations (Backhouse *et al.*, 1991). Hence, the increased use and ubiquity of IS throughout the (business) world has had a significant impact on the field of IS research, which is requiring researchers to demonstrate an understanding of both the technological and behavioural factors (Avison and Fitzgerald, 1991).

4.3 Research Methods

This section will look at methodologies that are employed in research projects. The purpose is to outline the procedural elements for the research, including issues of construct validity, reliability, the study's questions and rival theories (Cooper, 2004, pp96-97). It will outline in detail the research process, including a discussion of the mixed method approach and data gathering techniques. Blaxter, Hughes and Tight (2006) outline the common research process in Figure 42.

Figure 42: Representing the research process (Blaxter, Hughes and Tight, 2006, pp7-8)

The process must begin with a period of planning and reflection, followed by the proper selection of actors, participants, tools or samples, for example, from which data can be extracted or tested on. Evidently, there are many research methods available to the researcher across different subject disciplines. It is also suggested that each mode of the investigation approaches three key conditions in different ways as: "(a) the type of research question posed, (B) the extent of control an investigator has over the actual behaviour of events, and (C) the degree of focus on contemporary as opposed to historical events." (Yin, 1994).

Research perspectives can be classified into a number of research methods, including Action Research, Case Studies, Ethnographic, Experimental, Correlational, Causal – Comparative, Historical, etc. (Fellows and Liu, 2005) (see Table 7). The terms 'qualitative' (inquiry), 'quantitative' (validation) and 'triangulation' (or cross-examination) are also most commonly used to differentiate between different research styles. Quantitative methods are most commonly associated with the Natural Sciences in order to study natural phenomena. Qualitative research methods originate from the social sciences to facilitate researchers to study cultural and social phenomena. Triangulation acknowledges a blend of research methods with a view to double checking the analysis.

Table 7: Classification of research methods (Fellows and Liu, 2005, pp28-29)

RESEARCH CLASSIFICATION		
Type	*Quantitative*	*Qualitative*
Methods	Surveys Laboratory experiments Formal methods Numerical methods (mathematical modelling)	Action research Case studies Participant observation Interviews Ethnography
Area	Natural Sciences	Social Sciences

In describing the mixed model approach, Bazeley (2004, p142) notes that qualitative and quantitative approaches have been distinguished and defined on:

> "…the basis of the type of data used (textual or numeric; structured or unstructured), the logic employed (inductive or deductive), the type of investigation (exploratory or confirmatory), the method of analysis (interpretive or statistical), the approach to explanation (variance theory or process theory), and for some, on the basis of the presumed underlying paradigm (positivist or interpretive/critical; rationalistic or naturalistic)."

4.3.1 QUANTITATIVE INVESTIGATION

Kaplan (2004) defines this as the numerical manipulation and representation of observations for the purpose of explaining the phenomena that those observations reflect. It is considered to be objective in nature, as it uses the collection of statistics that are based on 'real data', observations or questionnaires to test a hypothesis or theory. Mathematical methods are usually employed to analyse the quantitative relationships between the studied elements, so the data collection requires high levels of control and research boundaries.

Quantitative methods are favourable to any sample that can effectively be measurable, which is not particularly suited for the primary data collection that this research project requires due to its broad interdisciplinary nature. The required information for the research project regarding what constitutes 'best practice' is both descriptive and subjective in nature or in other words, not measurable. Findings from the literature review concluded that although information pertaining to city modelling could be gathered from a range of hosts, extracting any useful information regarding the management techniques will require an impractically broad sampling area and therefore resources to carry this out.

4.3.2 QUALITATIVE INVESTIGATION

The philosophy behind this method of enquiry is the exploration and understanding of a social or human problem (Creswell, 2009). In contrast to quantitative, qualitative research is based upon the non-numerical examination and interpretation of observations for the purpose of discovering underlying meanings and patterns of relationships (Strauss and Corbin, 1998, cited in Yeoman, 2005). It attempts to obtain an in-depth understanding of the meanings and definitions of the research situation presented by informants, rather than the production of a quantitative measurement of either their characteristics or behaviour (Wainwright, 1997). Or as Robson (2003) notes, they are considered more relevant when addressing questions relating to participant's thoughts, perceptions and beliefs. Hence, qualitative research is considered to be 'subjective' in nature. In this way, the purpose and methods for decision-making in human behaviour are analysed that allow for smaller sample groups for data capture. Appropriate techniques are explored in the following sections, including action research, case studies, experimental and survey research. As with quantitative (statistical) analysis, there is a number of IT software to assist the process of analysing large amounts of data. Bazeley (2007, pp2-3) explains that the use of IT is not intended to replace methods of learning from data, but to increase the effectiveness and efficiency of the learning process by harnessing the computer's capacity for recording, sorting, matching and linking information. The main ways in which qualitative data analysis software can assist the researcher are:

- Data management: organising cluttered records in a variety of formats.
- Manage ideas
- Query data
- Graphically mode
- Data reporting.

Action Research

Action Research is seen as a process in which a group of people come together regularly to help the group learn from the witnessed experience (Dick, 2006). The researcher actively participates in the process under study, in order to identify, promote and evaluate problems and potential solutions (Fellows and Liu, 2005). Avison, *et al*. (1999) argue that "to make academic research relevant, researchers should try out their theories with practitioners in real situations and real organisations". Hence, action research falls into the category of qualitative research, originating in the area of social sciences and educational research, closely related to organisational behaviour and change management. Planning an action research project is based on a series of cycles around the planning, acting, observing and reflecting stages of the research (see Figure 43, below), Lewin (1946).

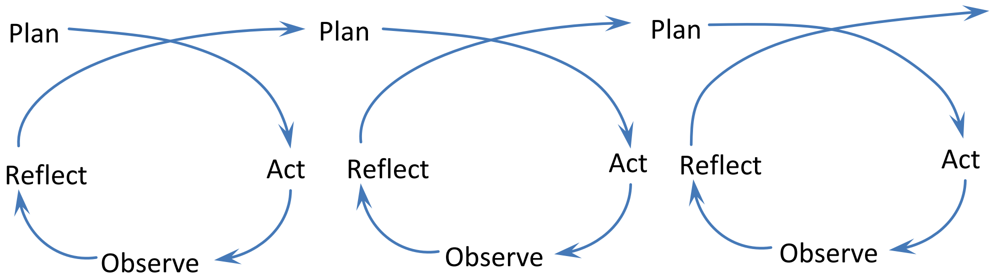


Figure 43: Action research 'Cycles of Spirals' (Lewin, 1946)

The process begins with its planning and a general idea or objective. Subsequent fact-finding about the situation helps to develop an overall plan and how this can be implemented. A series of actions, observations and reflection follows which produces some results or outcomes from the first cycle, which is used to guide actions for the next cycle and any subsequent iterations. The level of user participation in action research depends on the requirements of the project. By accepting the involvement of users within action research, Karlsen (1991) notes the potential problems associated with user participation, suggesting that full participation of a researcher in an organisation can risk the watering down of ideas, all parties compromising in the process of discussion and the discussion itself promoting conservatism.

Investigating the practical application of a 3D virtual city was considered for gathering the necessary information. However, an action research methodology does not completely suit the requirements for the collection of primary data for this research project, as the length of time required for the investigation is not practical. Moreover, it does not sufficiently nor fairly challenge the research aim as the method would focus on one (or a small number) particular organisation (or host), rather than a variety of virtual city projects. Discovering the methods for 'best practice' in a comparatively new field requires a broad range of sources for a comparative analysis, rather than a detailed study of one (or few). It is also envisaged that an organisational framework for virtual cities will require various options, rather than a singular replicable path. This notion is outlined by Lindsay, Downs and Lunn (2003, p1017), explaining that literature on business process management often mentions the need for an holistic approach and the business models that are used often do not reflect this, instead they are concerned with past knowledge and promoting standardised or 'best' practice. However, an action research model was adopted for testing certain aspects of the business framework, particularly exploring some of the technical issues that would become part of the organisational framework. This allowed certain elements of the research to be tested within a real world environment using Virtual NewcastleGateshead as the host organisation, but taking sufficient care to address proper research parameters that could affect the results through bias.

Survey Research

As one of the most commonly used methods of measurement in applied social research, a survey can be carried out in a variety of ways ranging from questionnaires to a formal interview (Trochim 2002). The main benefit of survey research is the ability to collect information efficiently from an almost limitless number of distributed respondents. The main weaknesses, however, are the reliance on respondents to be honest and accurate in their responses, as well as the inability to deal with complex social phenomena (Baker 2003).

Interviews can follow a structured, semi-structured, or unstructured format, which are characterised by their level of formality and rigor to which a set of pre-defined questions are followed. Semi-structured interviews are often used in social sciences as they allow a more flexible dialogue or line of questioning depending on the responses of the interviewee. Instead of following a limited set of questions in a structured interview, the interviewer generally follows a framework of themes with open ended questioning. Burns (2000) explains the advantages of a semi-structured interview technique:

- The informant's perspective is provided, rather than perspective of the researcher being imposed.
- The informant uses language natural to them, rather than trying to understand and fit into concepts of the study.
- The informant has equal status to the researcher in the dialogue.
- Increased rapport with the informant is formed.

However, Blaxter, Hughes and Tight (2000) point out the considerable time necessary to transcribe and analyse the data, which could be a potential disadvantage of carrying out interviews and be a limiting factor to the type or quantity carried out. This issue was considered at the early stages of this research project in order to avoid discarding data and a time consuming analysis. Furthermore, exploratory research was carried out to ascertain whether the quantity of respondents or the quality of their experience or responses was more important in their selection. Questionnaires and other (written) surveys was inappropriate for this research context as it was considered that such a survey would produce only superficial findings limited to the themes of the survey.

Case Studies

Put simply, a case study is a focused investigation of an organisation, group or individual. Yin (1984) defines case studies as an empirical inquiry that investigates a contemporary phenomenon within its real-life context and in which multiple sources of evidence are used. Furthermore, the author explains that case studies "bring a range of factors into a common analysis, but perhaps more importantly, the depth of understanding they offer is increasingly seen as critical in analysing wider socio-political processes" (Yin, 1989). Soy (1996) approves, highlighting that its strengths allow for an understanding of complex issues and can extend experience to what is already known through previous research. Although it can lead to new and creative insights with high approval amongst practitioners, this approach can be time consuming and care must be taken not to draw generalised conclusions from limited cases (Yeoman, 2005). Triangulation research methods with multiple means of data collection can increase its validity further (Voss, Tsikriktsis and Frohlich, 2002). Case studies have been criticised for the following reasons (Yin, 1994):

- Failure to control subjective elements
- Time-consuming nature
- A lack of evidence for scientific generalisation

This particular method was discarded for the purposes of gathering the primary research data as evidence from the literature investigation and audit pointed out that a broad spectrum of city model hosts were needed so that the ensuing Organisational Framework would be more applicable to a wider user base.

4.3.3 MIXED MODELS

This type of inquiry intentionally combines different methods that are meant to gather different kinds of information (Greene and Caracelli, 1997). The combination or integration of diverse qualitative or quantitative components describes the broad concept of mixed methods research that is employed to build theory. The weighting of quantitative versus qualitative is not necessarily important and as an interview process is likely, both methods could be used to create closed-ended questions (a quantitative hypotheses) and open ended questions (qualitative interview questions) (Creswell, 2009). Greene and Caracelli (1997, pp5-6) warn that just as survey research, panel studies and case studies require careful planning and thoughtful decisions, so do mixed-method studies, drawing on guidance from three levels of inquiry decision-making:

1. Political level (purpose): encompassing the value-based questions regarding the purpose and role of evaluation in society.
2. Philosophical (paradigm): incorporating assumptions about the social world and our ability to understand it.
3. Technical (method): representing discrete methods and procedures for gathering and analysing information.

TRIANGULATION

Jakob (2001) defines this as the combination and application of several research methodologies in the study of the same phenomenon, used to obtain confirmation of findings through convergence of different perspectives taken from both quantitative and qualitative methodologies. Traditionally, it was conceived as the conduct of parallel studies using differing methods in order to achieve the same purpose, with a view to providing corroborating evidence for the conclusions drawn (Bazeley, 2004, pp144-145). There is much debate on the various format or types of triangulation, but Mathison (1988), Begley (1996) and Guion (2002) agree that the general consensus appears to indicate that five variants exist (Yeoman, 2005) that can be categorised in the following ways:

1. **Data**: triangulation of different sources of data across time, space or persons.
2. **Investigator**: triangulation of work amongst several researchers.

3. **Methodological**: triangulation of multiple methods to study a single problem.
4. **Theory**: triangulation of two or more contrasting theoretical positions.
5. **Analysis**: triangulation via use of more than one analysis technique.

4.4 THE RESEARCH METHODOLOGY

The purpose of this section is to outline the chosen methodology, contextualising the research methods and in particular the relationship between the chosen method and the findings. The most suitable methods for this type of research project were examined in more detail to enable proper decision-making on the most appropriate research strategy that will facilitate completion of the overall research project.

Conclusions drawn from the literature review, pilot studies and methodological study indicated towards a qualitative study. The topics that were covered during the literature review concerning a virtual city project required some boundaries and structure to the subsequent research. Therefore, semi-structured interviews were chosen to collect the primary data for the purposes of developing the organisational framework along a set of defined themes. The practicalities and availability of working with the development of Virtual NewcastleGateshead enabled three pilot studies to be designed to explore the technical issues involved in the research and test some of the technical processes involved in managing 3D datasets. This mixed methods approach presented a suitable methodology to challenge the research questions, hypothesis and interdisciplinary nature of the literature review findings. Additionally, both the primary data collection and framework formulation require different methods for their execution. The findings from the literature review indicated that virtual city modelling is very much a developing and fragmented process. Although there are some obvious trends in 3D modelling or data management methods, for instance, there appears to be too many variables or unknowns to allow for suitable, indicative quantitative data or other research methods (e.g. experimental research).

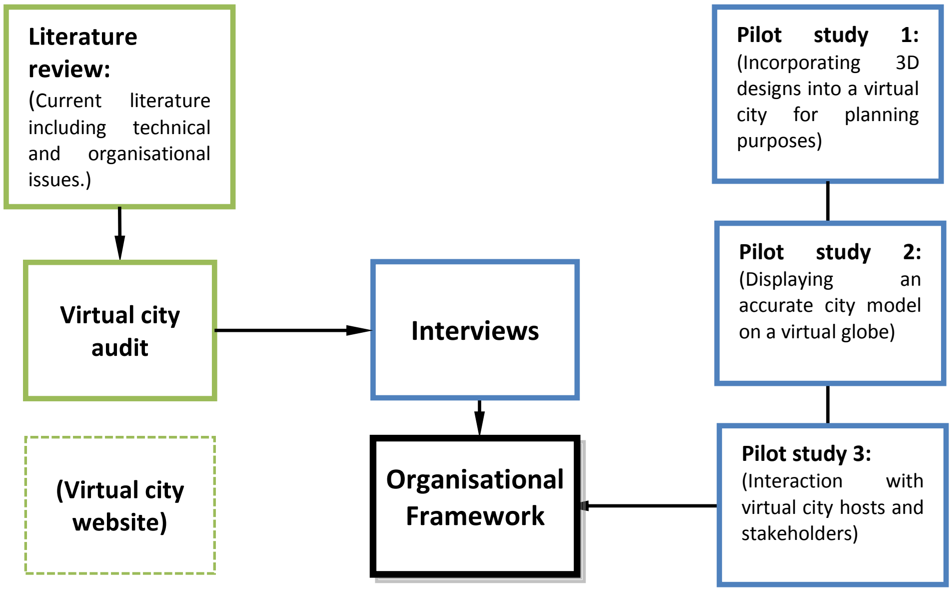


Figure 44: The research methodology: sources of primary (blue) and secondary (green) data

An extensive literature review was carried out to facilitate comprehension of existing theories and work by others (Yeoman, 2005) that enabled the familiarisation of the broader virtual city modelling environment, current trends and key terminology across the different fields. This basis would form a coherent argument for further research and to demonstrate a fundamental understanding of the concepts of virtual city modelling. The information gathered from the literature review was used to conduct an audit of city models that would:

1. Formulate and assemble the semi-structured interviews
2. Establish the boundaries for the on-going research
3. Identify the interview sample

This primary data from the completed interview process captured emerging methods andformed the core research of the current principles of collaborative city model projects or enterprises.

4.4.1 Literature Investigation Methodology

This initial investigation was intended to highlight some of the important issues in the context of the research project and aimed to distil from a broad analysis the relevant issues, paradoxes and dilemmas. These issues were highlighted during the development of the research hypothesis, objectives and literature search, as well as discussions with experts and academics at workshops, training events, key conferences and within Northumbria University's School of the Built and Natural Environment.

The review involved a combination of primary and secondary sources in two identifiable stages, the first of which was a review of secondary sources including textbooks and the second being a review of more primary sources including journal articles and conference presentations. The literature search initially approached a range of subjects including VR and 3D modelling, urban planning, GIS, data management, legal issues related to digital data, business and project management and business modelling to gain an understanding of the main theories and trends in the subject area. Cutting-edge virtual cities are demonstrating increasing similarities between GIS, or more broadly speaking, information systems (IS). Ozdilek and Seker (2004, p1) define IS as a system "that relates to a chain of operations leading to planning the observation and collection of data, to the storage and analysis of data, to the use of derived information in decision-making processes".

In order to further address the key research questions, the literature search was subsequently split into two areas: modelling virtual cities and business models. These were separated for a number of reasons. Firstly, it transpired that there was little evidence of business processes in any literature related to city modelling. Data management was extensively outlined, particularly in the fields of GIS, but there was little or no written work on the management processes of virtual city modelling. Secondly, the resources and language used in business literature is distinct from city modelling, which was reflected in the review. One of the chief purposes of the literature investigation was to help draw out key areas that required further investigation in the research projects and in particular, the interview process.

4.4.2 AUDIT

Evidence from the literature and preliminary investigations indicated that it was necessary to gather information on exemplar city models, as primary or secondary research data showed that there was a variety of 'virtual cities' in existence that displayed a range of coverage, completion or even theoretical bases. Hence, it was necessary to collate these city models in an audit environment based on a set of defined features or characteristics that encompass what is traditionally referred to as a 'virtual city', rather than a casual reference. For instance, game developers often produce detailed urban environments that are created for a specific and limited application. Likewise, theoretical or prototype virtual cities that have been created as a design, technological or theoretical showcase (e.g. Istanbul second city) (Tally, 2008) were omitted.

The audit collected both qualitative and quantitative research data from a cross-sectional, representative sample of current European city models. This extensive list of models was later categorised so that a representative sample could be selected to create a shortlist of interviewee participants. The audit was carried out over a three month period, following an exploratory phase to identify the key actors and institutions. The initial population was generated from the literature investigation and stakeholder analysis of the organisations involved. This extensive list of models was subsequently categorised so that a representative sample could be selected to create a shortlist of interviewee participants.

In order to establish boundaries for this data collection, only city models that lie within the EU were shortlisted for the audit. Information gathered from the literature investigation indicated that there are many common issues pertaining to hosting and managing city models within this group, such as software, applications and legal issues. The latter point also includes recently implemented EU legislation that has been the key driving factor for the establishment of many city models by its members. Moreover, practical reasons such as the accessibility of the audit participants was an important factor for consideration for the purposes of the research, as interviews will be necessary and issues such as language and time differences were taken into account. Finally, Clos (2005) outlines many common characteristics that are present in most European cities, be they Anglo-Saxon, Central European, Nordic or Mediterranean.

The aim of the audit process was to gather factual information about city models, therefore any functions that were ambiguous, particularly 'cost', were disregarded following the results from the preliminary interviews. These initial semi-structured interviews were carried out to gather qualitative information regarding the sample and content for the audit. Therefore, this placed more emphasis on the primary data gathered from a second set of semi-structured interviews that would be shortlisted from the audit process, as it became clear that much information would only be revealed through an interview process. Another sampling effect of the audit was that it brought clarity to the relative quality of city models, with regard to their accuracy and completeness, compared to their use. Hence, it showed a clear distinction to city models that had been established, or were currently being used, for applications in the planning process. City models were analysed with respect to their method of use and consideration to their on-going function. Furthermore, planning-based models utilised data types and formats that had been considered for their informational practicalities, rather than graphical purposes and realism. The models were analysed with respect to high levels of accuracy and comprehensiveness, although in many cases they were represented by relatively low levels-of-detail. Nevertheless, these were established as suitable boundaries to the research and resultant framework. The audit and interview process therefore ran as follows:

- Identify and formulate an extensive list of 3D virtual city models within Europe (70–100 cities).

- Categorise the list according to a number of factors (e.g. location, size, detail, use).
- Select a representative sample of city models (20–30).
- Interview the smaller sample of cities.

Secondary data was gathered from literature and web-based information in order to formulate the initial list and categorise the information. The second, smaller sample of city model hosts was interviewed to gather information for a set of defined questions and themes related to the research objectives and the elements of the framework, with particular focus on organisational issues. The sample of hosts was determined after analysing the list of city models and establishing those that demonstrated good practice in their processes.

4.4.3 Pilot Studies

Three pilot studies were carried out in order to explore the technical issues involved in the research and test some of the technical processes involved in managing 3D datasets. These were chosen for their applicability to the research objectives and underlying themes of the framework. Furthermore, the literature research and other sources revealed a variety of developments in city modelling technology that was not suitably covered in academic literature or primary sources. Specifically, the practical application or processes of city model tasks, such as 3D data integration or the use of global globes (see Pilot Study 1, 2, below). Although some information could have been gathered during the data collection stages, it was considered that a more pragmatic approach was needed to explore these issues during the initial stages of the project. The proximity of the research project to Virtual NewcastleGateshead enabled these studies to be carried out as pilot studies on an existing city model project and would follow an action research methodology. Each of the pilot studies required different levels of user participation, due to the type of tasks that were carried out, the number of stakeholders involved in the process and the expertise that was available.

Pilot Study 1: Incorporating 3D Data into a virtual city context for urban planning analysis

The objective for the first pilot study was to determine current practice in the technical integration of city model data, using practical methods to explore the process for a significant urban planning proposal and the relationship between the actors involved. The study also explored the process of embedding VR into a traditional planning process that included local architects, their clients and senior city planning officers. The scheme looked at the issues of 3D data integration from different sources in order to devise suitable recommendations for this process. Ryder Architecture Ltd is a large architectural practice operating in Newcastle and the UK. In 2007 they were appointed to develop a site owned by a well-known property developer, Buccleuch Group. Virtual NewcastleGateshead (VNG) was originally established as a research project at Northumbria University (NU) as well as future planning activities. Through previous contacts with Ryder, senior architects at the company had expressed an interest in using the facilities of VNG to explore their current pre-application planning process. Hence, the opportunity arose through their commission of a prominent building development to explore some of the research objectives in this environment. Regular meetings (six in total) were organised between the research group and Ryder, as well as informal planning meetings that are explained later in this section.

The study analysed the technical and organisational issues of 3D data integration from two different sources of 3D data in order to devise suitable recommendations for this process for the purposes of the organisational framework. It created an environment in which to assess and discuss an accurate building representation in its context. The overall aims of the study were to:

- explore the methods of embedding VR into a traditional planning process.
- explore the roles and relationship of the various stakeholders within this process (local architect, client, and city planners) in terms of both their technical roles and organisational or functional roles.
- gain practical knowledge of a large, local urban planning proposal process.

An action research methodology was used to explore this process in practice. Specifically, an improved technical process was devised and put into practice by other practitioners of Virtual NewcastleGateshead. The result of the process was observed and feedback from this stage led to a second, improved iteration of the process that required a reduced level of user participation. Information relating to both the technical and organisational processes was gathered as a variety of users or participants were involved with this study, which followed a real world planning project.

The project followed the development of a site in an architecturally sensitive area, adjacent to an important listed iconic building in Newcastle city centre and a section of the Medieval city wall. It also lay at the top of a steep bank adjacent to the river Tyne that made it visible from many key viewpoints around the city. This combination of historical value, geographical and topographical challenges demonstrated particularly difficult circumstances for a planning activity. Hence, the architect and their client were keen to explore a more efficient, as well as transparent, planning process than the typical consultancy and approval procedure that a large development must typically carry out.

Currently, the designer is required to produce 'redline images' of the building proposal in its context that involves outlining the proposed building profile over an existing photograph of the site from various angles (as stipulated by planning guidelines in the Tyne Gorge Environmental Impact Assessment documentation) to create photomontages. This indicates the scale and form of the proposed development without the distraction and visual seduction that ‘artist’s impressions’ produce. In addition, videos (animated fly-throughs) are now common for large developments that are used, to some extent, during the planning approval stage, as well as for marketing exercises.

Figure 45: The interface to enhance and assist the integrated design proposals with the virtual city

The project first required that the 3D building proposal models created by the architect were merged into VNG’s existing city model. This relatively straightforward integration process required three iterations, the first of which was a preliminary test to resolve compatibility issues. The second was for the benefit of the architects after some modification of the original building was made. A feature was introduced at this stage to enable the top floor of the building to be ‘toggled’ on or off, in the event that the planners would not support the larger version of the building and to create dynamic discussions that engaged all of the parties. A custom interface was also designed to assist this process (see Figure 45, above). The final visit was carried out to create the presentation material for the planning analysis that would involve all of the parties – the architect, the client and two members from Newcastle City Council’s (NCC) planning department. Finally, a meeting was set up by the architects to present the model to a member of English Heritage in order to assess how architecturally sensitive the building was to its surrounding buildings. Although, this was not a formal assessment by English Heritage (this would be carried out at a later date), the meeting raised issues that could be rectified at this pre-planning application stage.

The successful completion of this investigation led to a secondary study six months later to compare the accuracy of photomontages produced by an independent architectural visualiser with one derived from VNG's city model. The visualisers, Eyelevel Ltd, had prepared photomontages for a conceptual revival of the 1951 Festival of Britain's 'Skylon' tower in NewcastleGateshead. The images were produced by Eyelevel following guidelines that aim to maintain accuracy within the process, with the Skylon representations introduced using OS coordinates. The equivalent process using the city model required a model import and renderings taken from the identical camera positions. A visual comparison of the two photomontages revealed an identical result (see Figure 46, below). The Skylon models in the photomontage were overlaid in front of buildings to improve visual comparison. The images were also measured using a relative scale for each for each photograph and showed that the positional accuracy deviated by between 0 and 2% between the two images.

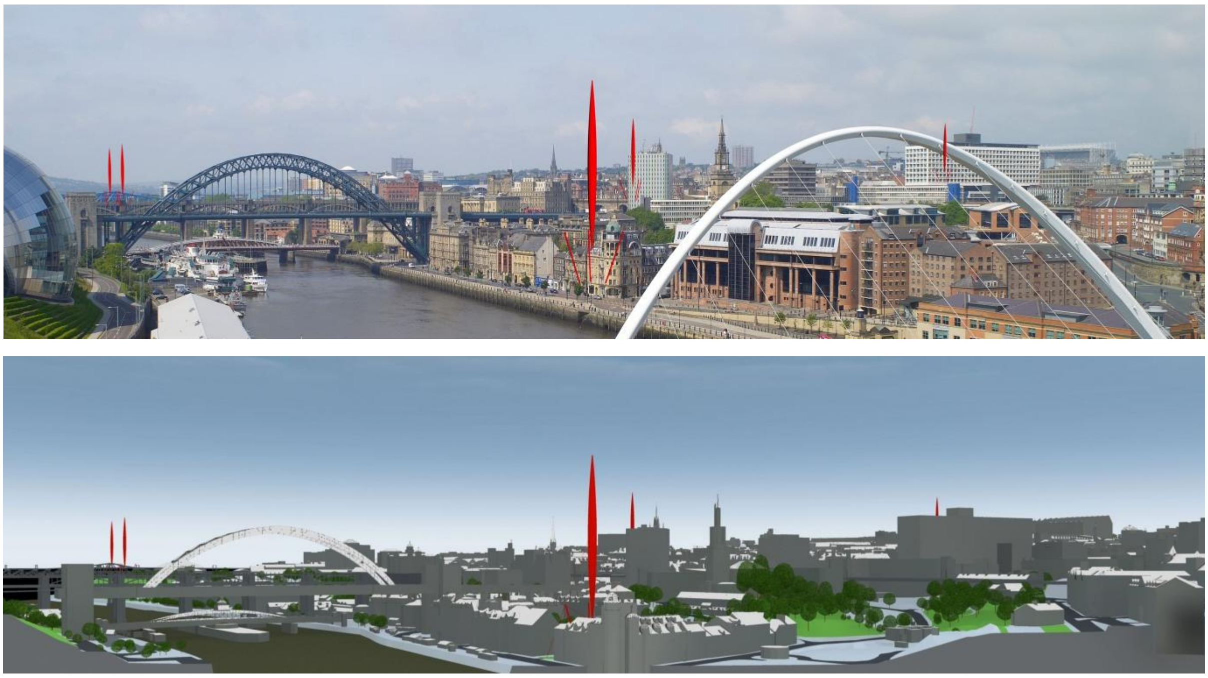


Figure 46: Verified photomontage from Eyelevel Ltd (top) compared to Virtual NewcastleGateshead virtual city (bottom)

Pilot Study 2: Displaying accurate virtual city model data on a Virtual Globe

Review of the literature highlighted concerns for accuracy and credibility of 3D model data that is used to assist urban planning decisions, which led to a second case study that would explore issues emerging in web-based Geographical Information (GI) services with a particular focus on their approach to data accuracy. Furthermore, preliminary investigations identified the need to consider these developments, since it was widely recognised that virtual globes would have a significant impact in the field of city modelling. Institutions and organisations are beginning to consider their use in favour of a traditional server and services infrastructure (Strobl, 2006), whereby the perceived cost barriers that can impede the use of VR in planning are rapidly decreasing as on-line options emerge (Perkins and Barnhart, 2005). Google Earth (2008a) is a web-based virtual globe for viewing maps, aerial images, 3D buildings and an increasing amount of media and geographic content. There are a number of digital earth platforms available, but this became the focus of the study due to its widest use in practice and has already carried out a significant worldwide 3D city modelling program (Ohazama, 2008). The submission process of importing 3D building models onto Google Earth's '3D Warehouse' was also tested for the following reasons:

- To explore the process of urban modelling for Google Earth and compare techniques with more established packages.
- To explore the management issues of the platform, including legal and safety issues that acknowledge multiple stakeholders.
- To test the use of a 'network link' as a way of communicating 3D data for planning purposes.

This pilot study required a high level of user participation, as there were far fewer participants who could be involved in this study for practical reasons. However, the results of the study had the capacity to involve a far greater amount of stakeholders than Virtual NewcastleGateshead currently addresses, as it allowed the model to be distributed over the internet. Although the project involved a great deal of technical involvement (particularly 3D modelling), the process revealed the scope of the legal issues that are to be addressed when distributing valuable information over the web. Restrictions by Google hindered the distribution of the data, as it would involve giving certain data rights to the software company that would violate the Virtual NewcastleGateshead third party data license agreement. This technicality would be addressed in the final pilot study, which integrated premises from the previous studies.

Google Earth (GE) and Microsoft's Bing Maps are web-based virtual globes for viewing maps, aerial images, 3D buildings and an increasing amount of geographic and media content. Both are free software that require an internet connection to receive data. There are currently a number of virtual globe platforms available, but these products have both carried out significant virtual city model development. The competing software have taken two separate approaches to the creation of 3D building data, whereby Google allows its users to import their own 3D building data and was the primary reason why GE became the focus of the study. SketchUp is a free 3D modelling software package also offered by Google that allows its users to upload 3D buildings onto the publicly available '3D buildings' layer. This layer is also supplemented by Google's own 3D data update process, through its own modelling or the acquisition of external building and city information. For example, a fully textured model of Westport (Co. Mayo, Republic of Ireland), which was originally developed as a planning tool, is now available in GE through and an agreement between its modellers and Google.

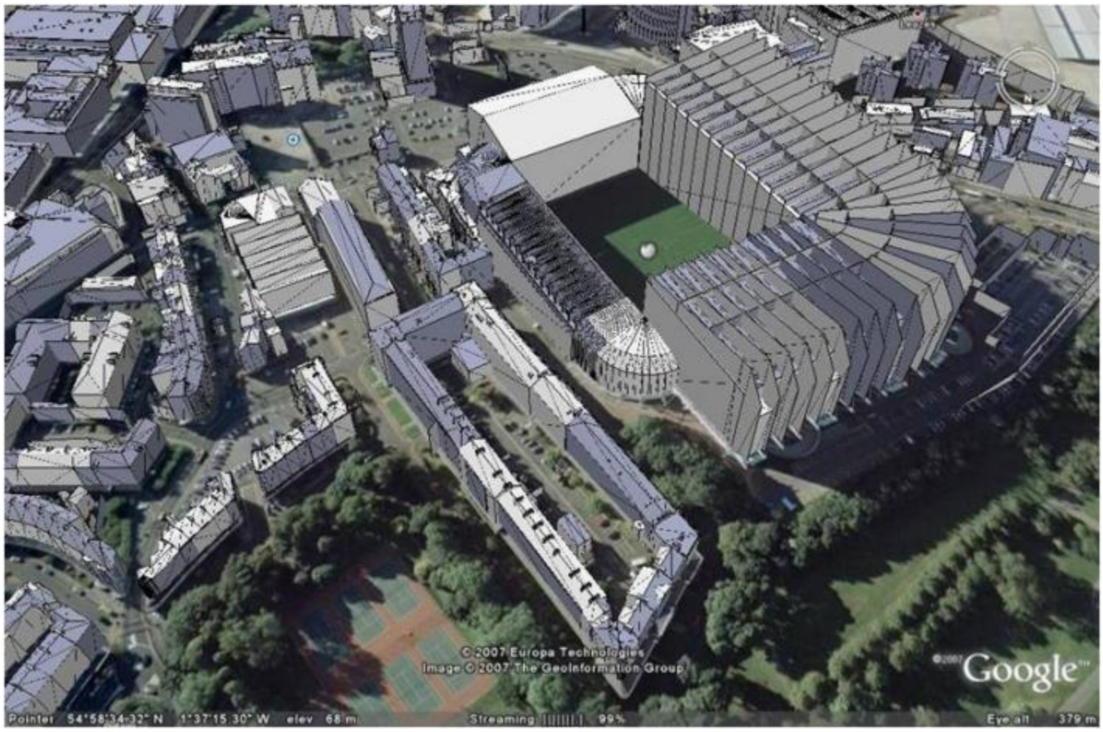


Figure 47: A screenshot of the imported 3D model data using the Google Earth platform

In order to investigate the feasibility of GE as a viable tool for urban planning functions, a pilot project was carried out to test the software using VNG's city model data. Furthermore, the submission process of importing textured 3D building models onto Google Earth's 3D Warehouse was explored during the study by uploading individual buildings from Northumbria University's (NU) campus. This was done for the following reasons:

- To investigate the process of urban modelling for GE and compare techniques with more established packages.

- To explore the management issues of the platform, including legal and safety issues that acknowledge multiple stakeholders.
- To test the use of a network link as a way of communicating 3D data for planning purposes.

A University campus model had been commissioned two years previously and created using field survey methods and digital photography. Although this accurate campus data was available and the necessary permissions had been sought to distribute it on the web, much optimisation of the data was necessary to prepare the data for web use and distribution over the web. This modification process involved:

- Compressing the texture maps (.jpg) into more suitable sizes (typically 1/10th of their original size). This was significantly the most effective way of reducing the model sizes in this case.
- Removing unnecessary geometry.

Effectively, two datasets were used to investigate GE's features. The larger data, VNG city data, was modelled using photogrammetry to LOD2 and a fully textured area of the NU campus.The existing 3D models could have been uploaded directly into the 3D warehouse, but this was not done for two reasons. Firstly, large file sizes would have little or no chance of being included (approved) in the '3D building' layer of GE. Secondly, some features of the buildings needed checking and removing from the models for security reasons. In this way, simplified versions of the models would retain the function of the original, detailed campus model that was commissioned and paid for by Northumbria University. Existing building models of the University's City Campus were converted and modified for compatibility with GE. This involved extensive re-modelling to simplify the building data and significantly reducing the file size of each building. Google publish their assessment criteria and modelling guidelines online, but these are somewhat brief and there is still no guarantee that buildings submitted will be accepted permanently into the '3D Buildings' layer in GE.

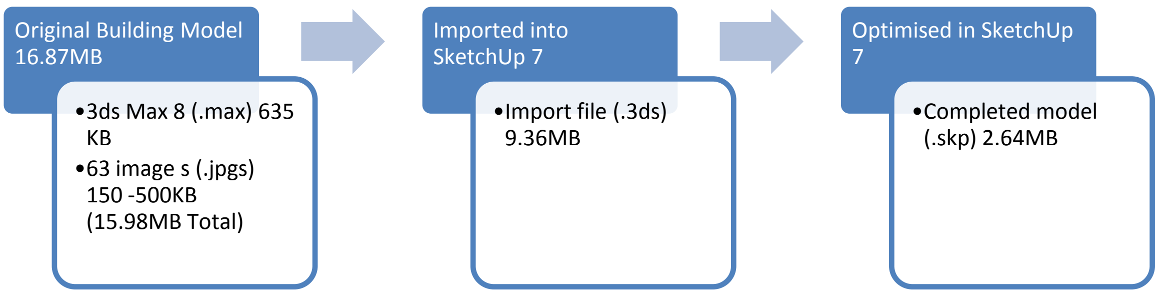


Figure 48: Data file transfer process

Pilot Study 3: Developing Tools for Sharing 3D information across multiple actors ('Scotswood Housing Expo')

The third study brought together many of the highlighted issues concerning the management of a virtual city model within a practical context. It was devised to test the results from the previous pilot studies and its objective to determine current practice in technical, as well as the organisational, integration of data. This study followed the Scotswood Housing Expo and a project between NU and Newcastle City Council (NCC) to run an architectural and student competition that would select the designs and designers for a redeveloped area of Newcastle. The estimated value of the project was approximately £400 million, which was backed by Newcastle City Council, Bridging NewcastleGateshead and the Homes and Communities Agency (formerly English Partnerships). The project was to be run as an architectural competition, inviting architects and designers to submit design proposals as 3D CAD models and restricted to 7.5m x 26m plots, as well as some other design restrictions.The opportunity was put forward to the local council to assist in a large planning activity that would involve facilitating multiple design proposals and placing them into a virtual city context. Not only did this involve the management of third party source (virtual city) data, but planning for the integration of 3D building models from a variety of sources, namely architects and designers. A competition was also launched that tested the use of global visualisation engines and the legality of distributed data.

Scotswood is situated three miles west of the city centre and beyond the current boundaries of the VNG dataset, with the Expo representing the first phase of a new neighbourhood. However, NCC had commissioned the 3D modelling of this area for preliminary studies and to produce their promotional material so it was essential to acquire their approval before certain parts of the 3D data could be used for the purposes of the competition. A further complication was that a 3D template based on their conceptual master plan was to be uploaded to the '3D Warehouse' under Google's conditions. The third party data consisted of a digital terrain model (DTM) based on OS data, overlaid with an indicative master plan of the proposed site. In practice resolving the modelling and license agreement issues were a straightforward process, as the DTM was replaced to avoid OS' restrictions. The necessary acknowledgments were made to the sources of the data and their approval was readily given in this case.

Financial limitations from 2008 delayed the project and encouraged the City Council to adopt a more traditional design, tender and construction process rather than the intended 'Expo' design competition. Nevertheless, before these changes occurred the project strategy and its processes were established after a number of meetings with the team leader from NCC. All of the necessary protocols, documentation and 3D models were prepared and although the 3D model submission process was tested on a sample building, it was not properly validated in its practical environment. However, much of the work carried out was explored in depth with members of Newcastle City Council and a detailed process for the Scotswood project was completed and delivered before its implementation was prevented. The lessons learnt regarding the import process and modelling protocols (attributes) from the previous pilot study were implemented and thus validated during the study.

Similar to the previous studies, the action research methodology allowed for some user participation to establish the organisational processes of the project. Essentially, further iterations of the process were not possible for reasons mentioned, which prevented the observation, revision and validation of the improved process. Nevertheless, important feedback was gained from the study, as well as indirect results that has induced the research to suggest more robust measures within the organisational framework, in light of the financial environment since the late 2000's.

Newcastle City Council had established a team to manage the redevelopment of Scotswood, an area west of Newcastle city centre. Initially the intention was to run a web-based competition to encourage submissions from international designers. However, after early discussions with local architects it was recommended that the methods for the competition would discourage many professional designers and architects, particularly the requirement to submit a 3D model and their agreement to publish this over a competition website. Therefore, the competition was separated into two categories, a student competition that would run alongside a professional competition. The research team was responsible for organising the technicalities of managing and presenting the design proposals. The project gathered a range of stakeholders in the development and competition that included the two bodies mentioned, as well as the data providers for VNG, NCC's data providers and eventually numerous applicants who would be submitting their designs at a later date.

After examining the various possibilities for hosting the student competition, it was agreed that a web-based platform was the most suitable method. The free platform allowed the broadest range of submissions, while some of the data management could be carried out by another party whose established guidelines could be modified for the submission process. The primary tasks that were carried out for this study were:

- To assist the formulation of a submission guideline protocol for the competition (architectural and student competition).
- To create a model template (student competition).

- To host a model submission database (architectural competition).

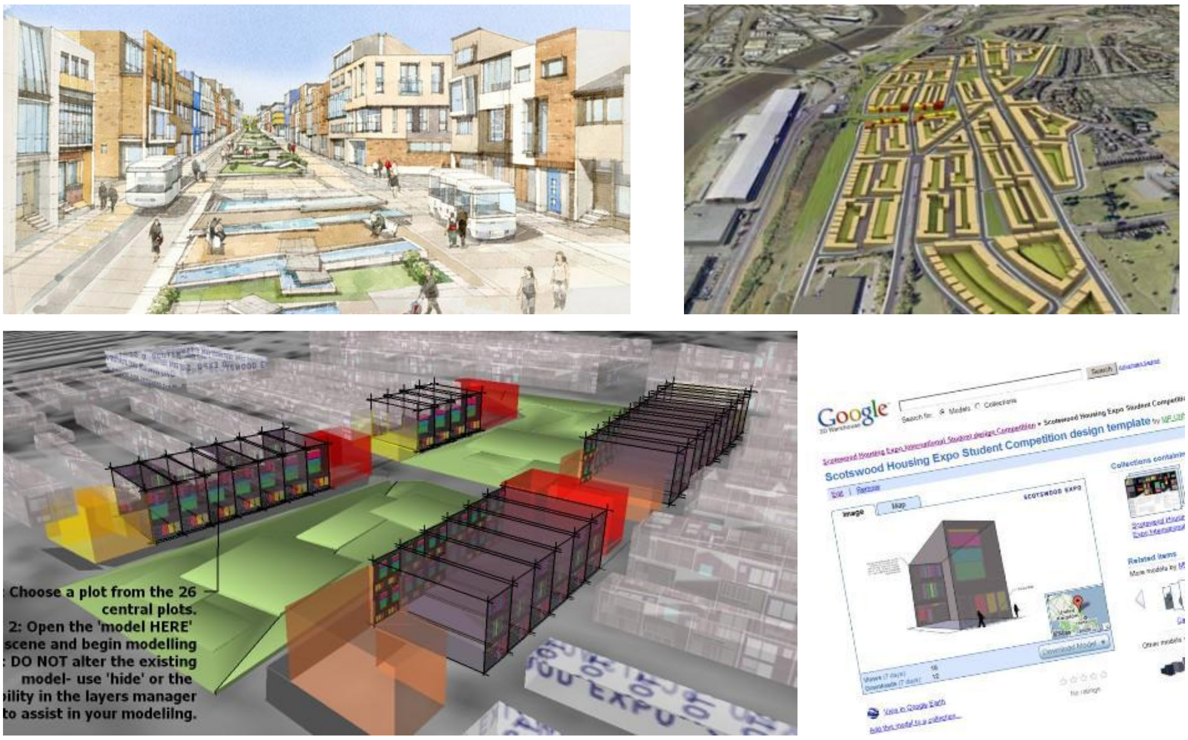


Figure 49: Scotswood Housing Expo (clockwise from top left): indicative artist impression; conceptual master plan; Google competition webpage; SketchUp template

4.4.4 Virtual City Website

Developing an active web presence presents many direct and indirect benefits for a technology-based research project, such as the ability to network with a broader audience of peers. A website also provides a platform for research dissemination and validation, while being well informed in the subject area through encouraging a culture for feedback. The 'Virtual City Exchange' website was set up (virtualcityexchange.co.uk) to create a community for virtual city modellers or hosts and a forum for discussion concerning virtual cities. The intention of this approach is a contemporary method to enhance engagement with virtual city stakeholders and to disseminate the research topics, related news and information to an international community.

4.4.5 Interviews

Semi-structured interviews were used to capture formal and informal aspects of the project. Smith (2007) explains that they can offer more anonymity compared to focus groups, expedient when addressing information of a sensitive or confidential nature. The duration of these ranged from 40–80 minutes and were used to focus upon standard questions concerning the project, followed by a relatively unstructured discussion of variable length used to explore opinions and less formal aspects of the research topic and interviewee's involvement. This latter part of the interview generated a greater understanding of the interviewee's involvement in the project and relationship between actors, organisations and the various stakeholders.

In total, 23 interviews (representing 22 cities) were conducted, generating approximately 21 hours of recorded material. Table 8, below, lists the details for the interviewees, including the hosted city, host type (and country) and the role of the interviewee. Individuals were identified within these organisations following the audit, from web-searches, formal job descriptions, contacts developed through previous research projects (J. Evans, 2003) and, as the project progressed, by snowballing contacts from interviewees to form the eventual sample.

Following the results from the audit and initial semi-structured interview stage, this type of dialogue was chosen as the most appropriate method for carrying out the interviews, rather than unstructured or structured interviews. The interviews consisted of 16 questions, which were designed to be open ended and not leading. The semi-structured theme allowed a process of guiding the interviewer towards various themes and key questions that were consistent throughout all of the interviews, while allowing the discovery of unknowns or other emerging issues. Unstructured methods were also considered to allow for a flexible and informal approach to the gathered information, but this was discounted due to the potential breadth of the topic. The interview questions were established as a consequence of preliminary findings of the literature search and pilot projects. The development of ideas through interaction with the interviewee was important, allowing the experts to influence the way that the questions led their own description of the work. As such, the function of the interview questions was to ensure the treatment of the different interviewees were consistent, yet to allow scope for them to take the discussion into other topics. Having carried out the preliminary interviews at the beginning of the research project, it was considered to be more constructive for the participants to receive a copy of the interview questions at least three days before the interview took place. This was to ensure that all of the questions could be answered by the participant and if not, another participant could be suggested or the answer could be suitably researched. This was particularly evident for cost-based questioning.

Table 8: Interviewee and host details

Host Type	Interviewee Role	City represented	Host Country
3D modelling, GIS data providers	Technical Director	Barcelona	Norway
Academia/ Local Government	Head of Visualisation	Glasgow	UK
Academia	Head of GIS	Berlin	Germany
3D modelling	Director	Westport	Ireland
Engineering & GI consultants	Project Manager	Geneva	Germany
Architecture	Director	London	UK
Local Government	Team Leader	Sheffield	UK
3D modelling, GIS data providers	Technical Director	Salzburg	Austria
3D mapping, 3D modelling	Technical Director	Oslo	Norway
GI and 3D modelling	Project Manager	Bocholt	Germany
Engineering consultants	Project Manager	Manchester	UK
3D modelling	Director	London	UK
3D mapping, 3D modelling	Technical Manager	Helsinki	Finland
3D mapping, 3D modelling	Project Manager	Poitiers	France
Local Government	Team Leader	Frankfurt	Germany
Academia	Project Manager	Heidelberg	Germany
Academia	Executive Manager	Hannover	Germany
3D GI, 3D modelling	Technical Manager & Project Manager	Vienna	Austria
R & D	Project Manager	Gothenburg	Sweden
3D GI, 3D modelling	Project Manager	Milan	Israel
3D modelling/ Local Government	Technical Director	Southampton	UK
3D modelling/ Local Government/ Engineering consultants	Project Manager	Paris	France

Telephone interviews were the only practical method of carrying out the interviews, as the majority of respondents were situated outside of the UK. Moreover, Boland *et al.* (2006) suggest that interview participants can react positively to the 'perceived anonymity' that telephone interviews can offer. Hence, the decision was made to telephone those within the UK for the sake of consistency in the structure of the interviews. Specifically, calls were made using ‘Skype’, a ‘peer to peer’ service that uses Voice over Internet Protocol (VOIP) for calling other Skype users, mobile or landline telephones. A supplementary plug-in called ‘Pamela’ was also used to record (audio only) the Skype conversations, with verbal consent being given at the start of each interview. Notes were taken during the conversation to highlight key themes as they emerged which could be taken up in subsequent interviews, as well as assisting the analysis stage.

The interview questions (see Appendix) were drawn up to explore virtual city modelling practice in two fundamental areas. Firstly, to gather information on the type of virtual cities that are used for the purposes of planning, outlining their features, requirements from their processes and those who are involved in their use. This would inform the organisational framework on recommending the type of virtual city data that is required for the purposes of the most commonly used planning tasks. This followed the literature investigation and audit which revealed a variety of virtual city types that are used. The second line of questioning was to gather information on the best practice methods for managing the virtual city. The semi-structured approach allowed specific details from each interviewee to reveal their own methods, as well as their recommendations on how this could be achieved.

4.4.6 Data Analysis

Information from the interview recordings and notes were analysed twice to highlight relevant content and themes. The first review was informal in nature, carried out immediately (within 48 hours in most cases) and the second using content analysis techniques that involved transcribing the interviews so that the information could be used in a qualitative research software program (QSR N6). The software helped to analyse the information for common themes in the discourse and specific details, concepts and recommendations. These were distilled into the key issues and solutions in an organisational framework in Chapter 6, through a theory building technique. This process followed a divergent-convergent model (Rhea, 2003) that enables the extraction of key principles.

4.4.7 OrganisationalFramework

The principal phase of the research involves the application of the key findings from the various investigations to create a framework for the effective management of a 3D virtual city model, after the initial data collection and analysis process was completed. The framework consists of a series of guidelines and recommendations for key stages during the lifecycle of a virtual city, and incorporates business, technical and governance issues. Accordingly, this chapter relinquishes the core material for the research project's contribution to knowledge, assimilating the many considerations related to virtual city models.

4.5 Ethical Considerations

An appropriate code of conduct was strictly adhered to throughout the course of the research. Necessary precautions were taken to protect the rights of interviewees and auditees with respect to any sensitive information that was conferred over the course of the research, as the divulged information is considered commercially sensitive. Hence, the names and organisations of those involved in the research have been kept confidential. All of the participants in the research were informed of the research background, such as its aims and objectives. A Northumbria University ethics consent form was sent prior to all of the interviews (see Appendix) and their consent was recorded when interviews were carried out. None of the participants were classed as a vulnerable group and it is unlikely that there are any risks for the participants in the research. Data was kept secure by storing all digital information in a password protected hard-drive held in a secure location. Other, non-digital information was kept in a locked filing cabinet.

4.6 Summary

This chapter has outlined the main types of methodologies available to a researcher, within the context of the subject area. It also provides justification for the application of the methods to address the given problems. Table 9, below, outlines the overall research project aims, objectives and applied methodologies. The original contribution to knowledge that this research project aims to address is also reaffirmed.

The chosen methodology reflects a mixed methods approach. The literature review and virtual city audit comprised the secondary data for the purposes of the research. This was followed by the pilot studies that followed an action research model and an interview process. These stages encompassed the primary data for the research and are analysed in the following chapter.

Table 9: Summary of the research methodologies

<table>
<tr><td colspan="3">Primary Aim:
To formulate an organisational framework that outlines best practice and recommendations for the process of 3D city modelling, focusing on virtual cities that are used for urban planning related activities.</td></tr>
<tr><th>AIM</th><th>OBJECTIVE</th><th>METHODOLOGY</th></tr>
<tr><td rowspan="5">Investigate the current state of knowledge on 3D virtual city models</td><td>1. Review current virtual city modelling context and techniques</td><td>Literature-based review</td></tr>
<tr><td>2. Determine current practice in technical integration of data</td><td>Action research</td></tr>
<tr><td>3. Survey virtual cities</td><td>Audit
Semi-structured interviews</td></tr>
<tr><td>4. Results analysis and dissemination</td><td>Conference paper</td></tr>
<tr><td>5. Engage with Virtual City community</td><td>Website</td></tr>
<tr><td rowspan="3">Develop an organisational framework for hosting virtual city enterprises</td><td>6. Review methods of business modelling</td><td>Literature-based review</td></tr>
<tr><td>7. Determine current practice in technical integration of data</td><td>Action research
Semi-structured interviews</td></tr>
<tr><td>8. Interview industry practitioners</td><td>Semi-structured interviews</td></tr>
</table>

CHAPTER 5: RESEARCH FINDINGS

5.1 INTRODUCTION

This chapter brings together the research findings from the primary data investigations with analyses that explore the specific solutions, recommendations and experiences with virtual city modelling. This is organised into the central themes relating to the specific governance, technical and organisational issues.

The 23 semi-structured interviews proved an effective method of data collection as it enabled an exploratory conversation of both a factual account of the respondents' specific city model environment as well as a dialogue about their recommendations and opinions based on their experiences.Interview participants were found from the virtual city audit and literature investigation. Firstly, model hosts were chosen from European cities whose models had been used primarily for urban planning activities. The models were analysed with respect to higher levels of accuracy and comprehensiveness (although in many cases they were represented by relatively low levels-of-detail). Secondly, the interview participants were refined by qualitative analysis to those that had established (or commissioned) an enterprise to host the city data and its use, thus demonstrating an outsourcing method towards their application and on-going function. A cross-representative sample of hosts that maintained data across a range of qualities and LOD were required for the research so respondents were chosen from various model types. Six hosts from the UK were shortlisted to encourage a small amount of bias towards the UK planning system and give some focus to this effect.

The various investigations revealed three distinct 'types' of city model or classifications for their levels of detail. Although there are recognised LOD's from CityGML specifications, this did not reflect the type of models that were described by the interview respondents (as well as from evidence in the other investigations). Specialist virtual city model providers continue to produce models to just three levels-of-detail: non-textured block models, non-textured detail models and textured detail models. In many cases, the CityGML LOD classification grouped together many city models that displayed a variety of detail and accuracy. Many city models combine a range of LOD's, such as laser scanned façades with roof surfaces modelled from photogrammetry. Therefore an alternative classification was devised for the purposes of distinguishing between city models in this investigation, outlined in Table 10 (on page 144). In some cases virtual city datasets can be represented by more than LOD, such as an HD as well as a purchased standard model type.

In these cases, the primary data class was acknowledged for the research, highlighting the model that is used for the majority of its services or considered as the 'master model'. Hence, the quantity for each classification refers to how the hosts classified their models. For example, every HD virtual city type was also represented in standard data types.

Table 10: Classification of primary virtual cities

Classification	Description	Quantity (%)	CityGML LOD equivalent
'Basic'	Block models without architectural or roof details overlaid on a DTM produced by footprint extrusion; also referred to as 2.5D where textures are applied.	5 (22%)	LOD1
'Standard'	Basic block models enhanced with some details and roof structures, produced by photogrammetry or LiDAR.	15 (65%)	LOD1/ LOD2
'HD' *(High Detail)*	High detail representation; accurate to within 20cm; fully textured; produced from terrestrial laser scanning.	3 (13%)	LOD2/ LOD3

5.2 Governance

5.2.1 Hosting

During the course of the interviews it was necessary to clarify terminology used for the role of 'host' to some of the respondents and thus distinguish between the end user and the administrator of the data. Some feedback that was gained from the informal discussion on this topic revealed that many of the end users of the city model considered themselves to be hosts, as they oversaw a role that involved various parties or simply the ability to modify the data where others could not. Hence, an outline of the various tasks that befit a city model host and its actors include:

- Data editing, modification.
- Data mining.
- City model delivery – presentation, communication and distribution.
- Financial management of the city model, including data and resources.

- Revision control
- Content management
- IP management
- Access security
- Accuracy validation

The first three tasks also apply to (external) users of the model. Hence, this illustrates that it is the roles rather than the tasks that define the host, be they stated, assumed, explicit, informal or contractual. Such roles were not always a formal term, but took on many assumed activities and applications following the course of a city model project or enterprise. Two of the interview respondents reported that the management of the data was a secondary function to their organisational role as host, as their key task was in bringing together a number of contributors and partners in a neutral environment that would otherwise not occur. Hence, the investigations illustrated and confirmed the regard for careful hosting of a city model by an independent organisation (Whyte, 2002; Pritchard, 2007). In the first pilot study, Newcastle City Council (NCC) was assured that both the city model and the imported 3D building representation were not being manipulated to enhance the imported building design through the implementation of a transparent process. The ability for architects to see their design proposal in a broader context added much value to the design process in the early stages (pre-planning) as it became apparent that certain modifications could be made and which saved a great deal of time for all of the parties involved. The features introduced during the second visit were the result of direct interaction and discussion with the architects. The capabilities of a virtual city model were not yet known to this party, despite their experience in 3D design. Hence, the study became a more bilateral involvement than was originally anticipated and highlighted the need for an experienced and independent virtual city host that can facilitate communication between its participants.

This however, raises issues with ownership that were highlighted in the literature review and explored in a number of the interviews. In the cases where the data providers or city modellers were also acting as a host, there were two methods for this strategy. Firstly, as in the case of tender projects, the client keeps the (IP) rights to the data and is able to use unreservedly. Contracts have been devised where the modellers can sub-license this city model but usually with restrictions to markets and applications or limited to their own marketing and promotional material. The second business model is where the data provider keeps the rights and licenses the data to a client for a certain application. In the situations where virtual city models had been commissioned by a single party(particularly HD city model types), license agreements were far more straightforward. Here city models were produced and the information was given to the clients who were free to use them in any way they wished. These differed considerably from the standard city model types, produced using photogrammetry and usually originated from specialist city modellers and their ‘off-the-shelf’ models. In these situations the city models were purchased by a range of users and these data providers carried some license restrictions, usually limiting further commercial use of the data, including re-sale. The analogy was suggested by a number of practitioners that this arrangement was similar to that of digital rights management (DRM) applied to music – the ‘data’ can be used for particular applications, but not re-sold or given to another party.

In many cases, city models had originated as an exploratory project in an attempt to modernise or improve a current design process. For instance, one enterprise was initiated to develop methods of representing and maintaining city model data and subsequently won European Commission (EC) funding to continue this work while providing a service to the Local Authority, as well as operating as a commercial service. This collaborative attitude was evident in many of the enterprises, by gathering 3D building data from their LA’s cadastral department as well as urban planners and local architects. Conversely, one interview respondent revealed that their model was originally established as a commercial enterprise, but had developed into an applied research project for the purposes of acquiring funding from other sources (e.g. EPRC). Although just three of the interviewees were based in academia (University), it is clear that many hosts were related to this area. Contextual research, when analysing the respondents for the interviews, showed that at least two other hosts were from academic backgrounds or the virtual city enterprise had originated from a University project. In European cities where the hosts were not specialist 3D data providers, they were an entity of the local ‘cadastral’ department, which encompass mapping and GIS functions. In all cases, however, an enterprise was established to host the city model and its associated functions, applications and services, mostly as a limited company or LLP (limited liability partnership). For example, one of the hosts had previously been part of the planning department but were re-organised when it became an enterprise that sold its services outside of this organisation. These conditions can involve a number of other companies who were participating in the city model enterprise. Establishing a city model project usually took between two and six months, or up to 18 months in one case. Regardless, of the existence of collaboration with larger organisations, the hosts were described as small enterprises in the early stages of (business) maturity. More significantly, the message from value disciplines business models show that most of the hosts are unknowingly focusing their ‘strategies’ on both operational excellence and product leadership, rather than focusing on oneapproach as recommended. In other words, the enterprises are attempting to define themselves as organisations that produce cutting-edge technologies, as well as providing the service at the best cost available to their clients. Not only does this create an unsustainable financial environment, but customer, client or stakeholder ‘satisfaction’ is often neglected in the pursuit of innovative technology at the lowest cost.

An experienced virtual city model practitioner reported that the main focus on previous projects had been on the process of modelling a city, with little concern for the on-going management and update of the data. Developments in the last 18 to 24 months such as the 'Ultracam' technology, semi-automatic modelling and automatic processing of LiDAR data enables an abundance of data, but it is considered still 'relatively expensive' due to the extra costs that airborne data capture accrues. Nevertheless, it is expected that this technology will cause a shift towards issues of managing and keeping the data current, as hosts can often buy the data without the on-going considerations that ultimately let the data decay, which is considered more apparent in 3D models compared to 2D information. On average, commissioning new aerial photography for the purposes of photogrammetry was reported by interview respondents to be approximately £6,000 for a 50 Km^2 area (as opposed to purchasing more cost effective 'archive' data).In certain countries, such as Sweden,interview respondents revealed that their Local Authorities had a less formal arrangement for the management structure of the city model. In Sweden, the national mapping agency gathers 3D information that is freely available to its general public as well as its local government. Hence, there is little distinction between the data provider and city model user that would usually require a host. This also allows for a more extensive use of 3D in planning functions.

In two of the HD models, grants had been awarded from EU bodies to develop the first phase of the model (also DTI funding). Hence, the creation of the model had to conform to EU tendering protocols. These detailed models are created for 'heritage reasons' in mind, but also as a commercial tool for planning activities. Although these were based within a LA, a position was appointed to carry out the management andcommercial development of the virtual city, 'post-modelling', marketing and internal management.

The respondents reiterated (from the previous investigations) that a city council itself can have multiple contributors and their specific demands. Traffic plannerswithin the same organisation, for example, can have very specific software demands that add extra cost to a project. Furthermore, in cultures that encompass external collaborators and contributors who help to supply 3D data or information, these parties can also expect certain requirements, despite the benefit of data sharing. A process of 'synchronisation' of the same model was outlined in this situation. This would involve regular update of not only the data, but of these various requirements from its contributors. The findings from the research investigations show that there is still much experimentation between the roles of the stakeholders (host, contributors, partners and users) and there are rarely defined for virtual city projects. It was suggested that this is due to the stakeholders' perceptions and expectations of city models, which is a familiar consequence in technology-based projects (Laurini, 2001).The notion of 'satisfying various stakeholders, users or contributors' was a common occurrence in all aspects of the investigation. However, it became clear during the interviews that requests from these stakeholders were based on high expectations of a virtual city as these parties were not always fully aware of the technical capabilities.

One of the most extensive and utilised city models belonged to a city council outside of the UK and contained almost half a million buildings that covered 140 km^2. This was used consistently by some 100 users and the LA host benefited from a local middleware developer in the same city. These stakeholders maintained a close professional relationship that enabled a mutual development of the city model and the software. Its user base included many GIS users that benefited from the spatial database in which the city model was integrated. A complete update (renewal) cycle was based on a three year continuous cycle (i.e. 1/3 of the model is updated every year).

As a matter of observation, a particularly revealing aspect of the investigation occurred when contacting certain hosts for information and when searching for the subsequent interview respondents. Finding the contacts who could speak informatively about the city model in question was often an extensive affair. In many cases, respondents were unsure of who was currently responsible for the city model. It became clear that in many cases the extent of a city model enterprise was the purchase of 3D data for a specific project, the subsequent production of marketing material and an aspiration to re-use the model in some way. This was particularly evident in architectural practices.

5.2.2 Management

The interview stage revealed that hosts employed small teams to carry out the necessary tasks for their data services, management and update. The largest team that was reported comprised of three full-time modellers and two other part-time employees to oversee the management and administrative tasks. In contrast, the modelling tasks for creating an entire model require a much larger team and are proportional to its LOD. Hence, the largest HD model of 40 km^2 reportedly took a team of eight staff approximately 12 months to gather the data and model the city model area. In contrast, a standard model of similar size reportedly takes a team of two staff members just two months to model. HD models were generally maintained (day to day management) by much smaller teams and demonstrated minor update processes due to cost. Employees were generally involved in tasks other than modelling. Standard model hosts afforded slightly more personnel to maintain their model and their roles included all aspects of city modelling. For models that were used continuously, typically between 1–3 full-time employees could sustain a standard virtual city up to 80 km^2.

Many of the cities (outside the UK) expressed a close network with their local GIS, mapping and surveying departments within the LA. For example, one respondentreported access to approximately 30 field-based surveyors who were an integral part of both the city's cadastral department as well as the city model project. Two full-time modellers were permanently updating the city model geometry based on this steady stream of field-based information. One of the UK LA's reported that they had negotiated a formal agreement with the OS that allowed them to pass on data to third parties. This ensured that the most current information was shared and used by both parties. Similarly, another (UK) LA reported an agreement, whereby they had become a data provider so that the OS would benefit from their latest surveys.

Despite the purchase of their 'off the shelf' standard models, these hosts reported that specialist modelling skills are still required to carry out many tasks that are involved in everyday applications or activities (level or term of appointment depending on the extent to which they are used). For example, urban planners are usually experienced in current 3D CAD software and can carry out most tasks involved, as well as more specific analysis. However, users from GIS have less knowledge of the 3D modelling process, which is more akin to architectural or built environment activities.

The other parties or stakeholders were reported as those with a financial interest or stake in the city model enterprise and evidence from the interviews showed that these included:

- Local development agencies
- Planning departments
- Universities
- Engineers
- Building professionals (architecture and developers)

Furthermore, one respondent outlined that value for money for a virtual city project can be gained in two ways: "Firstly, by making the data more usable. Secondly, by improving compatibility and so making it usable for multiple uses."The pilot studies identified issues involved in incorporating a city model, hosted by an independent body, into a typical planning process that typifies a collaborative project. The study created an environment in which to assess and discuss an accurate building representation in its context. It succeeded in introducing and testing a new collaborative and engaging process. Although data interoperability between software or model data has improved impressively over the last decade, if 3D city models are to be successfully integrated into a planning framework it is important to establish guidelines for the purposes of validation and standardisation. These guidelines would not just be instructional, but encourage communication between modellers and city model hosts to anticipate and resolve any interoperability issues that may occur.

Evidence from the first literature suggests that virtual city technology is often at the forefront of the latest technological developments. Hence it could be assumed that many of the organisations that are involved consider themselves to be in a 'product leadership' enterprise (see 'Value Disciplines', Chapter 3). This intentional or unintentional choice of strategy that follows this type of enterprise is potentially high risk and can lead to a problematic path. In some ways, a city model enterprise can pragmatically be classed as a service business, rather than a consultancy. In this capacity, consultations may be a feature of this service and should be taken into account in the organisational framework. Organisations that produce tangible products often must also involve (sometimes complex) supply chains and manufacturing processes – characteristics that are not normally associated with virtual city models. Hence, it is the application of a city model that defines its role. Specialist city modellers who produce 'off-the-shelf' 3D city data to their customers regard their city models as a tangible product, but the subsequent application by their clients can be indefinite (within the boundaries of any existing license agreements). Local governments who have purchased this data for use in planning activities, for example, may consider their subsequent presentation of a city model as a service and promote this service as a commercial consultation.

5.2.3 Legal Issues and Data Security

It was clear from the respondents that hosts pay much regard to the security of their data, taking great care in the control and distribution of data. This was attributed to a number of factors, which were ultimately beyond the scope of this part of the investigation, including the confidential nature of the information, the security implications, the associated cost of the data and the maintenance of competitive control and expertise. It was clear that almost half of the hosts who had purchased data were unclear of the legal restrictions, if any, on the ability to share and use it. In most cases, it was reported that the restrictions were limiting its use, even though they were unsure of the express terms.The licensing of data was a recurrent issue for most hosts. For hosts in local government who had experienced restrictions on sub-licensing the data, it was reported as 'problematic' but these same respondents did not express interest in using the data outside of the organisation, which would have violated any license agreements. Furthermore, these groups were normally far more stringent concerning the general security of access to the data.

Legal concerns began with the source of the data. In some cases, agreements had been sought by the suppliers of the data, but in most cases compromises had to be made, adding to the overall complexity of the situation. License agreements between hosts and data providers are a common feature, which permits the resale of the data if the source is honoured (financially).One of the clear trends from the interview stage, relating to data ownership, was that German city models tend toinsiston ownership over the 3D data and therefore the rights to use it freely. In situations where the data cannot be purchased outright, 3D data is gathered and modelling is carried out in-house.

Due to copyright and licensing restrictions, if an independent body is to host a city model, it will be a requirement from the data provider that city model data is not released to third-parties, or re-sold for commercial purposes. However, with the correct licensing arrangements in place, model data may be made available in ‘read-only’ format which could be used for online public viewing purposes without the underlying original data being extracted, modified and re-used. In the UK many city models or related projects are based on OS data. This means that the model must then conform to OS’ Intellectual Property rights that restricts the distribution and prevents the re-sale of its data. Some UK data suppliers are providing data using a combination of aerial photogrammetry and GPS surveys and the use of such data is defined in the licensing agreements provided by the supplier, rather than the OS. Such data providers will expect that clients, developers and architects will purchase 3D data for each new development project prior to inserting this into a larger urban model owned by a city authority, or an impartial body working with a city authority. For the purposes of the pilot studies, the data providers were contacted in order to clarify the express terms of the agreement. It was revealed that due to the lack of clarity in the legal terms that accompany the data, further communication is needed between the parties to explain or negotiate how the data can be used. Despite this, the data providers were flexible in their terms as the city model data was kept within an ‘enclosed loop’ of stakeholders who were not paying for such a pre-planning service. However, had the project been offered as a commercial service with the city model being at the forefront of this consultation, a license agreement would have to be honoured (or established, in this case) that respected the data providers with either a regular fixed fee or royalty of the charged service.

End user license agreements (EULA) were attributed to resolving certain data sharing or purchasing issues, but were not applicable in some situations. This type of agreement was preferred by city model providers, but it was observed by many respondents that this was not suitable for sharing a city model with other users or stakeholders. The difficulties of managing the interests of stakeholders are well documented, but there was a notable group that had a broad commercial interest. For example, large engineering consultancies are prevalent in many aspects of construction and building services consultations. A number of city model hosts reported that such firms can be both a stakeholder as well as being a developer for a new building proposal. In other words, many hosts were reluctant to establish partnerships because of possible conflicts of interest. With regard to access, LA’s in the UK were keen to share data or resources between consultants and planners, but all felt the need to restrict some control to avoid these parties having ‘carte blanche’ access to the data and its use. A common method that was adopted in database city models was the use of a multi LOD in order to satisfy a range of stakeholders but also to maintain a level of control.

Certain tools within the ESRI series were attributed to access control, such as ArcIMS 4.0[1] – a web-based GIS viewer, ArcView and ArcInfo for increased functionality and editing control. The ability to produce standalone 3D models for sharing city model data is increasingly becoming a cause for concern for some hosts as it has been shown that data can be extracted regardless of this non-editable or 'read only' state and re-used beyond the control of the original owner. The interviews revealed encouraging notions of information sharing through remote access to its data, by producing a model according to the 'simplest format'. However, the general security implications that publishing 3D models on the web could induce is a chief concern shared by all hosts or data owners that were involved in the various investigations. For example, it is accepted to be good practice to avoid modelling exposed building services (usually on the roof), despite the visibility of these details on a variety of web-based mapping services. Nevertheless, it is perceived that there is no benefit to virtual city users and the general public to justify keeping these features. Preliminary discussions with local building professionals confirmed that the design community is careful about distributing design concepts, particularly in the pre-planning stages.

5.2.4 Update Procedure

Of the city models produced in-house, over half of the interview respondents reported that they were constantly updating their data, although the frequency and methods in which this was carried out varied considerably. A close relationship with a LA was considered beneficial for sharing information about recent developments, while a local knowledge of a city is also a useful or invaluable quality for prompting areas that require data update. One respondent reported an 'effective ad hoc approach' to the city model update, whereby an area of the model was checked, verified and updated (if necessary) alongside their current project or task. This usually covered any 3D geometry within a 20 metre radius but this was dependant on each iteration to include a coherent area, such as a city block. A challenging aspect of updating 3D information is the integration with the existing elements, such as updated terrain with existing building models. Maintaining correct building heights was mentioned in many cases as a difficult aspect, with regards to preserving the accurate building height and footprint level with a change of terrain information, or vice versa.

Over half of the respondents reported an update strategy involving the re-acquisition of entire city models from independent data providers. This was always done when the

[1] However, ArcIMS is no longer supported since the release of ArcGIS 10.1

hosts judged that the model was out-dated and could generally be on a cycle of between two and six years. It was reported by a city modeller that in the UK, the average city centre (approximately $6km^2$) can require between 60 and 100 'major changes' for each city. Hence, new aerial photography is purchased and the entire city area is re-modelled, rather than just the areas of change. This is done for a number of reasons. Firstly, analysing an area of this size and making the necessary changes is as time consuming as complete re-modelling Secondly, improvements in the technology used in the process (specifically aerial photography resolution, photogrammetry and modelling software) is continuously improving and adds to the overall speed and accuracy of the results.

Generally speaking, the 'off-the-shelf' datasets were not updated (re-purchased) on a regular basis. Some respondents commented that this was not 'ideal' and most expressed their intention to establish a proper update procedure at some stage in the future. Hosts from Local Authorities all expressed a desire to update their own data, even if it had been purchased from an external source. The non-database models that hold multiple versions caused many technical difficulties in synthesising the updated data, hence entire remodelling is carried out (or planned) by these hosts.

Of the HD model types, two thirds were planned as phased data upgrade processes (up to five phases in one such case). These updates were dependent on receiving funds from stakeholders (city councils in all cases), rather than on a scheduled basis. A respondent reported that it was not their wish to continue in this way, and they would prefer to instigate a quarterly update based on a monthly subscription for use of the city model. However, this was entirely dependent on their client's requirements.

One interview respondent outlined an imminent update process that would be instigated by their clients and would require new LiDAR data capture and new aerial images. The model would be updated by using a 2D footprint overlay to indicate the location of new or modified buildings and created using photogrammetry. In this case, the update was carried out every four years and integrated into an ESRI-based geo-database.

5.3 Technical Solutions

5.3.1 Modelling Processes

A distinction was made between interview respondents' attitudes towards sources of data, showing two clear inclinations. On the one hand, many hosts prefer a single, consistent source of data (either purchased or modelled in-house). This group typically had one model, with distinct boundaries, that displayed a single, constant level-of-detail. A single source of data is chosen and usually maintained as a standalone model file. The second approach is best described as a collaborative attitude to city model data. Here 3D information is purchased, acquired or contributed from a range of sources. Databases were prevalent in this situation as the information needed a more adaptable structure to support it. Hosts that followed the 'consistent' approach had investigated modelling processes and made an informed decision to pursue a specific method. The 'collaborative' group was usually the result of a more exploratory development process. Data was sourced from a range of contributors and a database infrastructure was a necessity in this situation, which expediently creates many benefits, such as flexibility in its application, a more straightforward update process and more beneficial to a range of users as well as stakeholders. Hence, two distinct strategies can be summarised. Firstly, a 'one-size-fits all' approach that uses a database containing multiple representations of a virtual city that satisfies a variety of users for a range of applications (see Figure 50, below). Secondly, a 'universal' virtual city of consistent detail that can be used for specific (but limited) applications.

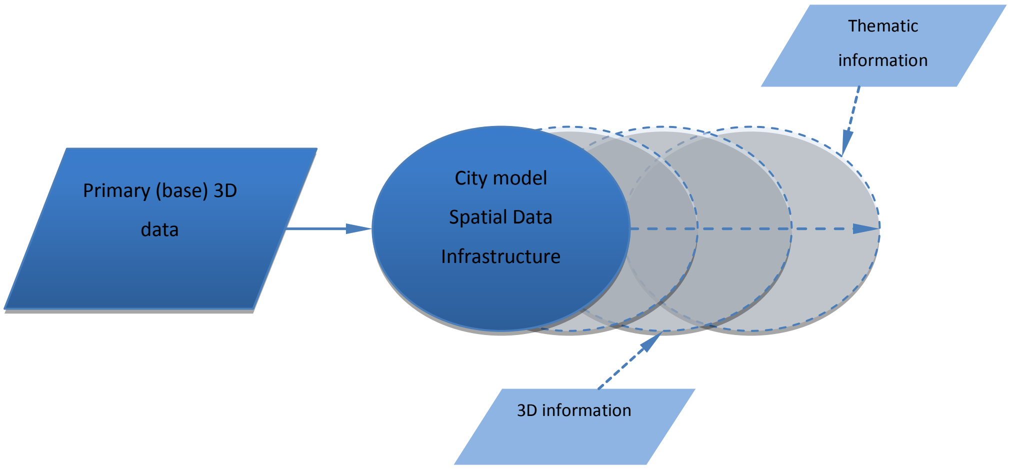


Figure 50: Indication of a collaborative approach to a virtual city project

Figure 50 outlines the collaborative approach, where the intial source of data is acquired and to which all other information relates. A spatial database infrastructure is established after which all other information can enhance this model.

Results from the investigations showed that there are three strategies for acquiring the 3D geometrical data, either by producing the city model data themselves (the host), purchasing the data from a specialist provider or by acquiring it from various contributors. Where models are produced in-house, the majority begin with the acquisition of 2D footprint data that is extruded to the correct building heights. In many ways, this is done to avoid license agreements with 3D data providers, although this does not always avoid a similar situation with 2D data. Of the HD city model types, all of the interview respondents reported that modelling was outsourced to a separate team. One of these hosts demonstrated an upgrade strategy after first creating a model using 2D plans and accurate LiDAR data to form the basis for the more accurate modelling process that followed. This host reported three versions of their city, an 'online' version (photogrammetry, purchased), a standard version based on the LiDAR and a HD model. This was common practice whereby hosts are keen to produce an extensive geographical coverage of their virtual city using the most practical data capture available, for both practicality and to encourage its use.

It became far more evident during the interview process of the tremendous workload that laser scanned data presents. Evidently, laser scanning still continues to be a tool for surveying and some specialist applications that have been adapted for 3D architectural modelling. Hence, modellers still considered their methods experimental and where anticipated much future software improvement could improve modelling time. Costs are considerably higher in all aspects of modelling and maintaining a city model, although the interview respondents used high end equipment available (Leica Scan Station or HDS) rather than more competitively priced models.The terrestrial laser scanning process differs very little between current virtual city hosts: data capture is carried out using long distance terrestrial laser scanners to gather the spatial information, usually by two people although up to five was needed in some situations for transporting and setting up equipment. (This can include scanner, scanner tripod, laptop, generator, 'Total station'). Photography is also captured at the same time using digital SLR cameras. Scan data is then merged to create a large point cloud, which is refined (the number of points is reduced), digitised and textured. Up to 10 scan positions can be used to model a building, depending on its size. Accuracy is gained from the quality of the laser scanners and by integrating with accurate terrain data that is also carried out in-house (using a Total station). One interview respondent reported to be leading a project to develop software that could automatically refine the point clouds and automate some of the process for 3D building modelling. Although it was observed that this field is being researched by a number of parties, it was suggested that none were suitable for their particular situation. Furthermore, despite the cutting-edge technology used, it is a laborious and cumbersome task to carry out. The costs of the laser scanners reported by interview respondents ranged from between £65,000 and £155,000. It was also evident that the largest of the laser-scanned (HD) city models are somewhat smaller (than standard) due to the cost of the modelling. The largest of these was 40km^2, whereas photogrammetric models were reported as being as large as 500km^2. One city modelling company reported that feedback from a developer revealed that their (HD) model was too detailed for their application and the early stages of the planning process (pre-planning). Similarly, a second respondent confirmed that such a detailed (HD) model was not generally required for a large area solely for the purposes of visualisation. This host suggested that a more efficient city modelling process could be to combine terrestrial laser scan data with LiDAR to produce a 3D point cloud representation of a city, which it was estimated could address about 90% of visualisation needs. This would describe a far cheaper solution as it would avoid excessive modelling, but would still provide a very accurate dataset for reference or subsequent modelling, despite the model being ‘patchy’ in certain areas and containing scan ‘shadows’ that are indicative of the terrestrial laser scanning process. On-going costs would also be reduced, which means that this method is particularly applicable for smaller councils who often have established LiDAR suppliers and the software for its mergence with terrestrial scan data is correspondingly cost effective. Hence, LiDAR continues to be a popular method for data capture, as its resulting DTM or DSM can produce effective virtual cities for a great deal of tasks, where extra modelling tasks or data management is not desired. ‘Overwatch LiDAR Analyst’ for ArcGIS is a software package used by respondents that extracts 3D information from LiDAR in a GIS environment. The resulting DSM (as opposed to DTM) has been used by many local authorities in the UK for a number of reasons. Firstly, they produce a good balance between detail and realism. They are also described as convenient to produce (fast delivery and cost effective for large projects). However, they are usually used for one-off projects as they are difficult to edit and update. Textured buildings and surfaces are not usually necessary for pre-application design or consultation, although the ability to apply tones (colours or shades) to building geometry was suggested by a respondent to be a useful feature.

Of the models purchased ‘off-the-shelf’, many of the respondents were beginning to favour a method of upgrade or enhancement of their data by modelling their city’s landmarks or significant buildings. This has been reflected by some city modellers who are offering this as a service on top of their existing photogrammetry city models (one city modelling company claims over 1,000 landmarks in 30 cities have been modelled). This is mainly done to demonstrate some upgrade to the model and ‘refresh’ their (hosts) model, but it also has the added benefit for planning activities as it is easy to locate these buildings for preserving lines of sight, massing and other planning tasks.

It was evident that many hosts favour the ‘off-the-shelf’, standard city models due to the practicalities of the service. Acquiring aerial photography and modelling the city requires a great deal of cost, resources and management. For example, commissioning aerial photography was considered to be increasingly problematic, due to poor weather conditions and the requirement to gain permissions (notably difficult in London), which reportedly prevented half of the intended flights in 2007. The cost of photogrammetry software itself lies between £4,500 and £50,000, which obviously does not take into account the raw data, IT resources, time nor expertise that are required to complete the modelling process. On the other hand, the price of a virtual city modelled using these methods can cost between £18,000 and £84,000 according to the respondents. However, the main disadvantages cited for this cheaper method of data acquisition were the often complex data ownership and the lack of customisation in the modelling. For example, Local Authorities usually desired that all of their ‘fixed assets’ were included in the modelling processes, which were not usually consistently achieved in previous projects. Hence, some data capture and modelling was needed on top of this but cannot always be integrated into the city model (legally or practically).

Some of the ‘off-the-shelf’ data providers reported extensive, speculative modelling strategy, one of which included the modelling of 100 cities in one year. This was done by outsourcing the 3D modelling itself to a partner overseas (typically China or India). This will then allow an online service whereby customers can define their desired modelled area and download directly from the website. The subsequent re-use of the city data will reduce the overall costs, similar to other remote sensing and ‘archive’ data. City modellers report that approximately 0.2km^2 can be modelled per person per day using current photogrammetry software.

Two respondents had referred to a process of ‘populating’ their city model with additional 3D information. In this way, their existing ‘authentic’ city model was supplemented with randomised or simulated building models (entire districts) to extend the boundaries of the existing 3D information. This was done for either one of two purposes: to add a more realistic environment for the city context or to enhance the model for creating video or images for promotional material. The buildings were created in this instance using existing software running a ‘randomised’ script that produces 3D geometry based on defined properties and within a set boundary. It is done to reduce cost, although the respondents were aware of ‘procedural modelling’ programs that could replicate this process with more variables and detail.

5.3.2 Software Solutions

In order to give some context of the extent of GIS use, one of the hosts from a Local Authority in the UK reported that spatial data users within its organisation comprised of 250 GIS licensed desktops, 300 map viewers, 100 CAD users (using ArcInfo 9.2 or 9.3.1 as public viewing for this release required 9.2 and why many were using an older package). However, despite spatial information and related systems (including the introduction of mobile GIS) all of the different departments within the council are gathering different data which makes it very difficult to encourage a culture of data sharing within this organisation. They reported that there were approximately 500 databases in operation, although an exact figure was not known. Reported spending was approximately £50K on ESRI licenses alone and approximately 80% of their data has some kind of spatial element. Google SketchUp 5 was used by all hosts, although it was not clear about the extent of its use. Notably one user described it as effective for simple massing but poor for when topography and accuracy are introduced (relating to Google

Earth). Its use is recognised by all hosts whereby its users bring experience and expectations of growing interactions. This affirms evidence from the literature investigation that suggested institutions and organisations are beginning to consider their use, as the perceived cost barriers that can impede the use of VR in planning are rapidly decreasing as on-line options emerge (Strobl, 2006; Perkins and Barnhart, 2005; Sunesson *et al.*, 2007). These technologies for relatively standard geospatial visualisation and interactive environments could also address issues of deficiencies in public participation.In the third pilot study, a relatively small scale design template (compared to a complete city model) was used and enabled a more fluid analysis of various software packages[2] and highlights the platform as a means of reaching a broad audience. However, since this pilot study was completed, some of the features of the software have been removed (.3ds import) demonstrating the need to constantly monitor software releases, which may remove features as well as add them. This is particularly evident in free and 'beta' software releases that are used by organisations when developing the software and business models for their application.

Results from the pilot studies showed that although the process of importing a complete virtual city dataset into current Google softwareis possible, large amounts of 3D model data are presently unsuitable for the smooth running of the software (Google Earth 4.2) and much optimisation is needed. This includes the removal of unnecessary features, such as model lines and planes that are indicative of a photogrammetry process. Further investigation involving integration of a more detailed, textured dataset revealed the extent of inaccuracy and inconsistencies in the Google Earth terrain layer (see Figure 51). The hosted data used in the study was based on accurate measurement, whereas the accuracy of Google's terrain is based on a smaller density of data points and its height information is effectively based on the average over a larger area. This can create a range of problems, such as parts of the building being underground or suspended above ground, especially evident for large buildings. Figure 51 compares two images of the same cross section from different software and terrain data. This terrain layer can be modified temporarily or supplemented when modelled in SketchUp, but this is a time consuming process.

[2]SketchUp 7, Google Earth 4.2, AutoCAD 2008

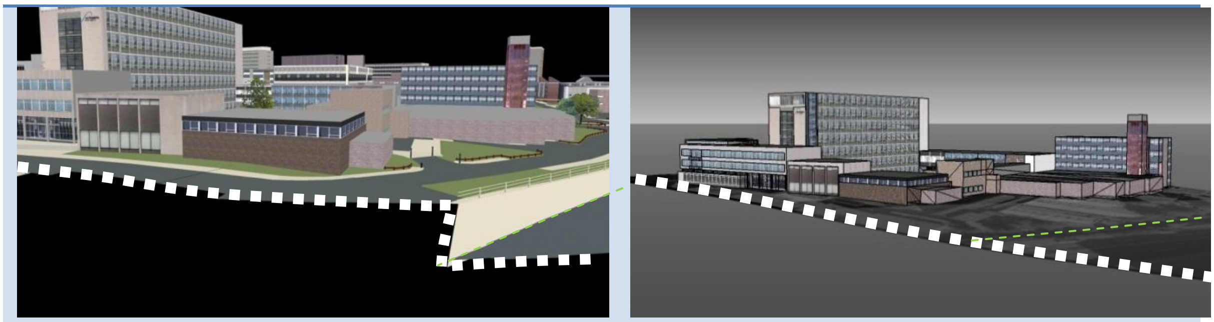


Figure 51: Google Earth terrain inaccuracies

Given the issues raised in the investigations (pilot study 2 in particular), it is clear that GE is not suitable as a credible tool for virtual city modelling and detailed design. GE, as well as SketchUp, has seen significant success in architectural and landscape design and its users state its ease of use that enables basic modelling and analysis (e.g. lighting simulations) with very little expensive or hardware demands. Hence, the software succeeds in its ability to quickly produce (compared to more expensive CAD packages) basic visualisations that are characteristic of the design and pre-planning stages. Problems occur for more accurate analysis, as the attention to detail requires more accurate terrain data. This also relies upon the constant improvement of data exchange over the internet, as the performance of the program requires large quantities of data streamed through the local web connection. The discrepancies between the accuracies are not uncommon in city modelling. (Some city models are based on a variety of different datasets, such as OS building footprints and LiDAR terrain data). This can depend on the age of the data, technology used, and calibration of the equipment or even human error. Hence, it would be difficult to validate the accuracy of a city model that is created from a range of sources.

Three compatibility categories were identified in the various investigations that must be addressed when sharing data in a collaborative project, regardless of data formats or software platforms:

1. Software and data compatibility: tested during preliminary investigation, including verifying backwards compatibility between established software. In this case, the compatibility was verified and the new building development was exchanged in .3ds format, for use in AutoCAD 2007 and 2008, Revit Building 9.1, 3ds Max 8 and SketchUp 6. These are commonly used packages currently used in practice albeit in more advanced releases. The extent of compatibility between software and file types can be the deciding factor of how much re-work has to be done after the file import process.
2. Modelling protocols: including the use of software, file management, material and texture templates, levels-of-detail, stylised models, etc. This can vary across all

practices, industries and countries. Although BS (British Standards) and ISO standards exist to alleviate these problems, they currently only apply to 2D plans.

3. Geographic position: similarly, the correct location, altitude and orientation of building models can vary depending on the organisation. It is often the case that architects will conduct a site survey that does not need to be properly geographically located on a national level, merely located in relation to adjacent buildings. The altitude and orientation of a site is a similar issue but are typically true in both cases, as these are normally required to properly indicate the topography of the building proposal, accurate roof heights, etc. The use of BIM (in this case by the means of Revit Building 9.1) encourages the correct geographic position and orientation based on OS coordinate system or datum.

Observations and feedback gained from the planning activities (as opposed to the 'design' meetings with the architects) during the pilot studies revealed key features of the virtual city that were noted as useful by the parties involved, some of which were not present in the current model. These attributes are:

- Non-textured facades
- Accuracy to within 1m
- Roof details

This would provide a sufficient blend of accuracy and detail that would allow the comparison of massing and the impact of a new development within its proposed context. A lack of textures was not necessarily a required attribute, rather a consistent texture across all buildings or 3D features that enabled a straightforward visual comparison. Furthermore, the following features of a virtual environment where shown to be beneficial to the process:

- Pre-defined viewpoints.
- Pre-defined fly-overs along specified routes, roads or pavements.
- Simple real-time editing features or tools (although this was not considered important by the planning officials).

The Virtual NewcastleGateshead model data that was used within this study was bought from a specialist city model data supplier. The terms of this purchase and its subsequent use stated that it could not be used or distributed for commercial purposes without the source's permission. Although this caused some practical issues with the integration of the 3D models, it was possible to remain within the legal terms without affecting the outcomes of the process as the studies were not carried out for commercial gain.

In terms of modelling protocols, the literature investigation revealed that certain features are required for many planning tasks that are not evident in many of the virtual city models, even HD examples. In particular, building stories were suggested as a requirement for modelled real world objects for use in 'local authority planning' (Capstick & Heathcote, 2006). However, in almost every instance these were not evident in models. Similarly, property boundaries can be appreciated in GIS environments, but not in every instance of the standard virtual city types (interviewed). There were also many inconsistencies amongst the requirements and specification for landscaping features, such as hedges and plants.

The subject of accuracy can be discouragingly broad and its measurement considers a great deal of factors. These relate to the geometric accuracy of the completed model, but also the positional accuracy of 3D information, with respect to its overall location or the position of its components (e.g. buildings). Furthermore, there is also a level of semantic accuracy, which is a particular concern in models based on airborne data capture. In this situation, modellers can omit certain elements or building features that are either too small (deliberate) or not visible (accidental) from the source of the imagery or data points. Hence, some of the causes and extent of these inaccuracies begin with its method of capture. Contractually, city model hosts are required to deliver a product, whereby this accuracy is expressly stated, yet it can be found that the product is in breach of the agreement. Hence, there should be suitable measures built into the applied planning process that involves the verification of the data.

5.3.3 Data Infrastructure

In terms of physical storage of virtual city data, 3D geo-databases are used byover half of the hosts from the interview process and particularly in large, standard model types in order to establish a 'suitable spatial data infrastructure' similar to a GIS environment. Despite these links to GIS, few of the virtual city models are used in a GIS environment as it was reported that ESRI 'multi-shapes' feature class still cannot suitably handle complex 3D geometry. Effectively, 3D geo-information is kept in a system architecture that "allows independent authoring, editing, presentation, etc. to be carried out without affecting the underlying data". In terms of databases, Oracle Spatial was used in all cases, as well as Oracle 'Workspace Manager' that was used as a method for representing models and information over time, such as earlier versions of the city or planning proposal alternatives. SimpleServer is also a product that was in use by one of the respondents for storing the data. However, it was reported that hosting a virtual city using a database infrastructure can be complex, notably with the feature of varied access or permissions. In situations where city models contained various levels of detail, the models are kept in separate databases. Of those that commented further, all shared the notion that they had intended (or were developing) a single database that would enable different (but closely linked) versions of the city model. Political reasons were reported as the main restriction, as certain contributors are not always willing to share their information. 3D building information was stored in a traditional standalone file structure and presented a high risk of data corruption. Editing these large files in a 3D environment resulted in poorer PC performance.

The interview respondents who spoke informatively on the matter suggested that conforming to any recommended or official data standards involves extra cost for time, training and software. In the case of CityGML, the structure of existing 3D data is effectively rebuilt and extra semantic metadata must be introduced for each 3D object in the city which is an extensive process that depends on the size of the model (as well as the LOD). The perceived benefits are familiar to all, notably interoperability, sustainability and flexibility. Hence it was highly recommended by three interviewees that the intention to conform or publish to a particular standard was essential at the data collection stage to ensure that the modelling process and organisation could be carried out properly. CityGML semantic information that was being utilised included building addresses, number of storeys and construction data. Generally speaking, only one respondent was unaware of CityGML although most of the non-Local Authority hosts were ignorant of the impending INSPIRE directive that has far greater implications on the overall organisation of GI data. Some of the respondents from European cities were anticipating that INSPIRE would eventually make spatial data freely available or may allow more collaborative data sharing in the future. However, much work is needed to link the two, possibly through software or dedicated middleware ('geo-portal toolkits'). IFC model compatibility was mentioned as a recommended feature of city model data, currently not yet supported by CityGML. Of the HD city models, none of the interview respondents were conforming to CityGML or other recognised standards. Some investigation or consideration had been carried out but in all cases the standards were considered to be too impractical or unnecessary to their needs or project environment. Almost all, however, had researched emerging standards and methods for laser-scanned derived models. Cityxml was another widely used data format and a proprietary format of CityGrid middleware, designed as an alternative to CityGML in order to overcome some of its present limitations. CityGrid middleware utilises a 'hierarchical data structure' for organising its data that reflects the representation of features of the built environment.

It was revealed that CityGML derived models were being used for viewing in Google Earth (although thematic querying mentioned above is not possible in this medium). In fact, all of the respondents had carried out some exploration of using GE for either viewing or distributing their city model, to varying degrees. This ranged from basic field tests of single objects, explorations of Google's legal terms to full model import and network links. Those that had adopted the network link were experiencing positive results, yet cited a poor performance of the information that made navigation by a normal user with broadband connection somewhat impractical. Three respondents had carried out discussions with Google to develop an improved service, with Google hosting the data. One of these, however, had chosen not to pursue this contribution as it did not provide a sufficient facility to update the information and they had requested access to Google's database to resolve this. Furthermore, it was suggested that Google would provide some access or editorial sub-contracting to other parties to add features. However, the software company is not currently in the practice of adding links to its listing as it cannot control or guarantee this data, particularly in the eventuality that a link goes offline or encounters problems, for instance. One respondent had explored the use of a third party software company that specialises in this area (web enabled GI) for the purposes of bridging the gap between their HD city model and GE. Furthermore, many respondents noted the difficulty with sharing models as they were aware that many organisations, particularly the Government, cannot access GE from their place of work. In order to resolve the 'one-way' transferral of data between the user and Google (or between the model host and Google) many hosts have explored other web-based or web-enabled software packages, such as the approved OGC web services that contain web map services, coverage services and web feature services. In most of these systems, the end user is able to download (as well as upload) and change features within the model, without affecting the master model. However, poor performance was reported in all of these services, owing to their limited use. At an organisational level, the major advantage that Google's software package presents is its use as a platform for communicating and presenting 3D city model and building information for a range of users. It is a viable solution to some of the technical issues and barriers that prevent access to city data for planning and public participation (Knapp *et al.*, 2007, Wang *et al.*, 2007, Kobayashi, 2006, Strobl, 2006). The performance of this software platform is steadily improving, in line with public access to broadband connections and increasing PC speeds. Many of the navigation issues and barriers associated with VR models outlined in the literature review (Bourdakis, 2001; Dobelis *et al*., 2004) are alleviated through the use of a simple interface and a familiar software platform.

It was estimated that middleware accounts for approximately 1/6 of the cost of raw data capture. It was described as an essential component for 3D data management, used in conjunction with an Oracle or SimpleServer database enabling its users to have 'true 3D data within a relational database'. Users reported tasks such as:

- footprints alignment tools
- multiple representations of buildings (based on the same datasets)
- historical tracking
- versioning

Of the specialist 3D city model data providers, the format in which the city models were produced showed some contradictory results. City modellers produced their data in a 'preferred format' or modelling protocol, y*et* all of these reported that their outputs could be tailored to their customers' needs for an extra cost. For example, some customers requested specific layer formats to suit their current systems. However, half of the modellers noted that this was often quoted before the modelling took place, but was never formally requested. One of the respondents suggested that many of their clients are not always entirely sure what they are going to be using their model for, so they explore certain options before making the purchase of their data.

Non-database (or 'standalone') models were organised using a layering system as in many CAD systems. For instance, pre-app, approved and under construction are colour coded against their 'master model', which can then be hidden from view as required. This notion of a master model was considered by a number of respondents and was described as an underlying dataset from which all other data would refer to in order to maintain consistency in the city model. In this way, many of the UK models rely on an underlying OS dataset, even though it is rarely visible or used during the city model's application. Users reported that it provides a failsafe during data update, upgrades and renewal that provides a consistency to the spatial information.

5.4 Organisational Protocols

5.4.1 Applications and Markets

In establishing a city model that would be fit for many purposes, evidence from the various investigations suggests that this does not necessarily lead to a widely used enterprise. In fact, the interviews point out that that the most consistently used are those that focus on just one or two key applications, tasks, activities or services. In many ways, the data structure from its acquisition dictates its on-going use and therefore its users. However, this does not necessarily relate to their type and detail. Furthermore, four hosts reported that textured buildings were not necessary for the majority of planning related activities, although this was not a clear enough trend to discount the feature altogether.Evidence from the literature investigation shows that contemporary and cutting-edge city model enterprises have much in common with information systems, which Ozdilek and Seker (2004, p1) define as a system "that relates to a chain of operations leading to planning the observation and collection of data, to storage and analysis of data, to the use of derived information in decision-making processes".

Levy (2011, pp2-7) suggests that despite the widespread use of 3D modelling and global visualisation engines in planning, the success of 3D cities lies in their integration into an established planning process. Projects based in Europe revealed a distinct advantage through a strongly integration between the city councils and regional business development agencies, although this is increasingly the case with UK Local Authorities and their associations or partnerships. This strategy provides an ideal environment for the development of a virtual city, whereby the wider commercial benefits beyond urban planning and geography are also explored. This can offer a more engaging and broad-reaching city model enterprise that is not considered as an insular resource. It is also clear that their use is not strictly restricted to either commercial or non-commercial activities. Real estate and business development are examples of such applications that have benefited from involvement in a virtual city project. However, this does not mean that the data itself is shared to the external party.

Despite their expertise in GIS and post-GIS, hosts from UK Local Authorities confirmed that the main users of an integrated virtual city dataset within their organisation would be planners during pre-application (planning) and consultation stages. Currently, the largest use of 3D GIS in these organisations was reportedly in planning and transportation, followed by traffic management. It was often the intention of UK LA hosts to use their 3D virtual city model in a GIS environment (e.g. ESRI ArcScene), but it was noted that this would either require special data capture and modelling techniques or model conversion to convert their current data. Many Local Authorities reported that they had originally purchased 3D data for this purpose but this had not been suitable for GIS. Respondents suggested that local planning systems in European cities demonstrate more autonomy in comparison to UK cities, who, it was suggested have been more hesitant to adopt virtual city technology. Respondents also revealed the disparity in aspects of the planning application process. In the UK, requirements for large developments are tailored to each client and require a great deal of communication between all of the parties. Applicants are requested (based on the established guidelines or frameworks) to produce certain reports, such as an Environmental Impact Assessment (EIA), strategic views, building heights, etc.

A minority of models (less than 10%) had arranged a formal agreement to share or license the city model to external parties. This feature was often referred to on a theoretical basis or as a potential development in the future, yet this was rarely done in practice. However, almost all of the respondents admitted that the use or uptake of their city model was not as much as they had hoped or anticipated, although some of these were in an introductory stage. This was also put to the financial environment in which these enterprises are currently emerging from. For instance, one respondent expressed that their local design (architecture, designers) community had expressed much interest in the model but this had failed to materialise into commercial exchanges. Most of the hosts for all backgrounds expressed their desire to be an integral part of the local planning service, although all agreed that it should not be a compulsory service for submitting plans. Hosts in Local Authorities in the UK usually encouraged the service through their planning officers during the pre-planning meetings. One of the respondents, who was a specialist city modeller, was developing a service for inserting models to produce images and possibly a section of a model that contained a developer's submitted model after feedback and experience gathered during their years in trading. This was aimed at smaller developments, architects or those who did not require a complete city model.

The use of scientific simulations had been carried out by almost 75% of respondents and included pedestrian or traffic flows. These ranged in their extents, but all had mentioned that this particular activity was finite and not part of an on-going or repeated study, except for the case of noise mapping, which was cited as an important application by all German hosts. Specifically, the Environmental Noise Directive (2002/49/EC) was cited as the main reason for this development. In fact, a large proportion of German projects had been established for this application alone. The uptake in UK cities for noise mapping was considerably slower, although it was referred to as a future or aspirational application by many respondents. The modelling and simulation tasks were carried out for the purposes of reporting on the current level of noise within a city, rather than as a tool for simulating new developments and improving the current environment (which was mentioned as an application for future consideration). The respondents considered this as a planning activity as it had been commissioned by a number of Local Authorities in response to the EU Directive that enforces it. The Directive does not explicitly state that noise mapping should be carried out in a 3D environment, but some hosts indicated that this is the most effective method for delivering the Directive's actions, including:

- determining the exposure to environmental noise through noise mapping
- adopting action plans based upon the noise mapping results and
- ensuring that the information on environmental noise is made available to the public (Commission of the European Communities, 2011, p1).

In some circumstances, city models were commissioned to an external organisation to carry out the modelling and simulation tasks, as well as the on-going hosting of the city model. This was done to reduce costs and considered to be the most efficient way to deliver noise mapping simulations, using appropriate expertise. The level or accuracy of scientific simulations that were carried out was not generally associated with their model type and detail. In particular, almost all of the respondents reported the use of simple shadow 'study', regardless of their city model's accuracy or representation. However, HD model types had been used successfully for accurate lighting simulations, such as exploring 'rights of light' issues concerning new developments and the exiting streetscape. Similarly, the actual simulations were usually carried out by external parties other than either the host, namely engineering consultants, building services engineers and traffic management consultants. Despite claims of only 0.5m accuracy LA's in the UK reported that errors or conflicts can be up to 2m when real survey data is compared to OS. However, the OS is a highly regarded source of information, which many systems use as a 'base' or benchmark. One application that benefits directly from accuracy and high detail at ground level was a design task reported by one of the HD models using an advanced line of sight to inform the design process at its earliest stages. Working backward from the planning requirements and visual impact assessment, the study would reveal the maximum size and form that a plot could enclose. Hence, this was described as an envelope tool for both planners and architects to assist, resulting in a more 'democratic planning process'. Emergency planning was also commonly cited as an application and one that benefited from simple visual analysis using a 3D model.

Hosts from the UK used their virtual city models for pre-application planning activities for the majority of applications. One of the respondents from a Local Authority reported that they process approximately 50 applications per year[3]. However, all of the hosts of HD city model classes reported that their projects were commissioned by a Local Authority (or the planning department within the council) who had a very clear intent for their application. Typically, this was for architectural heritage and tourism, as well as for aspirations in generic planning activities. Furthermore, all but two of the respondents cited 'tourism' as an application or secondary application of the city model, although it was unknown of the exact activity with which it was used. It was often reported that shortcomings in city model thematic information as well as lack of basic functionality did not allow a great deal of exploration or querying during visits from planners or designers. However, it was also clear (from the interviews, as well as previous investigations) that neither of these parties required or desired the host to provide modelling or editing abilities and thus introduce a creative process. Some respondents pointed out that this would be a feature to explore, but merely for research or PR as current planning and design processes are well established and guarded respectively. E-planning was a term used very broadly and encompassed any function that used a PC: from GIS to 3D modelling, office tools, email and internet use. Hence, 3D modelling accounts for a very small proportion of this bureaucratic adjustment. Of the respondents from LA's, almost 75% (17) expressed that if they were establishing a city model service they would ensure web access from the outset so that the 3D and thematic information could be kept up-to-date. It was revealed that during a particular development or project, urban planners or designers first require access to the entire dataset, followed by smaller sections of 3D geometry for their design stages. This is based on their experience with existing software and the diminished performance when using large 3D datasets.

[3] A large UK city with a population of 260,000.

Applications in heritage were strongly associated with laser scanned 'HD' models, as it was reported that this application requires high levels of detail for recording fine details of a building's fabric. Hence, applications in heritage require greater detail and therefore data points that would suit a more 'survey grade' dataset that terrestrial laser scanning can produce. The result is that more time is required on site to capture the data as well as modelling time in order to transform this extra information and refine the point cloud. Of the HD city models, a unique application that was reported was for analysing building shift or movement. In this situation, an area of just under $4km^2$ was re-scanned one year after the initial scan and remodelling had been carried out previously and when compared to the original data at least one building was shown to be leaning.

One of the respondents reported that their most recent city model was launched (using extensive promotional advertising) in order to demonstrate the technology and test their business model for the production of further virtual cities. Research and feedback from key practitioners confirmed a demand for city models, but its response after the launch had been significantly lower. The current financial environment was blamed for this slow acceptance, although this could not be validated. Moreover, the same respondent reported that one of their clients had recently commissioned a cardboard model of a city area be built instead (the LA represented a large city with approximately 500,000 residents). Although the subject of public consultation was not on the interview agenda, the subject was proposed on a few occasions. It was suggested that public consultation is usually led by public relations and marketing motivations, rather than to assist planning activity.

Property development was cited by a small number of respondents from the largest city models and either basic or standard city model types. The activities involved exploration of the model and allowed viewers to find undeveloped areas of large cities or navigate to areas that had been requested by clients or stakeholders prior to the meeting.

One respondent expressed a wish for use in assessing cost impact. A number of planned developments that are submitted are found to be not financially viable after a great deal of design and consultation work has been carried out. This is often because highways, services or utilities need to be relocated or modified at great cost. Hence, it would be useful if a model could be queried with respect to these modifications to assess the financial impact of the development.

Despite the variety of applications in use, creating visualisations is the most common 'output' for a virtual city model. These range from straightforward images of context or massing models to detailed, realistic renderings. The study that occurred after the first pilot study to compare photomontage with renderings from the city model was carried out to test the validity of cutting-edge photomontages carried out by professional architectural visualisers, but also demonstrated another application for a city model. Not only could they be used to validate and therefore justify the use of verified photomontages, but also to reinforce their use where they are required (e.g. London) and where highly detailed and textured city models are not financially feasible.

It was the opinion of some respondents in the UK that their LA's are particularly reluctant to change their decision-making process. This deters many designers from using a city model as this process must be a top-down development. Hence, pre-application design and consultation was favoured as one of the most useful applications of a virtual city that would allow ‘a quick turnaround’ for any changes between pre-application and final submission. In this way, it is evident why many hosts do not see their 3D data as a long-term endeavour – rather as a method for assisting a quicker planning application process, an investment that will save time in the long run. The relatively low cost of LiDAR data (approximately £200 per km2 for a LiDAR produced DSM with significant reductions [over 50%] for carrying out regional wide surveys) explains why this method is favoured in this environment.

Despite the reported short life span of virtual city projects in literature, the audit process revealed many examples of cities that boast more than one city model (e.g. London, Paris) from a growing list of 3D modellers, 3D data providers, GI organisations and engineering consultants. This demonstrates an enduring demand for 3D data from an increasing list of clients. In contrast to this, German cities such as Berlin and Frankfurt demonstrate a unique ‘master virtual city’ that many organisations contribute to.

5.4.2 Finance

The subject of cost was perceived to be the most sensitive area for interrogation from the preliminary studies, supporting the lack of literature in this area. Only 10 of the interview respondents were able to discuss the matter of costs of their virtual city project. The primary reason cited was due to the lack of clarity for the area. Data capture, data modelling and staff resources were relatively easy to numerate, but many other factors were indeterminable in many cases, as they were, in the case of the non-respondents, integrated into other departments, organisations or projects. Generally, principal costs were obscure because the hosts were receiving financial (substantial in some cases) help from a key partner or EU funding. Interviewees were involved in complex organisational structures that were already established before the formation of the virtual city project and therefore beyond the scope of the study. Where data was purchased from specialist modellers (using photogrammetry), the cost varied between £500 and £2,150 per km^2, which ranged from basic 3D geometry to textured datasets with defined building feature attributes and appropriate layering system.

A clear indication of the relationship between costs of a virtual city project was revealed through the interview process. The main factor that affected their cost was the LOD. Accordingly, the HD city model types were the most costly to produce and over budget in all instances. A higher LOD required a more accurate, customised data capture process, significantly more modelling time and expertise in the process. Furthermore, this level of expertise was needed for a set amount of time after the initial completion of the model, as well as at the data update stages. Almost all cost bearing aspects increased with the LOD, including the supporting hardware and software that ran the model.

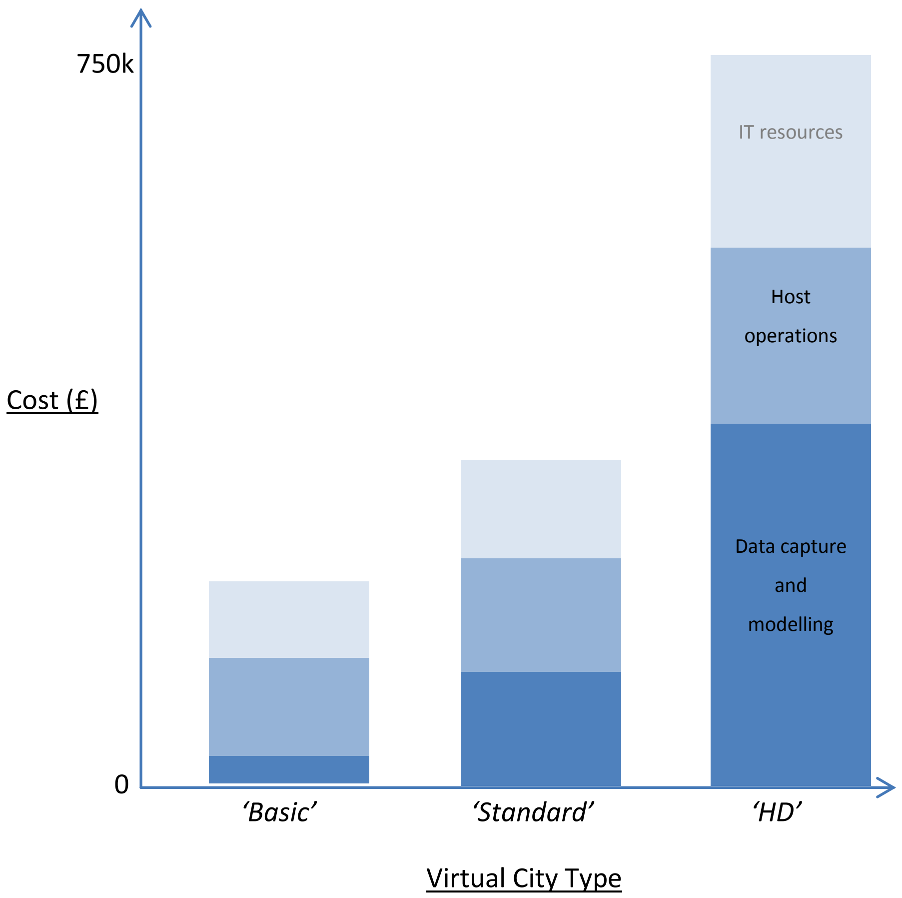


Figure 52: Indication of the cost breakdown according to city model types

Figure 52 outlines this relationship of increasing cost with the LOD and resources. For the cases of HD models and above, the increased LOD results in a more expensive update and were directly linked to those models that had a less frequent update process (typically 3–5 years for the first cycle). However, only one respondent that hosted an HD model had continued the update process, albeit in a more 'scaled down' fashion and one that was not intended during the project's inception. This high LOD had a knock on effect to all of its subsequent applications and tasks that were more time and resource consuming, by a factor of two. The higher LOD had significant on-going costs and an increased burden to compensate or recoup this cost. However, the respondents were convinced that the standard of analysis that was gained from the model was deemed invaluable to the overall project objectives. For example, highly detailed data capture recorded for historical purposes was described as a 'priceless' application for such accurate capture but one that is not easily compensated.

A proven method for supporting a city model was outlined by one of the HD city hosts who had issued their associated town council (who had commissioned the model) with a license for the use of the model, rather than an outright purchase. In this way the purchase price was spread over a five year period, and advertised the costing and maintenance of the model over this time. Furthermore, it allowed the hosting team to phase the modelling of the city, tackling the centre of the town first followed by the remaining areas after an elapsed time and when the council had the necessary funds. One of the ways in which funding was acquired for the extension of the model was from a local developer after a large application was made to develop an area of the city that was not yet modelled. One of the conditions of the application by the council was to complete the modelling of this area. (This was particularly unusual as it is not even a prerequisite that large developments are submitted in CAD format in this country).

Of the hosts from Local Authorities, over half of the respondents were explicit in pointing out that any of the income that was generated by their city model was recycled back into the project in some way and thus contributed to its on-going costs, effectively creating a 'development pot'. In situations of city model enterprises and where chargeable services were offered, the charging system was reported to be completely independent of the planning service. In almost all cases, the hosts had aspired that the city model would be self-sustaining by a certain date after setting up the enterprise (typically 2–5 years). However, no respondents yet reported that this had been achieved. Again, one of the reasons for this was the financial environment, as it was reported in all countries that there were simply less planning applications than had been anticipated.

Various cost structures were reported, with one of the UK LA hosts outlining a clear and transparent charge for all of its clients (primarily architects and planning consultants) for services that they provide. The LA charges £575 per building insertion and a further £77/hr. for supplementary tasks, such as producing images. At first point of contact, clients are asked to outline their requirements and specifications (e.g. file types) from which a quote is produced. In most situations, virtual city hosts maintained a relationship with their modellers and in just over ¾ of the cases repeat work was commissioned either through purchase of new data, data update, renewal, or for the purposes of another project. It was also common practice by European city hosts to form partnerships with data providers so that data and resources could be shared.

Despite its obvious restrictions to the third pilot project, the financial crisis in 2008 had an effect on the study and NCC's strategy for the Scotswood project. In spite of its relatively low operational cost, it was the resulting cost of the construction phase of regeneration that affected the strategy for the design stage. Although this was a different environment than a normal planning process, the investigation highlighted a polarised approach in a design event that aspired to greater transparency. The experimental design and construction stage was replaced by traditional building processes delivered by established developers. The disparate factors that affect project delivery in such circumstances are not merely limited to cost reduction, but also the avoidance of processes that are deemed experimental in nature and could produce unknown results. In such financial climates, the (construction) industry resorts to established, tried and tested methods and processes. In this way, a city modelling activity should aim to integrate itself into any existing processes, through interoperability and ease-of-use, for example.

5.5 Discussion

Berlin's virtual city was designed as an "integration platform for 2D and 3D geo-data and geo-referenced data instead of being only a 3D geometry or graphics model" (Dollner *et al.*, 2006), which describes an alternative, more focused 'attitude' to 3D city modelling that stems from GIS, rather than CAD as in UK virtual city hosting. In this respect, which was particularly evident from the literature review, city model hosts have developed their models from a VR heritage and placed excessive focus on modelling realism than is useful or appropriate in practice.

Hence, a clear trend emerged between the UK models and the European (Germany, Austria) approach to data, whereby UK hosts acquires its data on an ad hoc or project-by-project basis. Data is treated as standalone (geographically, as well as physically) information that is usually purchased from specialist city modellers. This can include LiDAR data which is regularly purchased to create DTMs and DEM for building heights, volumetric studies or aspect and slope studies. On the other hand, European hosts gather their data in-house and demonstrate its use as a more holistic tool for a range of applications in planning, thus justifying its use.

With the increasing access to 3D data and design software, it is difficult to determine how independent hosts can compete with specialist 3D data providers for selling 3D data. The ubiquity of 3D modelling in built environment related professions coupled with 3D software and data shows that basic virtual cities and detailed context models are easy to produce, while producing complex HD models is expensive and somewhat unjustifiable for the majority of basic planning tasks. Suggestively, respondents observed a resurgent trend towards semi-automatic/ automatic modelling, illustrating the evidence from the literature investigations showing that large city models require automatic and semi-automatic modelling techniques if they are to be sustained. Despite this, the investigations in this chapter shows that the façade textures that these techniques produce are unnecessary and sometimes obscuring for certain planning activities, confirming research from Dollner *et al.* (2006) that photorealistic models are only required for specific applications in tourism, entertainment and public participation (the latter, however, was not mentioned in interviews).

Analysis of the audit, interviews and pilot studies suggests that methods of data update or enhancement remains a key concern to hosts. As mentioned previously, technological approaches are still an expensive option and not feasible for most applications. The cost of data acquisition and large scale modelling is gradually decreasing so that it is often the simpler and cheaper option to re-commission and purchase a more up-to-date model. However, a collaborative approach, that includes a close relationship with local government, suggests amore cost effective collaboration. Meeting the demands of multiple stakeholders can be achieved by a process of 'synchronisation' that involves regular update of not only the data, but of these various requirements from its contributors.

European cities displayed a more established 'GIS heritage' (this does not reflect the length of time that GIS has been in use, but the level of integration and expertise that is in place), using virtual cities to extend their geo-information infrastructure and support more spatial tasks. On the other hand, UK hosts in particular regard city modelling as an additional endeavour or task, supplementary to existing services. In this way, interviewees report some difficulty in convincing potential stakeholders or clients as the perceived benefits are not always either perceivable or evident. The lack of suitable 3D integration in ESRI ArcGIS was indicative of slow uptake of virtual city modelling and could explain a similar growth in UK local government.

The various research investigations analysed the issues involved in a virtual city's broad use. An organisational framework is described as an over-arching structure, or a general methodology for defining a business process. Osterwalder and Pigneur (2010) suggest a generic business model 'canvas' containing nine areas that structure an organisation. The following chapter adapts this model to suit organisations from more varied backgrounds, while sustaining a virtual city project. Despite the established technical processes that go into the creation of a virtual city, their use in practice remains relatively exploratory which has led to chaotic methods for their creation and management. Through the use of a modified business model, many of the features and processes can be defined in a harmonised manner that helps to ensure longevity to the enterprise.

CHAPTER 6: AN ORGANISATIONAL FRAMEWORK FOR SUSTAINING VIRTUAL CITY MODELS

6.1 INTRODUCTION

The framework presented in this chapter describes a roadmap for the management of a 3D virtual city for the purposes of planning related activities. It consists of a series of guidelines and recommendations to assist in the decision-making process for the key stages in the lifecycle of a virtual city model, incorporating the financial, technical and organisational issues. This is based on PhD research from literature, pilot study investigations and interviews with current practitioners from across the EU. It is structured so that either prospective or established hosts can identify with its content.

It is widely acknowledged that the most beneficial aspect of a business model or framework is in the self-reflective process of its development (Porter 2008, Walton and Deming, 1986; ten Have, ten Have and Stevens, 2003; Phall and Muller, 2009). Hence, this chapter serves to aid this process, rather than superseding it. The framework presented in Figure 53 illustrates the core elements of a virtual city enterprise and serves as a 'canvas' (Osterwalder & Pigneur, 2010) that hosts consider and customise to suit the various circumstances and requirements (see 'Examples…'throughout the chapter).

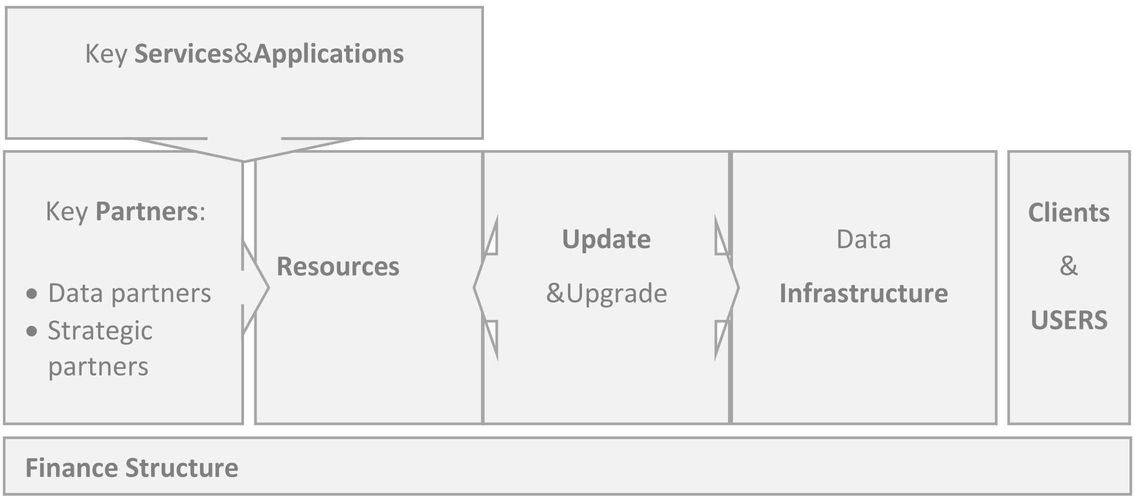


Figure 53: The organisational framework

Virtual cities have been established in a range of organisations, from engineering consultants to local government departments; however, they all demand people with very specific skills and IT with which they can perform tasks and manage the information. This information is often considered as the defining feature of the organisation but is by no means the most important. Virtual city hosts will have a variety of circumstances and motivations for using a virtual city model. For example, cities with a reputable GIS heritage; surveyors with 3D data capture techniques; historical cities with strict planning regulations; or massively urbanised cities that host a range of architectural styles. The enterprise should respond to its local circumstances, expertise and resources to develop a framework that is most suited to its environment. Nevertheless, a consistent business approach should reflect that a virtual city is a natural technological evolution of GIS and urban planning. It should be adopted to assist this process, rather than adding another barrier to an already complex activity, as in early attempts at virtual city modelling. Fundamentally, a virtual city should be adopted in response to an unmet user requirement. This can be as simple as the desire to improve the local urban design process. From this market drive, a framework can be developed that focuses on the end user(s) and their specific needs, while planning for inevitable subsequent changes in technology, legislation, economic conditions and the changing nature of cities.

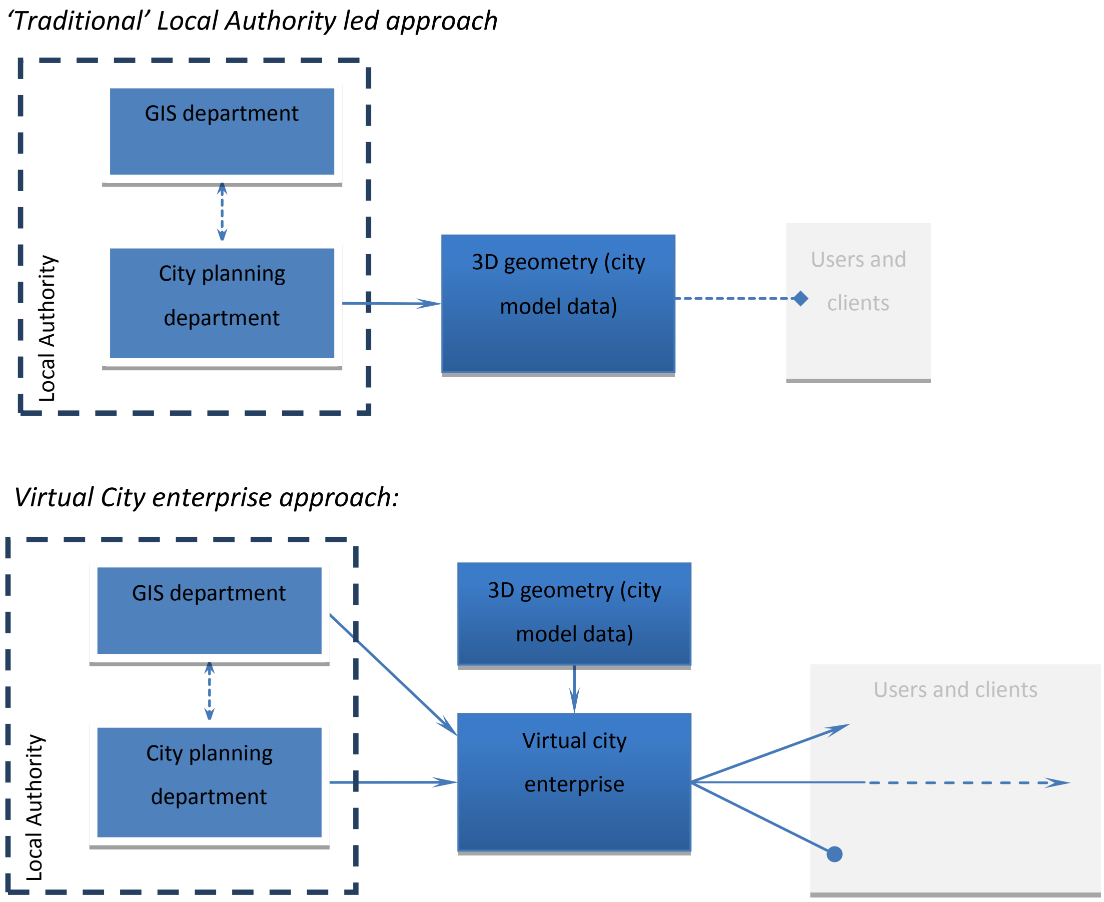


Figure 54: Traditional versus virtual city enterprise

Contemporary 3D virtual city models have developed from large, standalone digital[4] 3D geometry into complex geospatial datasets. It is important to regard a 3D city model in any context as an enterprise that comprises all of the essential data, resources, processes and expertise that are required in its successful application. The clients, its users and various stakeholders play central and varied roles in this enterprise that should be considered throughout the business model. Figure 54 (above page 175) outlines a structure that relates to a city model hosted by a local authority; however, this could apply to independent hosts with strong links to their local authority and an appropriate GIS data supplier. Aspects of this framework can be adopted by current hosts but it is important to carefully consider what type of organisation could and should host a virtual city model that will be used (primarily) for planning activities. The host should be able to manage the technical delivery of a product, the organisational aspects of a service as well as contributing to an established official process.

Virtual city models are expensive, requiring data and other resources that include staff, software, hardware and facilities. Not only are the overhead costs high but the potential for reimbursement is relatively low, particularly in a planning environment. Previous hosts have existed in one of two ways. Firstly, as a government or academic department, that subsidises its resources and data to exist as an extension of an existing planning process or service. Or secondly, as virtual city hosts that serve as 3D data providers and offer one-off products to a broad range of clients. However, it is possible for a host to offer products as well as services, through its data and technical resources respectively.

In many ways, it is more practical and cost effective to host more than one city. Currently, hosting as a business is carried out by 3D data providers, modellers and a handful of organisations for selling 3D data, but more increasingly to replicate a specific application. For example, In North Rhine-Westphalia (Germany) multiple city hosting has been carried out for scientific simulations (urban noise mapping). This reduces the cost of its resources and expertise per city, as well as the costs of data capture if this is carried out in-house (or discounts may be available from city model data providers). Although this method is for a specific application, this business model could be lent to other hosts that carry out urban planning related services. However, it is recommended that hosting is carried out for local cities or regions so that the enterprise can maintain a close working relationship with the intended users of the model, such as local planners and architects. Hosting multiple cities also requires a slightly different approach based on product leadership and a focus on research and development as it will face broader and sometimes unknown competitors. Otherwise, a city model enterprise should be focused on operational excellence, in streamlining their service and with a focus on end user satisfaction. Not only does this ensure that users' needs are met, but it also minimises waste in the process of producing

[4] Or the foregoing wooden scale models still used in many cities worldwide.

and delivering a virtual city. For instance, LOD is one of the most recognisable aspects of a model and evidently an area that many cities have over specified by not understanding how its data will be used.

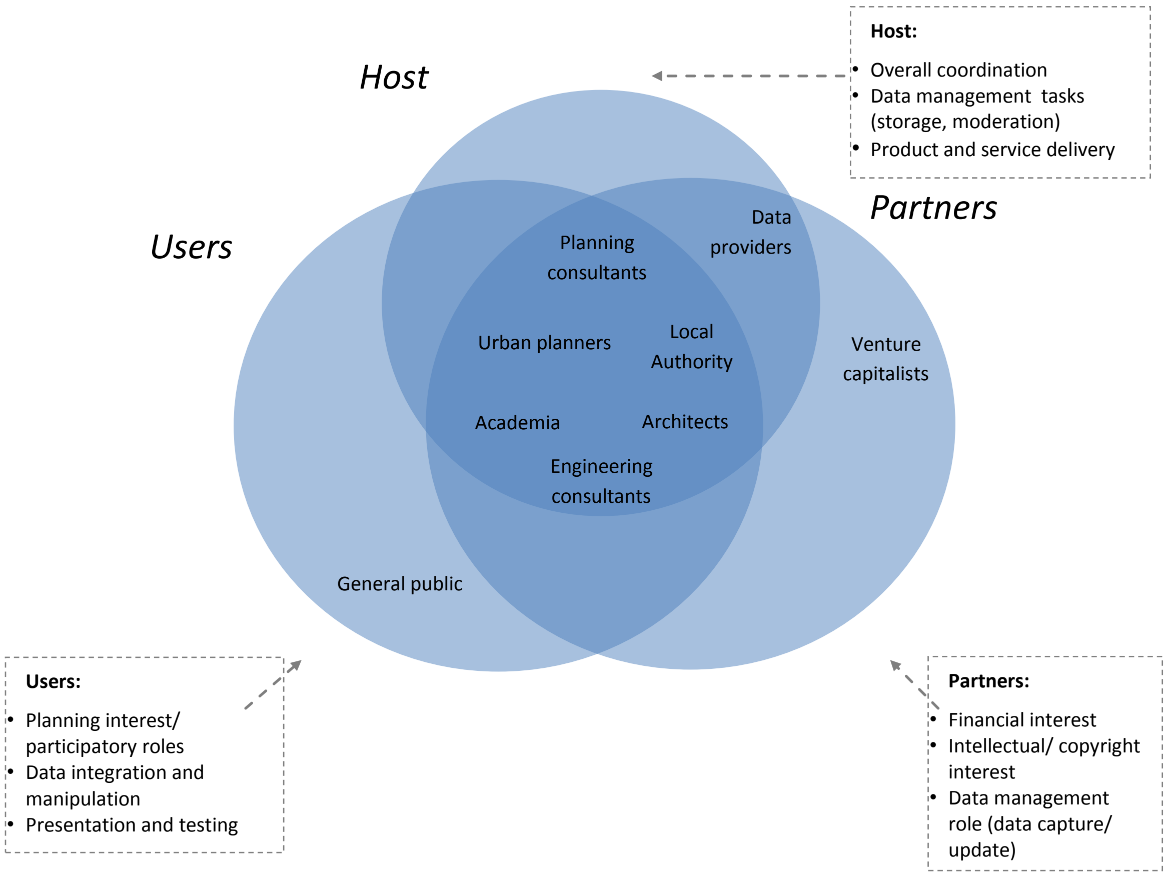


Figure 55: City model stakeholders - roles and responsibilities

A common feature of all virtual cities as well as business enterprises is their collaborative nature. They require a range of skills and information that is used by a range of people. This should be reflected in their management that allows controlled distribution and coordinated stakeholders. The roles of the host, its staff, external stakeholders and the ultimate users are highly interchangeable depending on their virtual city environment (see Figure 55, above). An important task for every host is to identify each of the stakeholders and determine their exact roles and responsibilities. This information should be available to all of those involved. Limiting the amount of stakeholders may also be of benefit, as the research shows that certain institutions can amass many parties that stipulate many demands for a virtual city yet contribute very little to it. Hence, partnerships for data sharing are common to reduce or share the costs of data capture or modelling. Each city has different circumstances and hence planning requirements. In London, for example, verifiable photomontages must be produced. A host that maintains a consistent service, engaging with key stakeholders such as their LA, can help to formulate a planning service agreement that is of great benefit to all parties. In summary, the following issues are considered important considerations for hosts:

- Maintain relationships with the local network
- Maintain operational excellence
- Consider end-user satisfaction, rather than the pursuit for data
- Establish an appropriate LOD
- Consider the management of the resources and controlled distribution of data
- Carefully consider appropriate stakeholders.

Technical tasks:

- Data editing, modification
- Data mining
- City model delivery – presentation, communication and distribution
- Financial management of the city model, including data and resources
- Revision control
- Content management
- IP management
- Access security
- Data content and accuracy validation

6.2 Business Objectives

The framework presents a set of common aims, along with optional or fluid objectives that direct some of the decisions recommended later in this framework. The goals, intended roles and limitations of a city model enterprise – its data and resources – should be clearly communicated to all stakeholders in a virtual city enterprise:

- To sustain an up-to-date virtual city.
- Support local planning and pre-planning activities.
- Return profitability/ to break even within a defined timescale.
- Provide a chargeable service for applications in planning related activities.
- To protect the rights to the data or information and maintain appropriate and responsible control of its use (including commercial control).

Other (optional):

- To support a service that allows the distribution of the model over the web.

- Promote business enterprise within the region by providing a free/ chargeable resource for this application.

Establishing a virtual city project or enterprise can take up anything between two and 18 months, depending on the type of data that is required. A standard, city model where 3D data is purchased, for instance, should allow at least six months to access funding, establish the required resources, commission the data and begin delivering services.

<table>
<tr>
<td colspan="2"><u>Key Services&Applications</u>

• What services do the local planning related community require?
• What are the most important applications for the enterprise to commit to?
• What type of activities suits our current resources and expertise?</td>
<td colspan="2"><u>Clients &Users</u>

• Who are the most important clients?
• Which of the client's problems are we helping to solve?</td>
</tr>
<tr>
<td><u>Key Partners</u>

• Which organisations...
• Which (local) networks can benefit the enterprise?</td>
<td><u>Resources</u>

• What resources are currently available within the organisation and its partnerships?
• What are needed to deliver the services?</td>
<td><u>Update& Upgrade</u>

• How frequently do our clients and users require updated data?
• What frequency of update ensures that data is suitable y up-to-date?
• How will the resources be maintained in line with the services?</td>
<td><u>Data Infrastructure</u>

• What is the most effective way of delivering the product and/ or service?
• What is the best way of managing (using, maintaining, updating) the data?
• In what format will our key clients require the virtual city data, or the access to it?</td>
</tr>
<tr>
<td colspan="2"><u>Cost Structure</u>

• What are the most important costs in the organisation (e.g. 3D data)?
• How do these relate to the services that are delivered?</td>
<td colspan="2"><u>Cost Structure</u>

• What are clients willing to pay for the service?
• What type of payment structure is most suitable (for single or on-going products and services)?</td>
</tr>
</table>

Figure 56: Key questions of the Business Framework 'canvas' (Osterwalder and Pigneur, 2010)

The purpose of the business framework canvas is to organise strategic thinking so that it can be applied more efficiently and resourcefully through its delivered services.

6.2.1 Financial Issues

Capital raised for the purposes of city modelling can come from a range of sources, particularly from Local Development Agencies and academic funding. This business framework shall assume that this initial capital has already been raised or commitment has been agreed by the stakeholders. It has also been demonstrated that virtual city enterprises can benefit from a number of grants or funds to develop or establish the service.

Many previous virtual city hosts have been established from similar organisations, such as GI specialists, data suppliers and geography departments. Alternatively, hosts from the interview stage were established for the purpose of modelling a virtual city that continues as an enterprise for its upkeep and application. For example, a successful funding method had been established as a license agreement over a five year period with its local authority. Local developers that were in consultation with the Local Authority to build large developments were requested by their LA that they pay for the modelling of the affected area so that both parties could be using the same dataset in a 3D environment. An agreement was made that the Local Authority would retain the Intellectual Property to the virtual city data

6.2.2 Low Cost Solutions

Online web services present an increasing amount of freely available resources, as software services and geospatial information (GI). In particular, Google Earth (GE) provides a free or low cost resource with which virtual cities (basic, standard) can be used for urban planning and architectural design. There is also an increasing amount of GI resources this are freely available through free mapping tools (e.g. OpenStreetMap). However, these solutions are not suitable for detailed planning activities due to the limitations in the data accuracy of the digital terrain models (DTM) that is normalised across an excessively large area to support visualisations at street level and scale. However, they have been adopted by many in this field for the purposes of massing and pre-planning design or consultations as they are sufficient for these tasks that require less accuracy. Other methods for cutting costs in data acquisition and data management include:

- Commissioning 3D modelling: imagery is provided by the host for other parties to carry out the specialist modelling tasks. Architectural visualisers, surveyors, architects and other specialists are increasingly adept with 3D modelling, depending on the practice. (This differs from purchasing 3D city model data from specialist 3D data providers). Such an arrangement can resolve many legal issues that concern third party data or ‘derived data’. However, consideration to modelling consistencies by applying strict formats about modelled objects, specification, layering protocols and data formats.
- Equipment hire: lease terrestrial laser scanning units, for example, reduces the upfront costs and on-going maintenance of the equipment. Similarly, surveyors could be commissioned to gather the 3D point clouds.
- Cloud computing and hosting: there are many aspects of business operations that can take advantage of web-based, free or low cost services, such as website

hosting, VOIP calling and video conferencing, online word processing packages, file storage, file sharing and cloud rendering services that can be used to outsource demanding rendering computation, for creating high quality visualisations (not to be confused with either virtual offices or virtual servers).

6.3 EXAMPLE 1: A LOW COST VIRTUAL CITY

It is possible to model and host an extensive city model using free modelling and storage software with minimal costs on data capture and resources for hosting, based on a simple business structure to focus on just a few key applications. The main drawback concerns the creation of the city model, which is extended across its lifecycle. Correspondingly, a 'complete' dataset (as in coverage) will take a long period of time (>five years) depending on the extent of its use.

<table>
<tr><td colspan="2"><u>Key Services&Applications</u>
• Pre-application consultation
• Context models</td><td colspan="2"><u>Clients &Users</u>
• Local architects and planning consultants
• Small and medium sized developers.</td></tr>
<tr><td><u>Key Partners</u>
• Local architecture network or body</td><td><u>Resources</u>
• 1 full time employee for operation, plus 1 part time for management/ admin tasks.
• IT- standard specification desktop, digital SLR camera</td><td><u>Update& Upgrade</u>
• Ad hoc update dictated by clients.
• Key development areas updated twice yearly.</td><td><u>Data Infrastructure</u>
• Virtual server structure.
• Use of GE 6 DTM
• Building geometry gathered using photography and image modelling software
• Google Earth network link or software s access (e.g. LandExplorer 2009).</td></tr>
<tr><td colspan="2"><u>Cost Structure</u>
• Operating costs of employees that require high level of expertise</td><td colspan="2"><u>Cost Structure</u>
• Income based on modelling services rate</td></tr>
</table>

Figure 57: Example 1- a low cost virtual city hosted by an independent enterprise

A DTM master model is based on Google Earth 6 and building data is captured using ground-based digital photography. This is carried out on an ad hoc basis, with a modelling process that is client or project led. The host should also model areas within the city or region that have been outlined as development areas that will undergo significant development and business regeneration. Having completed an extensive photographic survey of the site, image modelling software such as Google SketchUp 8 (free) or Autodesk ImageModeler 2009[5] can be used to create accurate[6] 3D geometry. In some cases, it is necessary to carry out a brief field survey to calibrate the correct geometry in the images. After completing a suitably large context model (depending on

[5] A license for ImageModeler can only be obtained with a subscription to another Autodesk product, such as Map 3D or 3ds Max 2010.
[6]depending on the resolution of the source image(s)

the client/ user requirements) this could be delivered using a Google Earth network link for remote access. By keeping this model up-to-date, hosts could sell access to its data using this platform on a license agreement. Focusing on current development areas will help to ensure its use. This type of enterprise is indicative of an independent organisation or subdivision of an architectural practice.

6.4 LEGAL CONSIDERATIONS

The legal issues that concern a virtual city host have the potential for deciding how a virtual city can be used and ultimately its success. This section shall cover how to control access of the data as well as some of the security concerns involved with the distribution of 3D data, in particular with HD virtual cities. Practical measures should be taken that do not cause restrictive legal and licensing issues that hinder the use of a virtual city. It should be kept in mind that the combinations of resources and expertise that make up the delivery of the virtual city service is not easily replicable and without these the data is relatively unusable. Thus, it is important to become established as a reliable virtual city host so that any illegally obtained data is not used in professional applications (without prior arrangement).

Nevertheless, much clarity is required for the transfer of data between parties. It is recommended that every instance that data or access is passed from one party to another, a basic summary of how this data can be used should also be passed (as well as the necessary legal documents that are required for sale of goods or services). This should include:

- Data source (ownership)
- Data access (e.g. single users)
- Application or how it can be used (e.g. non-commercial applications, single use)
- Security and privacy considerations
- Time restrictions that these also carry

Security and privacy issues that affect virtual city models concern any aspect of the information that is put in the public domain. Hence, hosts that publish a virtual city freely over the web must carefully consider the content of the modelled environment. Generally, basic and standard virtual cities pose little or no risk in terms of security and privacy as their insufficient detail avoid the risk of aiding crime or terrorist activities. However, HD or textured models can present some risks as certain building features that would not normally be visible from public areas or street level can be viewed. Protecting individual's rights should also be observed, where details such as faces and car registrations could be visible in textured portions of a mode. Finally, applications such as crowd simulations should be seriously considered before sharing to a wider audience.

Similarly, copyright considerations should be observed so that objects, advertising, imagery or any trademarked material (e.g. vehicles, advertising banners) are not used in a virtual city environment without consent.

A 'traffic light system' can be adopted to show key areas when the certain copyright or contractual terms are affected when transferring data from one party to another. From the outset, hosts may decide from the following list which method they should follow.

Table 11: 'Traffic light' system for managing the transfer of data

🔴	No access to data outside of host IT infrastructure.
🟡	(Recommended) rights allowed on a contractual license. Access allowed through server.
🟢	Open access to virtual city data.

Consideration should be given in an organisation's system of contracts, website and any other notices to ensure that any 'data' is expressly stated to be confidential, which may involve modifying contractual definitions of 'Confidential Information' to be sufficiently broad as to cover computerised data (Kemp, 2011). Additional legal costs should be considered in a budget, to include legal advice and the formation of legal agreements and documents.

End user licence agreements (EULA) can be arranged so that the owner of the data retains the ownership and copyright to the data but permits the re-use of the purchased data. Re-sale is only allowed subject to a fee, either as a percentage of the original cost, re-sale cost or an agreed fee. In this situation the data provider must be contacted and a legal agreement is established to enable this. A EULA is ideal for one-off data services such as model insertions that include an interactive model. However, this is not the case for sharing entire virtual city data and a more detailed agreement should be considered, such as a royalties fee based on a sliding scale according to the geographical area. Organising and understanding data licenses can be a complex process that needs careful planning before data is either purchased or passed on. It is also ideal that the intended use or application of the model is established before the data is acquired. Similarly, software is protected by license restrictions, which can also affect virtual city data if proprietary software is to be used, modified, distributed or re-sold.

Results from previous investigations show too much emphasis on the protection of the data that is too restrictive of access and use of a virtual city. This imbalance can have a more detrimental effect on its success (through lack of application and use) than the implications of its illegitimate use. Hence, it is recommended that a more open minded approach is adopted, in particular through access for navigating or viewing the city model.

In this way, the city model enterprise and services will benefit from a more open policy that is reflected in most modern (web-based) IT software and data.

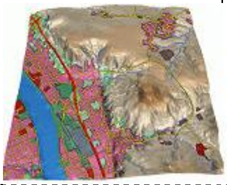
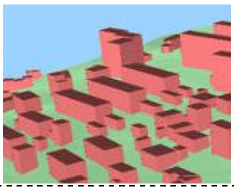
6.5 Key Services and Applications

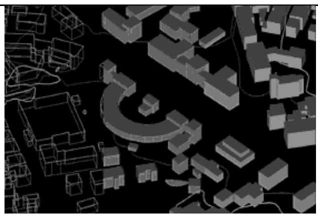
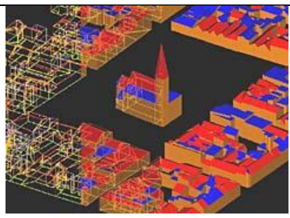
Virtual cities have varied applications within the planning system, fundamentally as aids to the design process or as a communication tool for major planning applications and regeneration schemes. Virtual city data must be established for a particular purpose so that IT hardware or software can be properly specified. The more detail that is required from the city model, the higher the costs of the resources that are needed. HD virtual city types will require more expensive data capture and modelling techniques, which also places more demand on the computing power and the people that are required for their applications. Standard virtual city model types, however, are suitable for a broader range of tasks and applications that can be carried out by a powerful [7] desktop PC. Nevertheless, each virtual city host will have unique circumstances that require a tailored specification of intended applications, data type and required resources to meet the demands of the end user. Hence, outlines some of the fundamental questions that a host should clarify before undertaking a virtual city enterprise.

Evidence from the interview process (see Chapter 5) showed that “architects and planners account for 90% of those who purchase 3D city model data” (referred to as data services). This highlights an extensive market for the purchase of 3D data, although these users do not necessarily relate to virtual city related services. Hence, it is highly recommended to carry out market research on local businesses and institutions to explore other potential markets and their applications. All cities have unique architecture, politics, history and circumstances that influence the use of city model services and how much clients are expected to pay for the service.

[7] Typical specification includes dual core 2.00 GHz processors with 2GB RAM minimum.

Table 12: Virtual city classification with respect to operating cost, LOD and key attributes

CityGML guide:	**LOD 0**: regional, landscape	**LOD 1**: City, region	**LOD 2**: City districts	**LOD 3**: Architectural models (exterior)	**LOD 4**: Architectural models (interior features)
					

	Basic	***Standard***	***HD (High Detail)***
Description	 Basic block models without architectural or roof details overlaid on a DTM, produced by foot print extrusion. • Accuracy: > +/-1m (depending on the source data)	 Basic models enhanced with additional detail and roof structures, produced by photogrammetry or LiDAR • Accuracy: +/- 25cm	 High detail representation; accurate to within 20cm; fully textured; produced from terrestrial laser scanning. • Accuracy: <10cm
Typical outlay[8]	£500– 50,000	£20,000–250,000	£150,000– 1,500,000
Cost	• GIS • Master planning and plan making • Traffic modelling and simulations • Noise mapping Other: • Forest management • Geology • Disaster management • Flood management/ catchment hydrology • Air pollution modelling • Wetland and wildlife management • Healthcare • Disaster management • Insurance	• Pre-planning design and consultation • Lighting simulations and light studies • Impact Assessments • Visualisation Other: • Project management • Virtual tourism • Vehicle navigation systems (Sat nav) • Telecommunications • Utilities • Historical studies • Education • Urban response planning • Military intelligence, response planning and simulation	• Visualisations • Facilities management • Conservation Other: • Volumetric calculations (interior)

Detail

A virtual city can be treated as a product that is available to a wide range of customers and applications through the sale of 3D data, licenses or by the use of professional services as a virtual city enterprise. The applications or tasks can be carried out by either

[8] Including fixed costs of purchasing/ producing data and operating costs

the enterprise or the client, depending on the expertise that is required. It is recommended that a set of core services become the focus of the enterprise, such as model insertions and context models. Subsequent, bespoke expertise services can be anticipated to a certain extent and a flexible payment structure should support and encourage its use. However, hosts should take care not to undervalue their services, as evidence from the research shows that virtual city models can attract substantial interest for various exploratory applications that do not necessarily benefit the enterprise.

The most useful application of a virtual city is during the pre-application and consultation stages. Practitioners report that seamless integration and service provides a 'quick turnaround' for these design stages. The increasing availability of 3D design packages and expertise in this area is broadening its user base significantly; hence, there is an increasing demand for 3D data so that users can carry out design tasks, rather than outsourcing model insertions.

MARKETS

The successful employment of services depends on identifying the most important clients or users. In most cases, these will be building professionals, which can include architects, planning consultants, developers and engineers across private and public sectors, such as a Local Authority. The latter is an important client, not merely for their role in local planning activities, but as a credible advocate of a virtual city enterprise for which there is no match. Association with a Local Authority may encourage users from other areas. The enterprise needs to tailor its services to offer what its clients cannot achieve themselves. Aside from the skills, expertise and resources, any data services offered should be competitively priced against 3D data from similar sources. The sales market can be approached through the following channels:

1. **Local press**: many city models have taken advantage of the impressive cutting-edge capabilities of virtual city models by using the local press including newspaper, television, etc.
2. **Networking opportunities**: Chamber of Commerce, professional bodies, local organisations or networks (e.g. RIBA, Constructing Excellence or Northern Architecture) hold regular events such as conferences, exhibitions or seminars. These are excellent opportunities to showcase the city model and a recent project to showcase the service.
3. **Website**: including latest news, project showcase and weblog. It is an essential component of a modern enterprise to maintain a website, continuously up-to-date with latest projects and information. Moreover, a web portal can be a way of delivering part of a service, such as through an interactive 3D map.

4. **Promotional event**: this can be an effective method of demonstrating the services available and in particular the virtual city enterprise facilities, if these are part of the service offered. These events should demonstrate the capabilities, some examples of work and explain the validation, update or accuracy of the model to put any unconvinced attendees at ease.

A combination of the above is recommended, beginning with a focused effort (inception) to consistent communication through local events and an updated website. Any simulations or academic projects that have been carried out could be disseminated through academic papers and conferences for on-going exposure.

MODEL INSERTIONS/ CONTEXT MODELS

Importing building models into a virtual city dataset is one of the most exercised tasks in this field. It can be a straightforward process in most instances, depending on the size and LOD of the models that are effectively being merged. Hence, this can be one of the most lucrative and highly repeatable process that a host can offer. Users are encouraged to outsource this service as it is expected that a virtual city host will have a more complete, expansive and up-to-date representation of the particular area of the city, offering a cost effective solution rather than purchasing or producing a context model for themselves. Although a simple process, it can be difficult to estimate extra modelling time due to the modifications that may be required to the models' geometry. Therefore, it is recommended to charge both an insertion fee, as well as a supplementary hourly charge for carrying out modelling tasks or services. Context models are sections of the virtual city containing an inserted model and can be offered as a physical, navigable model in a variety of formats. They can also be published as 'read-only' navigable models (as a 3D PDF, for example) or as an editable dataset with which the client can carry out subsequent modelling tasks. Needless to say, the virtual city data must be free of any copyright restrictions that prohibit the re-sale or re-use of the data or the necessary permissions and arrangements made.

A standard protocol for inserting models should be specified by the host that corresponds to compatible data formats, modelling protocols (e.g. geo-location or scale) with respect to the intended outputs (e.g. 3D model, video or 2D visualisation). These specifications should be communicated before any data (building model) have been exchanged, as well as applicable copyright agreements or terms of use.

PHOTOMONTAGE AND VISUALISATION

Visualisation tasks are used in almost every aspect of built environment design and a city model can be used to create context for a new building development. Basic and standard city model types are particularly suited to pre-planning stages of the design process so that building form and scale is explored. In fact, standard city model types can be used for almost all types of visualisations and modelling tasks, providing there is a good balance between detail and file size that the enterprise's resources (IT systems in particular) can support.

Despite the higher LOD, HD model types have proved unjustifiable for use in the early design stages, limited only for use in detailed architectural visualisation for impact assessment and marketing purposes that compete with traditional (and less costly) photomontages. Hence, this option is only viable for large cities that can support the demand for large quantities of visualisations. Despite the apparent competition with photomontages, the two methods can be used to support each other. In many cities, photomontages are a legal requirement for certain types of planning applications and in some regions the process itself must be verifiable. A virtual city model could be used in conjunction with this technology to validate images produced or even to plan the production of images before it is carried out.

SIMULATIONS

Simulations differ from design related tasks, requiring high levels of consistency from 3D geometry. It is also the case that the simulations and users require additional renderings or animations of the simulation and its environment to properly communicate the study and its results. Evidence from the research suggests that virtual cities are frequently used for a variety of scientific simulations, such as flood plain analyses. Although these can be beneficial for engaging with academia or related parties, they can be time consuming services. In this way, allowing the use of the data, which is maintained in a suitable database, ensures that 3D information can be used fairly. Agreements should be established between all parties that highlight the host and data source, acknowledging their services and expertise which can be beneficial for creating future custom from other clients and therefore securing additional sources of income. Access to the data for such projects should be restricted to a single defined project and a suitable timescale for this to be completed. However, some simulations are carried out repeatedly over a set timescale or seasonal basis, such as traffic simulations. The commercial background (if any) of those who are carrying out such simulations should be verified to ensure there are no conflicts of interest and that the virtual city is not being exploited.

Noise mapping, is a particularly relevant application that is being carried out for the Environmental Noise Directive throughout large areas in Germany (e.g. North-Rhine Westphalia), for example. The 3D component is not a requirement but it is being used in this way in order to take advantage of the expertise in this part of Europe. This demonstrates a long term business prospect for specialising in a particular simulation that is repeatable and funded by an external party, such as a government body.

Planning related simulations, such as line of sights, visibility impact assessments, light pollution assessments, light studies and shadow studies are used, or stipulate, increasingly across many cities in Europe from pre-planning stages and beyond. These are substantial, chargeable services that can be carried out routinely given the correct software and middleware are in use.

Consultation and Expertise Services

Established virtual city host may wish to carry out exploratory services for clients. Business opportunities that combine virtual city data with its supporting expertise can offer a range of consultancy-based services. Business location services, for example, make use of GI features in a 3D environment to give a better understanding of urban context, transport links and urban density for prospective real estate developers. Successful consultation and expertise services are shown to create a knock-on effect of further income generating opportunities. These can also be software specific, such as Civil Engineering applications and the use of Autodesk Civil 3D or CityCAD, which are used to plan developments to city infrastructure. Therefore, hosts may offer either their data or consultancy services accordingly.

Data services

Many clients or stakeholders will not have the facilities to support city model data, so remote access through appropriate middleware based on a license payment may be appropriate. It is preferable for a host to issue license agreements, particularly for entire city data coverage, over outright purchase for a number of reasons. Firstly, this approach can ensure structured payment over a period of time that supports data update. This also coincides with software subscriptions, which are offered increasingly as a ‘rolling license’. It also encourages long term clients or partnerships that help to sustain a virtual city model, through a more convenient price structure (i.e. lower costs, spread throughout the year).

6.6 RESOURCES

Operations and resources are the most valuable asset to a virtual city enterprise. 3D geometry and GI are widely available to almost anyone with an internet connection and a PC, but a cooperative combination of expertise, resources and successful application distinguishes this type of enterprise. A suitably named organisation (e.g. 'Virtual *Your City'*) helps to clarify the existence of a business service and distinguishes it as an enterprise. It is also important to maintain an up-to-date website to present the city model and associated services. Engaging in social media (e.g. LinkedIn, Twitter) will maintain communication with current users as well as publicising for new clients and alternative applications.

LOCATION AND FACILITIES

Regardless of the intended use of the city model, a host should have access to suitable up-to-date multimedia facilities with a large (>42") screen, such as a conference room. Not only will this serve as a space for carrying out business services, it will assist in promoting the services to prospective clients. However, it is important not to over-specify this type of facility – there are many examples of 'decision theatres' and expensive VR facilities that do not add value to a decision-making process for urban planning related activities and can, in fact, distract its viewers as a technological showcase. Hence, a balance must be sought by the design of a suitable conference space with good multimedia facilities. Inspirational virtual reality hardware boasts immersive realism, but many users in planning roles prefer desktop and remote access, both of which are widely available in offices and households. It is also possible to set up relatively inexpensive (£500– 15,000) immersive 3D environments using Google Earth 'Liquid Galaxy' guidelines (see Figure 58) if this is required.

Figure 58: A low cost 'Liquid Galaxy' installation

Sufficient office space is essential to accommodate the virtual city enterprise, whose staff will use desktop PCs for the majority of their work. These should be well ventilated and compliant with Workplace (Health, Safety and Welfare) Regulations.

Information Technology

High specification[9] IT equipment is desirable for all staff excluding administrative roles that do not require virtual city access. All users should have a good broadband internet access with a virtual private network (VPN). For database centred virtual cities, a client server architecture should be established that meet the requirements of the software and its users. Otherwise, a virtual server may be suitable for small datasets. A detailed specification for all of the IT should be designed following a thorough outline of the user requirements, business processes, security and maintenance or update of programs.

Expertise

For most virtual city enterprises, teams of between 1–3 employees can maintain a city model and carry out the services that are required. Irrespective of the source of the data (in-house or purchased) skilled modellers are needed to carry out many of these tasks. These are varied and depend on whether the enterprise will be producing its own 3D geometry, but can include laser scanning, 3D modelling, database management and suitable presentation and communication skills. Typically, employees from 3D modelling backgrounds in engineering or architecture are best suited as they balance strong skills in data management and optimisation with graphical creativity.

[9]Typically quad core 2.70 GHz 64 bit 4GB RAM minimum, with suitable graphics card.Dual monitors are recommended wherever possible to accommodate the type of work carried out.

STAKEHOLDERS

Managing the diverse stakeholders in a city model venture can pose a range of challenges, namely meeting their contractual, financial and legal requirements. Hence, it should be established from the outset what roles they should play and their requirements from the city model. A matrix is presented to outline this, with an open policy of exchange to view the position of each valid 'stakeholder'.

	Role	**Data access**
Virtual City Enterprise	Host	Unlimited
Funder	Financier, data licensee	Model view, monthly update
Public user	Viewing and navigation	Basic model access only

Stakeholders or strategic partners may include:

- Local development agencies
- Local Authority planning departments
- University/ academia
- Engineering consultancies
- Architectural practices

The research shows that some city models owe their success to their relationships with national or regional cadastral and mapping departments. Hence, it is beneficial to form key partnerships or strategic alliances for the purposes of sharing data and resources. Aerial photography, for instance, is an expensive source to commission, but is more cost effective if it is used for a range of purposes.

6.7 DATA INFRASTRUCTURE

Establishing an adaptable infrastructure to manage the data is an essential process to ensure its success and longevity. Early examples and users' experience with 3D modelling consists of standalone models that are too impractical to be able to carry out fairly basic tasks. However, a more practical solution is borrowed from GIS solutions with database systems that store a virtual city's geometry as a sum of parts. The goals of a spatial data infrastructure are to make the GI more usable, manageable and ensure compatibility for its broad and continued use. This evolution of city model data from 3D geometry is analogous to Ordnance Survey's advances, where basic geometric maps (OS

‘Landline’) have been digitised into a database format and the OS ‘Mastermap’. Features are now based on Topographic Identifiers (TOID) that contains both geometry and thematic information that is more easily edited, updated and accessible. The map appearance depends on the interface that is required by its current user. Hence, this should also apply to a virtual city, where its root data is not restricted to a particular type that limits the way it can be used.

The INSPIRE Directive (2007/2/EC) was established to create a spatial data infrastructure in the EU and affects Local Government (as well as some independent bodies). The Directive comes into force by 2019 with the aim of standardising and distributing spatial information to all EU member states. With this in mind, virtual cities hosted by Local Authorities or some independent organisations may benefit from the Directive. GIS data such as transport networks, digital terrain models and building information (location) are some of the themes that must be included in the Directive, hence it is important to establish a database that will allow conformity to the Directive (if necessary) or make use of the information when it becomes available. This highlights another incentive for establishing a robust spatial data infrastructure that ensures future updates and upgrades can be seamlessly integrated. Improving data capture techniques and the standardisation of city model data has coincided over the last few years so that data capture (aerial photography in this case) is carried out with the modelling process in mind and how this information is stored. In essence, incremental changes can be made to a virtual city database, such as individual building improvements.

One of the fundamental issues involved with built environment professionals is the variety of software that is used. These software packages generally solve only a handful of specific technical tasks, so models are often passed across numerous platforms to suit their needs. It is possible to design an infrastructure that allows a variety of compatible data types but ultimately there will always be some limitations. The host should document the data exchange capabilities to properly plan for any third party information that is imported to, or exported from. Despite the vast array of software packages that may be used for applications of virtual city data, the range of dedicated software available to hosts is more restrained, with solutions that combine 3D modelling, 3D environment and GIS characteristics (see Figure 59 on page 197). Early examples of city models inherently focus on first acquiring the data then tackling how this is stored and managed. However, a database infrastructure is highly recommended in all types of virtual cities and should be established from the outset where possible. However, advances in technology will inevitably require their retrospective application in some cases.

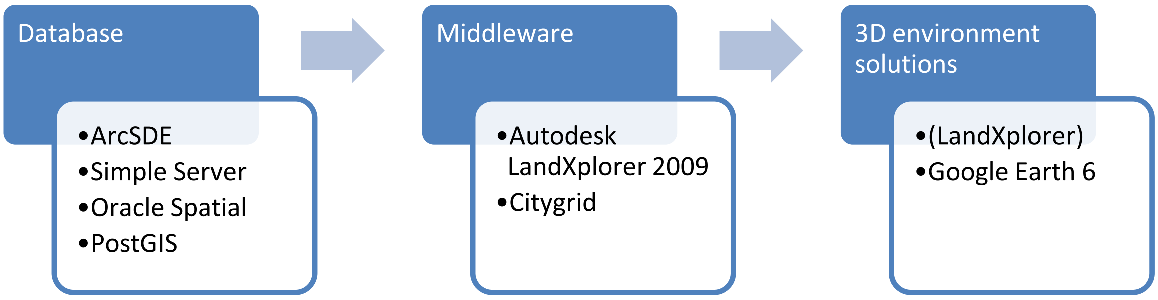


Figure 59: Current examples of applicable software solutions

The correct system for geo-locating a UK city is based on the OS system (UK cities only). For single use, standalone 3D city or building models, this is not always necessary as it can slow down modelling time due to the additional computation required. (However, height data is normally correctly maintained). Similarly, the use of metres as opposed to millimetres can be more practical on a virtual city scale. However, if its users are primarily from an architectural background then this can be problematic and care should be taken during model insertions. GIS data are inherently geo-located to allow seamless integration of data. Similarly, architects using BIM submit plans that are geo-located or at least referenced. In all other cases, informed metadata or documentation supplied with 3D building data should be supplied with a translation or displacement value for correct insertion. However, it is recommended to use properly geo-located data to avoid confusion in any GIS and imported model data. Middleware specifications vary and offer a variety of protocols for geo-location. Cloud servers such as ArcGIS for Server 10 with Cloud Infrastructure (ESRI or Amazon hosted) allow most of the features of a server technology without the need for expensive hardware. Subscription fees are applicable and the service relies on a large bandwidth internet connection.

MIDDLEWARE

Middleware is a key component to a virtual city enterprise's resources providing the interface for purposes of interaction, navigation, etc. between the data and user. It provides a level of basic 3D modelling within the software, although this is usually restricted to design tasks (editing, moving, creating simple objects) or data update for basic or standard virtual city types. Some automation of tasks can also be carried out. For example, many local authorities have a database of all trees within their region that include their type, size and location. Appropriate virtual city middleware can reproduce these trees in 3D, as well as update based on their growth patterns. Similarly, street lighting can be represented using replicable library objects for planning maintenance programs in a city. Dedicated GIS software are not suitable for standard virtual city models due to their restrictions handling large 3D datasets. Middleware solutions allow a good integration of GI services in a powerful 3D environment that allow features such as footprint alignment tools, multiple representation of buildings, historical tracking and versioning.

Middleware also allow internet-based client access for sharing urban design projects, even using a web browser. Data security can be ensured through restricting access or limiting editing abilities for certain users. Evidence from the research shows that the following features of a virtual environment were shown to be beneficial to the process:

- Pre-defined viewpoints.
- Pre-defined fly-overs along specified routes, roads or pavements.
- Simple real-time editing features or tools.

VIRTUAL GLOBES

The popularity of GI in the last decade has been fuelled by the availability of virtual globes and, fundamentally, access to free GI. They bridge the gap between expensive, dedicated GIS and online mapping solutions as a seamless digital version of the earth enhanced with an array of information and 3D cities. This section shall mainly focus on Google Earth (GE) 6, as it is currently the only product that enables two-way interactions whereby hosts can use their own data in its 3D environment. 3D buildings, terrain, GI data, aerial imagery and historical imagery are some of the features that are available in GE. Google Earth 6 is freely available to all users and a pro version is also available for £256 (for up to 10 licenses) that allows an improved variety of data import types and facilities. However, many of the UK's local authorities do not permit its employees to upload, share or view their building models in GE 6 due to the company's problematic terms of service with regard to data ownership.

A Google Earth Network link has the potential to be the primary method for delivering a city model to its users and a wider audience. This can reduce many operating costs, while ensuring the model is used by a broad collection of users, if so desired. Furthermore, this method avoids the terms of service relating to the upload of data, mentioned above.

6.8 DATA ACQUISITION

Acquiring the most suitable data and 3D geometry should support the decisions for its intended use. Generally speaking, city model data (3D geometry and geospatial information) can be shared, bought or created 'in-house' by the organisation, which also applies to its maintenance and data update. Evidence from the research shows that pre-planning activities or planning consultations require the following characteristics from the 3D geometry:

- Roof details
- Accuracy to within 1m
- Non-textured facades

This provides the most suitable combination of accuracy and detail for comparing building massing and the impact of a new development within its planned context. A lack of textures is not necessarily a requirement, rather a consistent texture across all buildings or 3D features that enable a more engaging and objective visual comparison. Furthermore, the following specification of minimum 3D real world objects (RWO) ('what to model') is recommended for virtual cities:

Essential	Desirable
• Buildings (including roof structures)	• Building storeys
• Trees	• Boundaries
• Roads	• Vegetation
• Bodies of water (including banks)	• Tunnels
• Parks and green areas	• Underground features
• Walls	• Street lighting and furniture
• Urban structures	
• Civil engineering structures	

One of the major drawbacks of purchasing 3D data that has been modelled using photogrammetry lies in its modelling process. Specialised modellers must interpret aerial imagery and transform it into 3D geometry. Although this method can produce accurate results and detailed roof structures, it is only limited to objects that are visible from above and how the modeller interprets this information. Recent advances in aerial data capture allow improved modelling and automation in the process, although some manual input is invariably needed.

In order to reduce the substantial costs of 3D data, hosts may consider alternative methods for data acquisition. (However, a thoroughly implemented database and middleware infrastructure is highly recommended in every instance to ensure the data can be properly stored and updated). Making best use of available resources can help to ensure a sustainable virtual city. For instance, hosts (particularly in academia) may have access to terrestrial laser scanners but do not have the facilities for this type of modelling.

In this situation, raw point cloud data may still be suitable for many planning tasks, apart from visualisations, with the ability to boast very high levels of accuracy (>5mm in most cases). Although some data refining will be needed, this is far less time consuming than the extensive and often excessive modelling tasks that are carried out. Alternatively, a similar method could be used to update the 3D geometry after developments have taken place, regardless of the LOD that is needed.

Most European cities have strict policies that restrict development in their most historic parts, often found within the city centre district, though this can vary. Hence, these circumstances can help to address aspects with the data acquisition and update procedure for this part of the city. Although laser scanning data capture may be available for these historical areas of the city, there would be little use of the virtual city centres if its primary application is for model insertions and visualisation tasks. Hence, the cost per service is not economical as many hosts have focused on coverage, rather than the cost per m^2. Hence, a more suitable approach is to plan for the most important areas of the city to be modelled and in some cases increase their levels of detail if necessary. Similarly, update cycles should be increased in areas that are both used the most often and change (developed) frequently. Areas within cities (in the UK) are periodically updating Local Development Frameworks (LDF) that focus on certain areas for development.

Evidence from the research shows that some hosts have adopted a collaborative approach to their data collection. Surveyors, planning consultants, engineering consultants, architects and local authorities can all play a role in the development of a single virtual city dataset. Usually, these parties have gathered survey data (2D and 3D) and need the host to carry out specialist modelling, model insertions and arguably a mediation role that will impartially serve both parties. Local planning departments, architects and academia can present a source for GI, depending on the legality of this exchange. For instance, it is common for purchased data to be contractually restricted to use by a single party or non-commercial use. One of the drawbacks to a collaborative approach to data acquisition is that the resulting virtual city can contain a range of LOD. This restricts its use where consistent geometry is required, such as simulations, most visualisation or detailed design tasks. Hence, it is more suited to pre-planning design, virtual tourism, business development and some specialist applications. Furthermore, these applications do not present a sufficiently large enough market to sustain most virtual cities. Practically speaking, additional data validation, data management and complex legal agreements concerning data use can also limit a collaborative virtual city's use, making it difficult to sustain despite its relatively low cost data acquisition method.

If, however, a collaborative method is to be taken, it is recommended to treat one dataset or layer as the 'master model' from which all other data and 3D geometry refers. This is typically the most accurate or detailed source but should also be one of the most prominent (e.g. DTM/ DSM or buildings) as this will assist the subsequent modelling and data integration. In fact, this is also good practice for HD model types, as their building models are usually created as separate objects with a number of reference points (similar to OS datum points) for accurate position on a DTM.

Currently, the most cutting-edge data acquisition and modelling processes produce textured mapped buildings as part of the process. Ground-based laser scanning is usually carried out for the purpose of visualisation; hence realism and thus detailed surface textures are part of this requirement. Digital photography is captured during the scanning process for texturing as well as assisting the subsequent modelling process. It is widely considered that textured models add realism to a virtual city's geometry, but it can also be a way of adding the impression of detail to the buildings. This is an important aspect to consider in the design stages, in order to evaluate architectural style, material comparison and building density, for example. Non-textured building models are more suited for comparing building form and scale.

There are numerous benefits of using digital photography as a primary form of data capture, chiefly its speed, low cost and convenience that enable data (or derived data) gathered in this way to be kept up-to-date more easily than any other method. Image modelling is a relatively untested method of creating or updating 3D geometry in a virtual city context, but its qualities are unrivalled. Both the software and data capture processes are relatively inexpensive and sufficient accuracy can be achieved using the correct method. Modelling time is slightly longer than photogrammetry (approximately 1–3 hours, as opposed to less than 1/2 hour per building). However, multiple images are needed to gather the necessary visual information with which to extract the geometry, so this method is not always suitable for obstructed buildings or those with a poor line of sight. Hence, it is often difficult to capture photography of buildings' roofs and supplementary information is sometimes needed.

Procedural modelling is an effective way of populating a city model based on 2D footprint data or other mapping resources (e.g. OpenStreetMap). 3D buildings are generated based on a set of 'rules' or architectural specification so can be written to match existing buildings. It is a method used for visualisation purposes, rather than detailed planning.

Figure 60: Photogrammetry and modelling from laser scan point clouds combine in the modelling process to enhance model detail where it is required (Vertex Modelling, 2011)

A cost effective method for producing HD models is to enhance a model using photogrammetry with detailed facades that have been captured using terrestrial laser scanning. This differs from normal laser scanning methods as it builds upon existing 3D geometry effectively upgrading certain areas. This can reduce the usual laser scan modelling time as the process can be modelled more efficiently. The interview process highlighted users from the 'high end' of laser scanning technology, which can cost upwards of £65,000. However, low end systems[10] start at £18,000 and are capable of high levels of precision. Range (typically up to 150m) is often sacrificed, although evidence shows that a number of scan positions are gathered within this range to create building models, regardless of the range of the scanner in use.

Where city modelling is carried out in-house, an efficient program involves dividing a city into districts. Focusing on certain areas of interest when they are needed, rather than carrying out a comprehensive, city-wide modelling process and subsequently building up a more complete dataset over time can ensure that the most important (current developments) areas are created first.

Recording the urban landscape for the purposes of heritage is a common application that relies on large grants as this expensive task is rarely compensated for aside from external grants (e.g. English Heritage). Therefore it is good practice to capture and store point cloud data in a separate database for the purposes of archiving the information. Modelling the data can be carried out on an ad hoc basis, as the 3D information is

[10] E.g. Faro Focus 3D

gathered for the purposes of recording architectural details in case of urban decay. Alternatively, a detailed photographic survey can be carried out and stored for modelling at a later date. Photo modelling software is developing quickly and can automatically produce highly detailed 3D geometry from a series of images taken from various angles.

Hence, it is important to establish the format in which the users want the virtual city, if at all as remote access may be the only requirement. Although evidence from the research shows that this is rarely the case as despite its usefulness for communicating developments to third parties or the general public, physical (ability to host data on local PC) access to the data is essential for most constructive planning related tasks.

6.9 EXAMPLE 2: AN EXPERIMENTAL VIRTUAL CITY

<table>
<tr><td colspan="2">Key Services&Applications
• Model insertions
• Visualisations</td><td colspan="2">Clients &Users
• Planning consultants
• Local architects and building professionals.</td></tr>
<tr><td>Key Partners
• Local Authority (GIS and Planning Departments)
• Local architecture network or body</td><td>Resources
• Skilled modelling team
• High end desktop</td><td>Update& Upgrade
• Twice yearly periodic update cycle.
• Data upgrade during the process using low end laser scanner (hired).</td><td>Data Infrastructure
• Photogrammetric city model data to CityGML standards (LOD2)
• Cloud server database (Amazon X)</td></tr>
<tr><td colspan="2">Cost Structure
• Large capital outlay, balanced by relatively low operational costs</td><td colspan="2">Cost Structure
• What are clients willing to pay for the service?
• What type of payment structure is most suitable (for single or on-going products and services)?</td></tr>
</table>

Figure 61: Experimental Virtual City Business framework canvas

The original source data is commissioned from a data provider in order to gain the rights to the data and its unrestricted use. The core service of this host is to provide context models for use in urban design, highlighting a consistent, frequent data update cycle. Hence, staff and resources are focused on modelling related tasks and maintaining the data. Visualisations are produced from model insertions, but data (sales) products are not offered. The virtual city is promoted through an unrestricted Google Earth Network Link. This type of enterprise would suit a host with an existing technical background and resources, such as an academic institution or engineering consultancy, as well as an independent organisation given these conditions.

6.10 Update and Upgrade

Evidence from the literature research and subsequent investigations has shown that the existence of a suitable update procedure can have a direct impact on the longevity of a city model project. Changes in an urban environment should be reflected in the 3D city data that represents it, although a virtual model can plan these changes more effectively.

In the UK, the average city centre (approximately 6km^2) can carry out approximately 50 to 100 major developments every year. This figure is highly dependent on their circumstances so hosts should consult with their LA for a more accurate figure and information. A close relationship with the LA is a beneficial source for the sharing of information concerning recent developments and local knowledge of a city is invaluable for prompting areas that require update. In fact, an ad hoc approach can be adopted by hosts of smaller city models, where areas are updated in line with the most recent building development projects upon completion.

There are effectively three methods for 3D data update illustrated by this research – ‘continuous’, ‘periodic’ or ‘comprehensive’ which are explored below.

Continuous Update

This flexible method is ideally used in conjunction with database models as 3D geometry must be consistently and suitably optimised to carry out continuous modelling tasks. Comparing aerial photography, local research or communications from the LA can be used to prompt and prioritise these developments. This is an economical method of data update that spreads the cost of modelling and data capture, suitable for most sizes of cities, depending on a reliable system for identifying areas for update. Up-to-date aerial imagery could be used (and combined with change detection software if possible) to locate areas that require update. Alternatively, this could be carried out on an ad hoc basis whereby an area of the model is checked, verified and updated (if necessary) alongside the current project or task. This should also encompass any 3D geometry within a 20 metre radius or thereabouts.

Periodic Update

This differs from continuous updates, as large areas or a prioritised list of buildings, features or objects of a city model are remodelled after a specific period of time, such as every six months, regardless of the extent of development within the area. However, it means that certain areas of the city are more up-to-date than others and can present some difficulties when merging the updated areas with one another, misaligning terrain being one such example of a common problem. This method is most suitable for hosts that wish to record geographical phenomena within a city, such as building movement. The frequency of update is entirely dependent on the host's needs. It is common for a modelling team to prefer to carry out large modelling tasks in bulk, which can form a highly efficient process of data collection, refining and modelling. In this way, city models could be updated on a quarterly basis, allocating at least two weeks of time for the update.

Comprehensive Update

In this way, entire city model data is re-captured and modelled replacing the original data. This keeps the entire dataset consistent and is a more thorough method of ensuring an entire city is updated that does not rely on locating and prioritising where changes within a virtual city model should be made. However, due to its higher costs, this can only be carried out less frequently than other update methods.

Table 13: Comparison of update methods

	Continuous	Periodic	Comprehensive
Method	Building developments are added into the city model dataset upon their physical completion.	Building developments are added to the city model dataset in stages.	Entire city data is replaced with updated model.
Pros	• Spreads the cost of data update throughout the year. • Ensures the most up-to-date model is offered to users.	• Suitable for all virtual city types (basic, standard or HD). • Avoids difficulties in continuous recording of building developments. • Preferable for modellers and promotes an efficient modelling process. • Can be integrated with a data upgrade process.	• Creation date is easy to verify, if necessary. • Fastest, least intrusive method. • Ensures consistency across the updated dataset, as such considered most convenient and practical. • Most suitable method for carrying out data upgrade.
Cons	• More difficult to manage and priorities the modelling tasks. • Not suitable for HD models, which requires a more concentrated modelling process for multiple object modelling.	• Can be problematic when merging updated datasets that do not correspond correctly. • Difficult to estimate timescales and costs.	• Less convenient payment and higher cost. • Not suitable for HD model types for these reasons.

One of the reasons for the lack of suitable methods of update in current virtual city practice coincides with the lack of official sources that are available to prompt where changes should be made. Therefore if comprehensive data updates are not to be used, it helps to adopt a pragmatic approach to updating 3D city data model by either using sources in Local Government (planning) or gathering information first hand. Regardless of the method, updates should be consistent with the original data and modelling protocols. For example, standard city model types generally include objects that have a footprint of over $1m^2$. Data update should follow a similar rule, unless a data upgrade process is to be followed.

6.11 Example 3: Recommended Virtual City Enterprise

This model represents some of the most common methods used by current virtual city hosts (e.g. data infrastructure or key applications), synthesised with recommendations based on the results of the various investigations related to the management and update of the key components of the enterprise. The framework canvas (Figure 62) outlines the key features of this theoretical enterprise.

<table>
<tr><td colspan="2">Key Services&Applications
• Pre-application consultation
• Context models
• Data licensing</td><td colspan="2">Clients &Users
• Local architects and planning consultants.
• Small and medium sized developers.</td></tr>
<tr><td>Key Partners
• Local authority (planning).
• Local architecture network or body.</td><td>Resources
• One full- time employee for operation, plus one part-time for management/ admin tasks.
• IT- standard specification desktop, digital SLR camera.</td><td>Update& Upgrade
• Data purchase every two years.
• Key development areas updated twice yearly (by host).</td><td>Data Infrastructure
• Server structure.
• Building geometry gathered using photography and image modelling software .
• Google Earth network link or software specific access (e.g. LandExplorer 2009.</td></tr>
<tr><td colspan="2">Cost Structure
• Operating costs of employees that require high levels of expertise.</td><td colspan="2">Cost Structure
Indicative rate:
• Model Insertions and images:£550
• Context models: £ 1,250</td></tr>
</table>

Figure 62: Recommended business framework canvas for standard city models

The primary focus of this enterprise is a focus on the delivery of a consistent, standard virtual city model type to a range of subscribers remotely. The use of middleware and data management is therefore an important consideration for this host. A robust spatial data infrastructure supports these activities and also benefits from a range of simulations or exploratory projects for commercial or academic clients and partners. The 3D data is repurchased every two years to ensure consistency and completeness, but key development areas within the city are verified twice per year and updated accordingly by the hosts. Upgrading these areas using image modelling software may also be considered so that visualisation applications can be carried out and current information can be assured. Quarterly or monthly subscription to the virtual city relies on a license agreement with the original data providers. As with the previous example, this type of enterprise would suit a host with existing technical background and resources, such as an academic institution or engineering consultancy. Alternatively, independent organisations may be established from key partnerships with local knowledge centres (e.g. engineering or academia).

In this way, the virtual city makes use of a ‘representative’ (Conniff *et al*., 2010) LOD that ensures a good illustration of a city scape without experimenting with realism or modelling styles that can affect the users and burden host resources.

6.12 Planning for the future

There are three major areas of technology that are demonstrating significant improvements that will affect 3D modelling and virtual cities in the future. Firstly, (and arguably most significantly) is the field of aerial image capture. Cutting-edge aerial photography technology, such as Microsoft’s ‘Ultracam’ differs from established technology by capturing more images and from a variety of angles so that the subsequent modelling process can be carried out automatically and with greater accuracy than current photogrammetry that demonstrates a more cost effective method that is suitable for urban planning activities and suggestive of a more current dataset. Secondly, software technologies are being developed that generates accurate building models from point cloud data. This technology will have an impact on HD model types as it will significantly reduce the amount of processing and modelling time that must be carried out by skilled modellers after gathering the data. Laser scanning data capture is also improving substantially, driven by vehicle mounted applications such as ‘rapid surveying’. Finally, advances in image-based modelling combines certain elements of the technologies mentioned above; multiple images are used to generate point clouds from the geometry in images so that building models can be automatically produced without the need for expensive equipment. This technology has been demonstrated in a variety of research projects, even using the web (e.g. Flickr) as a source of up-to-date imagery.

These examples of developing technologies highlight an on-going importance for a common spatial data infrastructure. Nevertheless, it is important to maintain a fairly consistent data capture and update program, so that the data itself is also consistent. Processes should be chosen on simplicity and their connection to architectural modelling. In this way, it is likely that virtual city users will be familiar with data formats and the modelling process does not become contrived. Hence, if the availability of 3D city model information is easier to come by, a robust system should be established that allows for accuracy and consistency.

CHAPTER 7: CONCLUSION

7.1 INTRODUCTION

Virtual city models have successfully contributed to a range of applications, for a range of purposes and across a range of disciplines. Users from various backgrounds in planning have employed virtual city models to either fulfil a specific function or explore new ones that take advantage of modern 3D CAD capabilities. Virtual cities represent an emergence of information and communications technology (ICT), virtual reality (VR), GIS and 3D modelling. However, it is widely understood that virtual city projects have a limited life due to technological changes and the relatively short lifespan of the data that define them.

The research began with an investigation of current literature on both virtual city modelling and business models in order to identify key issues for the subsequent research. A virtual city audit was necessary at the end of this stage to contextualise the literature and assist in creating a suitable sample for the interview process. Engaging with virtual city practitioners highlighted best practice and areas for improvement of current practice. The aim of the research was to formulate a sustainable business framework that outlines best practice and recommendations for the process of 3D virtual city modelling, focusing on virtual cities that are used for urban planning related activities. Hence, the framework has been designed to support maximum flexibility in its application, illustrated with exemplar models to contextualise the methods for a range of hosts.

The interview stage identified three types of virtual city models that are being used in practice (basic, standard and high detail), which helped to classify virtual city models in a more recognisable format. The examples of virtual city models currently in use throughout Europe demonstrated cutting-edge data management skills in practice, but little concern for the on-going direction and management for the organisation. Berlin's city model, for example, highlights a collaborative approach to data acquisition and spatial data infrastructure. Glasgow's city model illustrates cutting-edge 3D modelling techniques to create one of the most realistic city models available. Yet both of these virtual cities have not been applied to the extent that they were established for, due to the inappropriate and inaccessible technologies that they require. One of the common shortcomings in virtual city modelling has been an exaggerated focus on the technicalities of the creation of 3D data or geometry. This has subsequently caused a lack of understanding on whom the end users are and their requirements for a virtual city. Altmaier and Kolbe (2003) state that certain users require immediate data access, tools for 3D analysis and data processing, as well as solutions for interactive visualisation and presentation.

Although software and middleware has developed over the course of the research, digital globes have developed a growth of interest in GI that has been supported by the exponential access to free data and resources that are available online. Ultimately, the end users of virtual cities (planners, architects, designers, etc.) have become accustomed to easy access to data and software, ultimately from their desktops. This has presented significant problems for virtual city hosts who have neither the resources nor inclination (or the legal capacity) to share their data with other parties. Hence, the organisational framework presents a methodology that focuses on the end users of the model and how the service can be maintained.

Attitudes towards virtual city modelling have showed two distinct approaches. Firstly, a '3D city model' describes early examples of virtual cities, which were produced as seamless CAD models to represent a city, managed as a single object and commissioned as a single product. Secondly, a 'virtual city' approach exemplifies a more dynamic virtual city project, with individual components held within in a database structure. Dollner *et al.* (2006, p3) exemplifies that "the virtual 3D city model of Berlin acts as an integration platform for 2D and 3D geo-data and geo-referenced data instead of being only a 3D geometry or graphics model". Originally a city model was driven by the modelling process, focus has shifted towards data management, maintenance and interoperability. A virtual city enterprise is the next elaboration of the field, taking advantage of cutting-edge modelling techniques and efficient processes to help sustain a model for its applications and end users. This is analogous to similar technologies over the last 40 years that have evolved from research-based environments into commercial products or services.

A virtual city can be used for a broad range of applications, with planning related tasks serving as a specific subset of these. However, the technical resources, expertise and facilities that these applications require demand a dedicated enterprise that surpasses current commercial 3D modelling organisations. Appropriate hosts should also be capable of creating good professional relationships with local (in relation to the modelled city) planning and architectural communities.

The evidence from this research shows that the increase in use of web-based 3D mapping applications has affected GI users, in terms of everyday 'desktop' use, the advancement of 3D modelling techniques, data availability and user expectations of GI services. Currently, these applications are motivated towards virtual tourism and web advertising rather than accurate planning activities. Current solutions do not present a suitable platform for even basic spatial planning tasks, such as massing studies. Even with improving technologies and data capture or collection techniques, the demand for privacy is a constant consideration that will prevent the delivery of highly detailed and accurate 3D environments that are publicly available over the internet. However, basic and mainstream model types defined in this research have shown rapid development that has altered the procurement process of many virtual city hosts. Current rapid data capture and modelling techniques provide a suitable level of abstraction at street level while providing an impressive level of realism at a larger, city scale. Despite their use in virtual tourism, architects, planners and urban designers favour non-textured and 'clean' virtual city models that more traditional photogrammetric models provide.

The recent demise of regional development agencies in the UK and the loss of 'top level' authorities will ultimately affect the choice and role of a virtual city host. In many ways, it will provide an opportunity for entrepreneurial enterprises to capitalise on the role, which have otherwise been dominated by groups established in larger organisations. Nevertheless, there is no correct formula for who the virtual city host should be, provided that the host can maintain a trustworthy dataset efficiently, as well as a relationship with local users.

7.2 The Organisational Framework

The framework describes an over-arching structure, or a general methodology for defining a business process. This organisational framework was devised to suit virtual city hosts from both public and private organisations by allowing the definition of specific project details around seven established themes to organise virtual city philosophy.

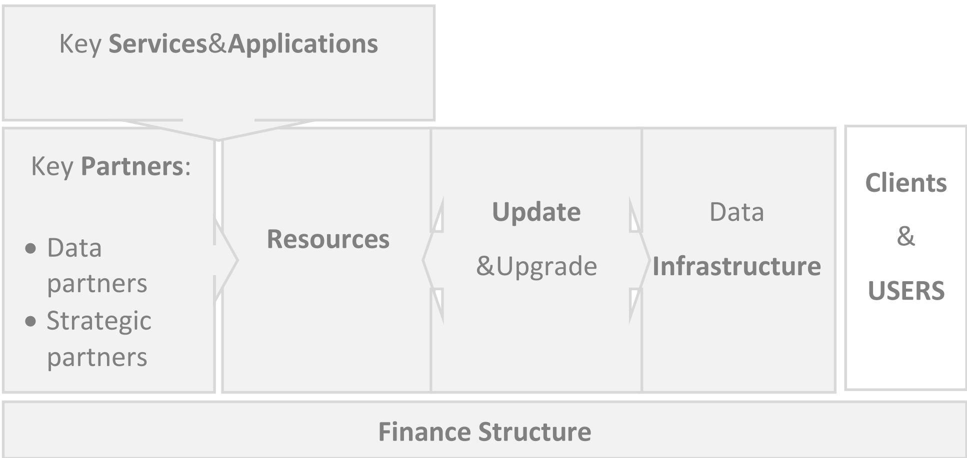


Figure 63: The Organisational Framework

The core components of the framework are represented using a business 'canvas' to organise the hosting rationale.

The key features include:

- The host organisation should offer a principal set of services (e.g. model insertions, context models or 3D data) to assertively specify its resources and methods of 3D data capture.
- A suitable spatial database infrastructure ensures longevity to a project, enabling a more effective update processes and flexibility in use for alternative applications (other than core services mentioned above).
- License agreements for access to data or updated datasets can ensure structured payment over a period of time to support data update as well as encouraging long term clients or partnerships to sustain a virtual city model, through a more convenient price structure.
- Currently, city models produced using manual photogrammetry methods are considered to be the most favourable/ suitable for planning activities related activities as they provide a suitable balance of representative detail versus cost.

7.3 CONTRIBUTION TO KNOWLEDGE

The purpose of this research was to address gaps in current research and understanding of how virtual city models are created, developed and managed for long term use in planning related activities. Previous virtual city research and investigations have looked to resolve technical issues such as data standardisation (see Kolbe and Groger, 2003), 3D building generation (Muller *et al.*, 2007) and their applications. Investigations showed emerging knowledge and commercial developments in the process of creating 3D city data. These considerable datasets require a unique approach to manage the enterprise and its resources. However, the operations that concern the use of these virtual city datasets are complex. The research brings together the two fields of virtual city modelling and business modelling to make a contribution to this subject. Chapter 6 and the organisational framework serves as a ‘guiding source book’ (Bourdakis, 2004) for existing or prospective virtual city hosts or founders in order to organise the core methods and principles that help to sustain a virtual city enterprise. This organisational framework introduces seven key areas that virtual city hosts should address for sustaining their enterprise that encompasses the technologies and expertise. Hence, this research also contributes to knowledge in bringing together the many considerations that virtual city hosts must take into account when creating a sustainable process to support urban planning.

7.4 Further Research

The business framework would benefit from a subsequent action research or case study participatory research methodology to ensure its robustness in practice. The framework would be introduced to two virtual city hosts and monitored for between 12 and 36 months to test the respective elements of the framework. Alternatively, a series of focus groups with current or prospective virtual city hosts could be carried out to assess the feasibility of the framework in planning environments. This should include established hosts in order to understand the feasibility of the long term success of the framework and its adopted enterprise.

Further investigation is required on the specific technical tasks that are carried out by the various planning activities. This will be important in outlining proper specifications for city models. Currently 3D model data is dictated by the data acquisition techniques (and its limitations) rather than the overall tasks in which it must fulfil. At present, much GIS data is inherently 2D (e.g. boundaries, building data) and is problematic when enhancing 3D models with this information. Modelling is carried out in absence of these requirements and usually remotely, which makes it very difficult to extract additional information, such as building storey or boundaries.

A comparison of the usefulness of textured versus non textured models will highlight the benefits of using either feature. On the one hand, textures can give the impression of detail but have been reported to distract the users for analysing building 'mass' and form. However, semi-automatic modelling techniques produce textured results and the research shows that these techniques must be adopted to maintain an up-to-date virtual city. Conniff *et al.* (2010) describes the effectiveness of realistic photomontages versus simple 2D sketches for urban design and Le Heron (2006) suggests that mapping has brought about an effective way of how users perceive geographical space, yet this is not necessarily also true of realistic virtual city models.

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8 INSPIRE DIRECTIVE- THEMES

There are 34 themes that are required for the INSPIRE Directive.

Annex I

1. Coordinate reference systems
2. Geographical grid systems
3. Geographical names
4. Administrative units
5. Addresses
6. Cadastral parcels
7. Transport networks
8. Hydrography
9. Protected sites

Annex II

1. Elevation
2. Land cover
3. Orthoimagery
4. Geology

Annex III

1. Statistical units
2. Buildings
3. Soil
4. Land use
5. Human health and safety
6. Utility and governmental services
7. Environmental monitoring facilities
8. Production and industrial facilities
9. Agricultural and aquaculture facilities
10. Population distribution and demography
11. Area management/ restriction/ regulation zones and reporting units
12. Natural risk zones
13. Atmospheric conditions
14. Meteorological geographical features
15. Oceanographic geographical features
16. Sea regions
17. Bio-geographical regions
18. Habitats and biotopes
19. Species distribution
20. Energy resources
21. Mineral resources

APPENDIX 2

9 VIRTUAL CITY AUDIT

The following table is a more extensive format of the virtual city audit introduced in Chapter 2.

City	Country	Host	Original Function	Other Uses	Description	Size, Detail	Date Est.	Still in use?
Salzburg	Austria	Cybercity, for Client ViewTec Inc.	general public information	promote tourism	Images derived from oblique photography, flown from helicopter	1500 buildings, textured@ LOD2. Though accuracy is not reliable	?	?
Vienna		City Council	planning	Emergency Planning				
Birmingham	UK	City Council	planning		data provided by Zmapping			
Glasgow_dds		Digital design studio, Glasgow School of Art	Planning	Public participation and consultation aid	Commissioned by the City Council to create a detailed city model after a tender process. GCC owns the data, cost split into stages based on agreed development of model. (450k for phase1)	Phase 2 will eventually cover 12 km sq of the city centre at LOD3	2005	Y
Manchester		Arup	Planning, masterplanning		Originally developed 10 years previously to plan the post-bomb cc. latest model unites data from councils, architects and developers from using a combination of modelling techniques based on building photographs, aerial photography and laser-based data sources	4km sq	2007	Y
Newcastle		Northumbria University	Research/ planning	Heritage, transport simulations, emergency planning, GIS		4.8 x 4km as of 09/08 (LOD 2)	2003	Y
Nottingham		City Council	Planning		data provided by Zmapping			
Liverpool		GMJ	Planning, visualisation					
London_ucl		CASA (UCL)	Planning, visualisation, public participation	Planning, GIS related research	OS base layer, LIDAR for height data to produce LOD1 simple city model. Made available to GLA through network link and GE. Restricted by OS copyright agreement.	~2500km2 (LOD 1)	2001	Y
London_cybercity		Cybercity	3D data provider					

London_zmap		ZMapping	3D data provider		various areas of the city	40 sq km @ LOD2		
London_GMJ		GMJ	Planning, visualisation			41 sq km		
Newport		GMJ	Planning, visualisation		city centre modelled			
Sheffield		City Council	planning		data provided by Zmapping			
Stockport		City Council	planning		data provided by Zmapping			
Brno	Czech Republic		Planning (relocation)	Transport simulations, visualisation	was established to assist the planning for relocating the main train station to the south side of the city			
Helsinki_font	Finland	Fontus	3D data provider	Tourism		25sq km, 400mb file size at a cost 1-1.5 million euro	2001	
Bezons (Paris)	France	Archivideo	Planning (transport)					
Dijon		Archivideo	Planning (transport)					
Nantes		Vectuel	3D data provider	Tourism				
Paris_vectuel		Vectuel	various planning functions		various clients	90 sqkm @ LOD1-3, includes 200,000 builings	?	?
Paris_cybercity		Cybercity	Planning, 3D data provider	Tourism	just launched on google earth, modelled semi automatically using aerial images using in-house CyberCity-Modeler.			
Vierzon		Vectuel	Planning		for the visualisation of new shopping centres in the area	LOD 1-3		
Berlin		Berlin Senate and Berlin Partner GmbH	Planning, business development	research			2000	Y
Bocholt		GTA Geoinformatik GmbH	Planning					
Bochum		Realcity	Planning	media and marketing animations	the model was created for various parts of the city and the associated developments- it was particularly useful as the town has buildings with many height differences		2004?	y
Chemnitz		Virtual City Systems	Planning					
Coburg		GTA Geoinformatik GmbH	Planning		downtown: LOD2 photogrammetric measurement of buildings; partially texturedsurrounding: LOD1 automatic generation of buildings,	50km2 covered @LOD1/ LOD2		y
Dortmund_realcity		Dortmund Economic Development Agency	Planning, business development		realcity established this model in 2001, claiming that this is constantly updated and that this is one of the largest city models in the world (not confirmed)	120000 buildings @ LOD3	2001, revised 2003	?
Frankfurt_realcity		Realcity	Planning	Marketing				

Hamburg_cybercity		Cybercity	3D data provider		Includes more than 300.000 buildings and will be offered in three different Levels-of-Detail: non-textured block models, non-textured detailed models and textured detailed models. The city center will consist of over 2.000 buildings and will include approximately 40.000 façade images. Textures will be semi-automatically applied from oblique aerial imagery using CyberCity-Modeler. The final deliverable available to the public via Internet (www.cybercity.tv) in October 2006	300,000 buildings@ LOD1-LOD3		
Hamburg_gta		GTA Geoinformatik GmbH	3D data provider		3D Planning Model Hamburg Blankenese, modelled photogrametrically.	6 ha approx, LOD 2 (also 3 perhaps?)		
Hannover		Leibniz Universität Hannover	Research	Planning	hosted by the university's institute for cartography and geoinformatics	LOD1-LOD3		y
Heidelberg		GDI 3D (various contirbutors)	Research	Planning	The main goals describe it as an exploration of city models and interoperability. Planning not the primary use but it is noted that this is an application- need to investigate.	LOD 0- LOD3		Y
Munich_cyber		Cybercity	Planning					
Neubrandenburg		GTA Geoinformatik GmbH	Tourism					
Stuttgart		State Capital of Stuttgart and GIS-AG of Stuttgart	Planning, research		produced on a citygml base, the Stuttgart model was produced by bringing together many models into one central database	207 sqkm of TIN; 180000 (LOD1); 160000 (LOD2); 400 'landmarks, hand modelled		
Weimar		GTA Geoinformatik GmbH	3D data provider	Planning				
Wiesbaden		Weisbaden and GTA Geoinformatik GmbH	Planning, 3D data provider					y
Westport	Ireland	AMT 3D	Planning, heritage	virtual tourism (google earth)	3D laser scanned data, commissioned by Westport town council. License agreement with CC, rather than outright purchase.	~2 x 2km @ LOD3	2006	Y
Florence	Italy	Cybercity	3D data provider	Planning	Generated from 20cm-resolution digital aerial images (dated June 2006), semi-automatically and photogrammetrically. Florence 3D includes the detailed 3D model of the city centre (approx. 3 sq.	3 sqkm@ LOD3; 37 sqkm@ LOD2	2007 tbc	

					km), the simplified 3D model of the surrounding (approx. 37 sq. km), the digital terrain model and the 20cm-resolution orthophoto.			
Lucca		GeoSIM systems	3D data provider	Planning	Derived from 1:6000 scale aerial photography stereo-pairs. Photogrammetry measurements (10-15cm) used to generate accurate models	LOD3 tbc		
Milan_geo		GeoSIM systems	3D data provider	Planning	Derived from 1:6000 scale aerial photography stereo-pairs. Photogrammetry measurements (10-15cm) used to generate accurate models	LOD3 tbc		
Parma		Compagnia Generale Ripreseaeree S.p.A. (CGR)	3D data provider			LOD3		
Venice		Compagnia Generale Ripreseaeree S.p.A. (CGR)	3D data provider					
Delft						3 ha, 185 buildings	2000	
Bratislava	Slovakia	Comenius University	Planning0	tourism, media		LOD2-LOD3		y
Maribor	Slovenia	CityGRID	Planning		The city of Maribor (Slovenia) commissions citygrid to start with the implementation of a 3D city model. Based on existing data, a block model will be created as the first step. Further on a detailed restitution of the roof surface and integration into the CityGRID system are the next milestones toward a fully modelled city model. The complete model will contain about 30 000 buildings.	final model to contain 30000 buildings	end 2006	
Gothenburg	Sweden	Department of Architecture at Chalmers Univeristy	Planning	visualisation	Swedish government allows free public access to map data. Work in Gothenburg has included planning and visualisation analysis, including a recent analysis of a proposed windfarm in the region.			
Geneva	Switzerland	COWI	Planning, GIS	GIS	COWI commissioned by canton (state) of geneva to prodeuce a detailed 3d model of whole area over a 10 month period	76000 builings, covering 245 sq km when complete	2008	y

APPENDIX 3

10 INTERVIEW QUESTIONS

The following list outlines the interview questions that were presented to the participants through the semi structured interviews:

1. Please explain your role and the organisation that hosts the virtual city.
2. Who/ which organisation commissioned the development of the city model?
3. Who provided the source of the city model data?
4. Were any license agreements required and what were the main terms?
5. What copyright restrictions are attached to these data?
6. What was the cost of the original data?
7. What are the operating costs of the city model?
8. How is the project funded?
9. Who is responsible for hosting and managing the city model data?
10. Who are the stakeholders in the city model and what are their roles?
11. Is the model updated and if so, how is this done? (Technical and organisational process)
12. How is the city model used and how is it communicated? (Explanation of the process)
13. How does the city model contribute to better urban planning?
14. Is the model used for applications other than urban planning?
15. Has the project been cost effective?
16. How could the application of the city model be improved?

APPENDIX 4

11 UNIVERSITY ETHICS FORM

The following form as sent to interview participants beforehand. Consent was achieved by recording verbal consent.

northumbria UNIVERSITY School of the Built Environment

RESEARCH PROJECT ETHICS REGISTER FORM

Project Title ....

Researcher's name ....

Supervisor's name .... (if researcher is a student)

Date of commencement ....

Ethical considerations in the research project

1. Have you/will you inform[ed] the participants about the research?	Y/N
2. Have you/will you obtain[ed] their consent using the standard consent form?	Y/N
3. Do any participants constitute a 'vulnerable group' (e.g. under 18 years of age?)	Y/N
4. Will the research involve commercially/personally/ politically sensitive information?	Y/N
5. If yes [to 3 or 4, above] have you taken steps to deal with this issue?	Y/N
6. Are there likely to be any risks for you or for the participants in your procedures?	Y/N
7. If yes [to 6, above] has a control measure been proposed in the IPA?	Y/N

Statement by researcher

I have read the University / School Guidelines on Ethical Procedures in Research and confirm that the answers I have given above are correct. Where further issues arise under items 3, 4 or 6 [above] I have described in writing how I intend to approach these issues in the research.

Researcher's signature..**Date**...

In the case of MPhil / PhD students a signed copy of this proforma should be appended to the Initial Project Approval Form and accompany it for ratification at the next available School Research Committee meeting.

In the case of a research contract the form should be completed by the research team [including the Principal Researcher and the Research assistant(s)] and submitted to the next available School Research Committee meeting.

12 PAPER 1: VIRTUAL CITIES: MANAGEMENT AND ORGANISATIONAL ISSUES.

Virtual Cities: Management and Organisational Issues

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Abstract: This paper describes an audit of current practice in VR city modelling within Europe, with focus on the management, financial and organisational issues of models used for urban planning. While computer hardware and software for city models continue to develop, the organisational aspects regarding their creation, operation and maintenance remain problematical. Little is known about available options, models of best practice (Bishop and Forster, 2007) or how VR functions as a means of communication for urban planning applications (Sunesson et al, 2007). City models that are used for planning functions are of particular value when assessing the likely visual impact of a new project in its context. As the technical process of integrating Architectural models into a city model is well practiced, this paper examines the trends in current city models around Europe.

Keywords: Virtual cities, city modelling, management, urban planning, stakeholders.

1. INTRODUCTION

This paper describes an audit of city models carried out between September 2008 and January 2009. City model stakeholders were consulted from industry, academia and government to investigate the varied roles that are involved in managing a city model. A website has been set up to create a community for city modellers and a forum for discussion concerning the development and maintenance of virtual city models (www.virtualcityexchange.com). The audit described in this paper is based upon European city models that have been identified through an extensive literature review and interview process conducted between June and December 2008.

City models were initially identified and selected from across Europe based upon pre-defined criteria (location, size, detail, secondary application) that were then shortlisted for further investigation. The study looks at the life cycle of city models established specifically for urban planning purposes, beginning with data acquisition and licensing issues. Copyright and legal issues are addressed, as well as the running costs involved with operating and updating city model data. This paper, offering the results of an extensive audit process, highlights current trends in city modelling being practiced in projects across Europe. Common themes in city model management techniques are explored and suggested methods of good practice could be considered by urban planners about to embark on the development of a virtual city model.

The overall aim of this research programme is to design a business framework for the management of 3D virtual city models for hosts who are seeking to operate a city model for urban planning functions. The research will outline standards and protocols for its creation, copyright and legal issues for its distribution and suggest processes for both its update and improvement. This responds to research by Dokonal, Martens (2001) and Bourdakis (2004), who have recommended a 'guiding source book' for the creation and use of city models. The diverse issues and needs of various stakeholders will be also addressed (Horne et al., 2006) in order to address the organisational issues and common concepts involved with establishing, hosting and managing a city model (Voigt et al., 2004).

2. BACKGROUND AND THEORETICAL CONCEPTS

2.1. 3D Virtual City Models in Urban planning

Many technical barriers to the inclusion of various stakeholders exist in the UK's urban planning process. Moreover, current methods for communicating development proposals to the general public are not only difficult to understand but do not give appropriate opportunities for participation (Mantle et al., 2007), contrary to the Office of the Deputy Prime Minister's 2005 publication of 'The Draft Town and Country Planning' (ODPM, 2005).

Establishing links with Local Authorities is crucial for city model hosts to ensure successful public participation in projects at national and EU level, who are strengthening public participation and e-democracy by encouraging involvement of urban development by residents (Knapp et al., 2007). Historically, calls for comments, statements and general public opinion on regional development plans, environmental impact assessments or zoning changes typically attract very low turnout (Strobl, 2006).

Among many others, Lange (2005) explains that computer-based visual simulations can potentially function as the link between the classic top-down approach in urban planning, i.e. experts providing information to the general public, and the bottom-up approach, i.e. the general public being consulted and participating in decision making. Brown et al (2005) states that a major problem that faces the a city model host is the issue of merging those involved in the participation, urban planning and the development processes together within a common framework of understanding. Bishop and Forster (2007) explain that the many technological and organisational barriers that affect the use of VR in collaborative planning may be overcome by a thoroughly designed model implementation and use. Much research has been carried out to explore the barriers and perceived barriers to adopting VR in various stages of the urban planning process (Hudson-Smith, 2005, Fu et al., 2005, Bourdakis, 2004, Firmino et al., 2006, Appleton and Lovett, 2005), which reveal that cost and time for training are major factors restricting its use (Mantle et al., 2007). The purpose of this research is to tackle some of the organisational barriers that face implementing a 3D city model.

2.2. Users and Stakeholders

Wang et al (2007) suggest that the insufficient integration and interoperability between software applications have caused considerable barriers to communication between the stakeholders. According to Hall (1996), there are four relevant parties in the urban planning process whom are seen as legitimate 'stakeholders': city planners, architects working for clients, the clients and the general public.

The planning participation environment can also determine the success of the process, as research shows that many VR environments or 'Decision Theatres' do not boast many returning visitors, once an initial project has been completed (Kobayashi, 2006). Cases such as Berlin's Business Location Centre and Glasgow's Digital Design Centre are examples of city models which have an increasing frequency of users and returning users for urban planning, architectural visualisation and real estate applications, demonstrating a robust framework for attracting and communicating to their users. Originally, it was architects and academia who have been the driving factor for the creation of city models for spatial analysis, there is a shift towards users from surveying, programming and GIS driving the development of city models around the world for a variety of applications (Dokonal, 2008).

2.3. Modelling Procedures and Standards

Much progress has occurred over the last 5 years in the standardisation of city model data, such as the recognition of the CityGML (City Geography Mark-up

Language) data standard, which is a multi-purpose representation for the storage and interoperable access to 3D city models (Kolbe et al., 2005). In 2008, the KML (Keyhole Mark-up Language) language was officially recognised as an ISO standard, emphasizing Google's foothold in the Geographic Information (GI) industry. This is also in line with the development of Industry Foundation Classes (IFC)[11] and Building Information Models (BIM), which have a great deal to offer to data-rich city models. Beside the technical issues of these large complex models (Wang et al., 2007), it is the lack of high level commitment by key players in both the construction and software industries that hinder the standardization efforts in the Architecture, Engineering and Construction (AEC) industry (Behrman, 2002). The uptake of BIM in practice will present information rich, accurate geometric models for larger 3D virtual city models (Kohlhaas and Mitchell, 2007).

Although CityGML does outline some thematic methods of representing digital building models ('Level-of-detail 0-3'), established recommendations are necessary for quality levels and methods of depicting the content of a building proposal (Bourdakis, 2004). This is essential for better understanding of a planning scheme and a democratic aspect of city planning decision-making (Sunesson et al., 2007). Furthermore, different stakeholders involved in the development process require to see the model from different perspectives and qualities (Brown et al., 2005).

2.4. Ownership and legal issues

Although virtual cities have been established by a range of users, from educational establishments to private urban modellers, Le Heron (1999) highlights the importance of the careful hosting of a city model for specialist applications. This is necessary to ensure that information is secure, its distribution is controlled and to protect Intellectual Property rights. Virtual Cities that are used for urban planning and Government functions require careful control of its data so that it does not become a commercial or marketing tool and lose its integrity and reliability. In this situation, the legal rights to the data can also become complex and fragmented, which can restrict the use and increase the costs of operating the city model. The risk of a host losing some commercial or contractual control raises obvious concerns to stakeholders in the urban planning decision-making process (Bishop and Forster, 2007).

Legal issues concerning 3D city models can be associated with the data acquisition and management of the data's use. This model data is often sourced from 3rd party aerial imagery or specialist city modellers. This approach can be restrictive for the distribution and intended use as the necessary Intellectual Property Rights (IPR), security or privacy laws may be applicable. Historically, it has been noted that the lack of proper copyright protection or digital signature stamping in 3D geometry, coupled with the relative ease at which file can be transferred across the internet was hindering the development and availability of urban models (Bourdakis, 2001).

[11] An IFC is a 3D file format enabling interoperability between ot her IFC compliant software.

In a collaborative city model situation, architects and designers who share their 3D models frequently request to retain rights to their data. This is usually to avoid misrepresentation, particularly during the course of planning proposals, not exclusively for IPR purposes as would be expected. For these reasons, more recent examples of city models have acquired data using laser scanning technologies to avoid legal restrictions and produce ‘as-built’ 3D geometry, rather than relying on architects’ drawings (e.g. Glasgow, Westport) (Pritchard, 2007).

2.5. Management and update of virtual city models

Based on research carried out on virtual city models, it is evident that although much research has been carried out on the process and application of virtual city models, little work has been carried out on the theoretical organisational and management issues that these technologies encounter. Hamilton et al (2005) verifies the notion that the ability to manage urban planning data leaves much to be desired and that practical aspects, such as the management of 3D city models and how they can be sustained, must be addressed (Dokonal and Martens, 2001). It has also been recognised that the majority of GI (Geographical Information) users do not yet know what they require from 3D building data (Sargent et al., 2007), which adds to a vast knowledge gap , further confused by the thwarting question: ‘what to model’.

Concepts for 3D change detection and automatic updates of city models have been developing for some years now and are evident in some of the city models in this study. These concepts however, generally focus on the comparison of temporal information (e.g. remote sensing imagery) to identify discrepancy so that areas for re-modelling can be detected and carried out (Song and Deren, 2003). Holland et al (2003) describes this process as the comparison of two sets of imagery that require the manual intervention from a user who must interpret and prioritise all change illustrated in the graphical display that is adopted. For city models as with most forms of Geospatial data, update can be carried out by either re-audit or revision, depending on the extent of work to be done (Song and Deren, 2003). One area of research on updating city models is rapidly converging on complete automation (Holland and Tompkinson, 2003, Song and Deren, 2003) although the cost and prolonged time-scale of this approach is still extremely high and data must be periodically acquired by remote sensing (aerial photography in most cases) for data comparison.

3. METHODOLOGY

The audit aimed to gather qualitative research data from a cross sectional sample of current city models in Europe, designed to be an informative critical appraisal of city model management methods.

In order to establish boundaries for this data collection, only European city models have been shortlisted for the audit. Information gathered from the literature review indicated that there are many common issues pertaining to hosting and managing city models within this group, such as software, applications and legal issues. The latter point also includes recently implemented EU legislation that has been the key driving factor for the establishment of many city models by its members. Finally, the accessibility of the audit participants was an important factor for consideration for the purposes of the research, as interviews will be necessary and issues such as language and time differences were taken into account.

A second reason for auditing city models that had been used for urban planning functions was done to target data of a particularly high quality and whose accuracy was an essential aspect of the data- from data collection/ acquisition, to the modelling process and application. Furthermore, this attention to accuracy and quality has been proven in practice, particularly for well established city models. The subsequent interview stages would then aim to consult city model hosts who had succeeded in managing self-sustaining and updated city models that would paint a picture on the best practice of managing city models.

The initial aim of the audit was to gather qualitative research data from a cross sectional, representative sample of current European city models. This extensive list of models will be categorised so that a representative sample can be selected to create a shortlist of interviewee participants. A series of interviews will follow to explore key issues and greater understanding of the management, financial and organisational issues of virtual city models. Having completed the second stage of the audit, the gathered data will be analysed in order to critically appraise the management methods that have been adopted from the interview sample.

The selection criteria were eventually chosen to highlight city models that demonstrated an emphasis on accuracy, quality and high level-of-detail (LOD). Furthermore, for the purposes of the research, only city models that were established primarily for urban planning functions were chosen for the audit.

Following an extensive, ongoing literature review it became apparent that city models that had been developed solely for GIS purposes had little emphasis on data accuracy and displayed a broad range of detail, precision and organisational value. Many of these had been developed for simple visual enhancement of 3D Digital Terrain Models (DTM) and have used fairly basic techniques to create a model, such as extruding 2D building footprints to varying heights. These tools that are used for creating simple, low-polygon, low detail city models are becoming increasingly economical and viable for many users, using simpler, low-cost or even free software and more competitive rates for GI and building data.

The information required for the audit was gathered primarily from literature and web-based information in order to formulate the initial list and categorise them based on their characteristics. Further information was collected by contacting the hosts directly.

4. CITY MODELS IN EUROPE

The audit identified the following city models in Europe that are currently being used for urban planning functions (2008):

Berlin	Dortmund	Lucca	Salzburg
Bezons (Paris)	Florence	Manchester	Sheffield
Birmingham	Frankfurt	Maribor	Stockport
Bocholt	Geneva	Milan	Stuttgart
Bochum	Glasgow	Munich	Venice
Bratislava	Gothenburg	Nantes	Vierzon
Brno	Hamburg (x2)	Neubrandenburg	Weimar
Chemnitz	Hannover	Newcastle	Westport
Coburg	Heidelberg	Newport	Wiesbaden
Delft	Helsinki	Nottingham	
Diestadt	Liverpool	Paris (x2)	
Dijon	London (x4)	Parma	

Clusters of detailed city models are evident in some countries for two main reasons. Firstly, established GI data providers that boast 3D modelling services can offer city model data for large parts of their resident country (e.g. GTA Geoinformatik GmbH in Germany, ZMapping in the UK and Vectuel in France). Secondly, recent EU legislation has encouraged their use, such as the Environmental Noise Directive (2002). Many cities in Germany have been modelled, partly for this reason, but also due to Germany's approach to the city modelling technology and an established GIS underpinning that have been driven by research and academia in the country.

From the sample list, no current city models were found that existed before 2001. This is surprising as 3D city models have been used in urban planning for almost 20 years, explaining a life span of less than a decade for many city model data. This could be linked to a distinct lack of regular update procedures by the hosts. The period between data acquisition and final city model using photogrammetry are, on average, 2 years apart. This is due to a number of factors, primarily being the practicalities and costs of capturing aerial photography. Although the modelling time is far greater to reflect the higher level-of-detail, terrestrial laser scanning has a far smaller development time for creating the models (typically 2-6 months) for the audit sample. This also reflects the in-house process of 3D data collection and modelling compared to an outsourcing approach that is favoured by many current hosts. This lengthy stage between data capture and final model for many of the city models can be extremely problematical, as a model can effectively be a number of years out of date 'straight out of the box' and their reliability for urban planning is immediately questionable.

The sample data collected ranged from 4 to 2,500 km^2 in representative model size, boasting anywhere between 185 and 300,000 buildings. Generally speaking, the greater the coverage, the lower the level-of-detail. Many models created in the last 3 years, however, that have used automatic or semi-automatic modelling processes from oblique imagery, display facade textures. However, this does not affect their Level-of-detail according to CityGML standards, as their positional accuracy and architectural detail remain fairly simplistic. This follows an holistic approach in the GI industry to ‘capture once use many’ in terms of airborne data collection so that a range of imagery and LIDAR data are captured at the same time (Ordnance Survey, 2006). Generally speaking, the audit sample displays an increased level of detail than a decade ago, where simple urban block models (LOD 1) were used to visualise the landscape. Roofscapes and facade details are evident in most cases, as well as photorealistic textures and building details (LOD 3, providing suitable positional and height accuracy), mostly due to technological advances in data storage and capture techniques.

Furthermore, some European countries are carrying out strategies that are forcing the entire country’s cities to be modelled in 3D. Denmark-based Blom asa recently announced an initiative to model every building in the country (2.2 million buildings approximately), which can be achieved using recent advances in automated city modelling technologies, provided that suitable data is collected and used for the process. Sweden’s national cadastral and mapping agency, Lantmäteriet, collects and publish 3D data that is freely available for its citizens (Hallebro, 2006). This means that there are many examples of small 3D models of its cities, which make it difficult to identify any official, unified or exemplar work from this region.

5. DATA ANALYSIS: TRENDS

The latest set of city models around Europe highlight a shift in trends towards more unified, interoperable data. Older examples of city models for urban planning functions were often setup using experimental techniques of data capture and modelling processes, with often very piecemeal results. Although some of these early models generally showed high levels of accuracy, they were usually of such a low level of detail to create any lasting practical application for urban planning.

The more modern examples of city models analysed for this study display a more unified set of data. CityGML standards are evident in a large amount of model data and previous interoperability issues have been addressed in many cases.

The results also highlight an increasing list of established city modellers and data providers who specialise in city modelling. Early attempts at modelling cities were expensive and time consuming tasks carried by a handful of academics with limited results (Dokonal, 2008).

There is also evidence that modern city modelling has reacted to the rapid development of global visualisation engines to some extent. Microsoft virtual earth and Google earth are two market rivals for web-based GIS platforms that boast 3D City model features. Although both have taken different approaches to their modelling processes, they are both developing 3D representations of major cities and countries at an impressive rate. However, it is arguable whether these platforms pose a commercial threat to city models that have been produced for the purposes of urban planning because of issues with data accuracy, copyright and quality. In other words, it would not be possible to guarantee a planning task, such as an architectural visualisation, that had been carried out using global visualisation engine.

Evidence from the audit suggests that the update and enhancement has still yet to be tackled. As mentioned above, technological approaches are still an expensive option and not feasible for most applications. However, an organisational approach, such as a close relationship with LA's and relevant information sharing, could be the solution to a cost effective collaboration. Although the city models audited were established at different times, a resolution for periodic update of the data has yet to be solved. The cost of data acquisition and large scale modelling is gradually decreasing so that it is often the simpler and cheaper option to re-commission and purchase a more up-to-date model.

Figure 1 (below) describes the relationship between the various stakeholders who are potentially involved in current city model projects in Europe.

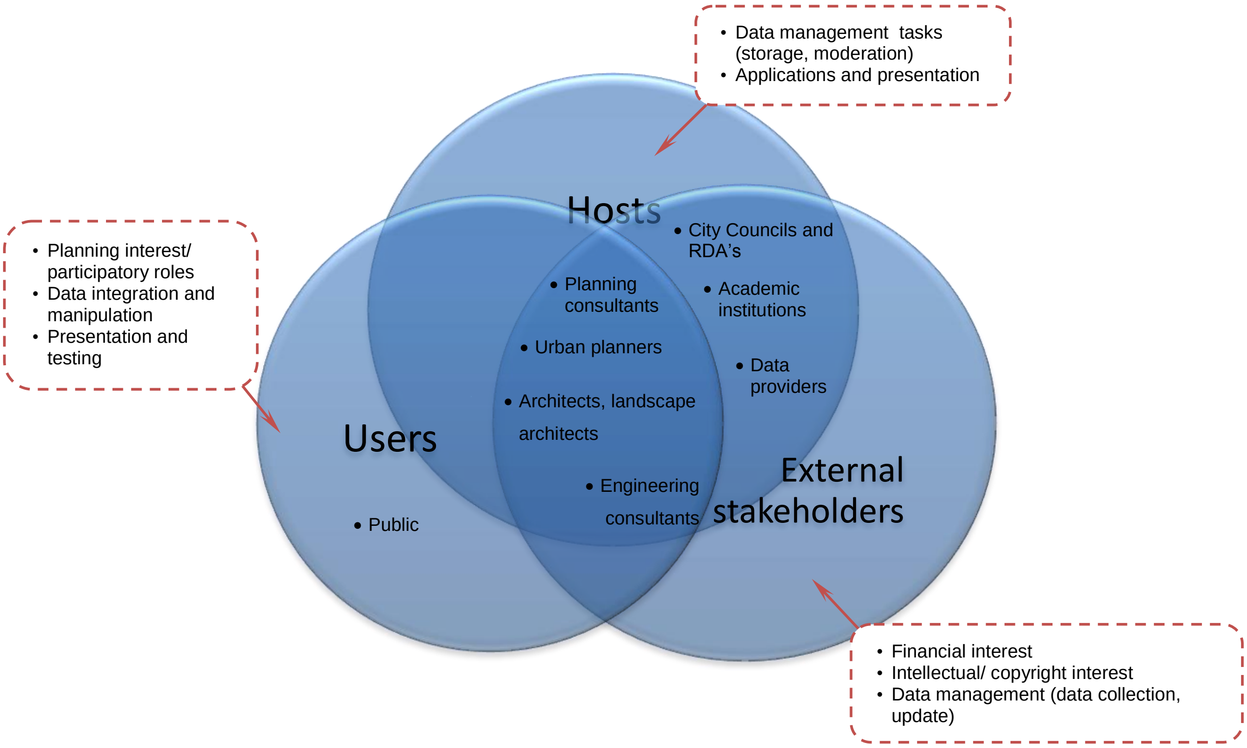

Figure 64 City model participants: roles and definitions.

The audit showed that there is still much experimentation between these roles, which are rarely clearly defined for virtual city projects. It has been proposed that this is due to the stakeholders' perceptions and expectations of city models, which is a familiar consequence in technology based projects (Laurini, 2001).

6. CONCLUSION

The latest set of city models around Europe highlight a more unified, interoperable 3D model data. The results also highlight an increasing list of established city modellers and data providers who specialise in city modelling with partnerships alongside cutting edge data capture experts. This illustrates a developing industry for the process of capturing and modelling 3D cities, which has progressed closely with academia and key research projects. Automatic and semi-automatic modelling techniques have become widespread across Europe and will play an increasing role for city models in planning.

Methods of update for 3D data are a key component to the success and sustainability of a city model. Many projects exist beyond their original planning function by their extension into other applications, typically virtual tourism, as very little consideration is given to the ongoing operating costs of a city model beyond the original data acquisition. Projects with established data licensing not only ensure a projects longevity, but also protect the legal rights of the stakeholders. Establishing the stakeholders' roles and project aims for city models in urban planning is also a key factor for their success and sustainability.

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13 PAPER 2: GLOBAL VISUALISATION ENGINES- ISSUES FOR URBAN LANDSCAPE PLANNING PARTICIPATION PROCESSES.

Global Visualisation Engines – issues for urban landscape planning participation processes

Martin Podevyn, Margaret Horne, Peter Fisher, Emine Thompson

Abstract

Traditional planning processes use two-dimensional drawings, plans, sections, elevations and artists' impressions to communicate design intent to interested parties. Three-dimensional computer visualisation technologies that support the planning process raise institutional and organisational challenges as their perceived benefits are considered. Virtual Reality (VR) models add interactivity and immersiveness to landscape visualisations but require appropriate technical input and management.
This paper explores two main themes. Firstly, how interactive 3D computer simulations of planning proposals can be adopted to successfully improve the traditional process. It reports on a pilot study to examine how architects, clients, planning officers and university researchers have worked together to systematically examine and analyse this changing process. It reports on issues concerned with ownership of city models, the roles and the compatibility, accuracy and remote sharing of urban data.
Secondly, we explore the emerging theme of web-based GIS applications and their impact on architectural visualisation. The process of placing urban data onto Google Earth was tested and the resulting issues emerging with this software, including IT and data management and accuracy issues for suitable architectural visualisation are discussed. The study also reports and offers an overview of placing accurate urban landscape data onto Google Earth and a discussion of using this method for online public participation and communicating technical building information.

1 Introduction

Traditional town planning processes use two-dimensional drawings, plans, sections, elevations and artists' impressions to communicate design intent to interested parties. Three-dimensional computer visualisation technologies that support the planning process raise institutional and organisational challenges as their perceived benefits are considered. Virtual Reality (VR) models of proposed schemes add interactivity and immersiveness to landscape visualisations but require appropriate technical input and management in order to meet the need of diverse audiences (Thompson and Horne, 2006).

This paper explores two main themes. Firstly, how interactive 3D computer simulations of planning proposals can be adopted to successfully integrate with, and support, the traditional planning process. It builds upon previous research which identifies the requirement for an accurate 3D urban model to be managed by an impartial body (Pritchard 2005) and reports on a pilot study to examine how architects, clients, planning officers and a university have worked together to systematically examine and analyse this evolving process. Whilst academic projects have shown the potential of VR models at the urban scale and provide good case study examples, few models built in academia are being used to their full potential in the planning process, by the relevant municipalities (Whyte 2002).

Secondly, the paper explores the emerging theme of web-based GIS applications and the role they can play in urban planning. Institutions and organisations may begin to consider their use in favour of a traditional server and services infrastructure (Stobl 2006). A case study evaluates the process of placing urban landscape data onto Google Earth and discusses the resulting issues emerging with this software, including IT and data management and accuracy issues and its appropriateness for use for online public participation and communicating technical design information.

2 Background

Participation in planning and design processes as Thompson I.(1999) points out dates back to the 1970s. Although there are several different ways to conduct public participation in planning and design, Thompson I

(1999) suggests the following methods are more common ones: Charrette, workshops, planning-for-real, design game, public meeting, steering group, focus group(s), and community forum. In all these types of involvements designers and planners refers to some sort of a visual aid in order to disseminate their ideas and engage public in the development. Lang E (2005) believes that so far, visualizations in planning are mainly seen as a tool that allows visualizing a certain pre-defined proposal. Visualizations are not seen as an integrated part of a participatory planning process leading towards a proposal.

In recent years the use of new types of visual aids in participation process are slowly becoming in practice. As Lang E (2005) explains, computer-based visual simulations can potentially function as the link between the classic top-down approach in planning, i.e. experts providing information to the general public, and the bottom-up approach, i.e. the general public being consulted and participating in decision making.

For instance Al-Kodmany (1999) used three different types of visualisation tools in different types of involvement models in a participatory planning in Chicago. In different levels of design workshops they introduced an artist using an electronic sketch pad, Geographical Information Systems and computer photo-manipulation process. Al-Kodmay (1999) suggests that above techniques, visualisation through digital technology provided a common language for the participants and computer-based visualisation techniques could be an important contribution to the evolution of the participatory planning and design. In another example Bishop (2005) goes further and suggests that real-time visualization is important for certain public participation objectives but either not possible or not important for others. Furthermore, Schroth et al (2005) put forward that 3D landscape visualizations applied as tools for participatory workshops in planning do benefit from interactive features.

2.1 Embedding VR into Traditional Planning and Design Process

Authors believe that using state-of-the-art visualisation technology could be instrumental to establishing an active, engaging and inspired participatory design and planning process. Using tools like virtual reality, web-based GIS systems etc will enhance the quality and the quantity of the participation.

Thompson et al (2006) suggests that the relationship between the different stakeholders in the planning process can be enhanced with a different, more open approach. Figure 1 shows this proposed alternative process and relationship that can start the better communication and understanding between parties. During a planning process, by allowing academia to take an impartial and independent role on working with different stakeholders in order to maintain the digital city model and coordinate the communication and participation of all parties, Whyte's (2002) observations on lack of utilization of these digital city models can be resolved. Hamilton et al (2005) verifies this notion that, in general, the ability to manage urban planning data leaves much to be desired.

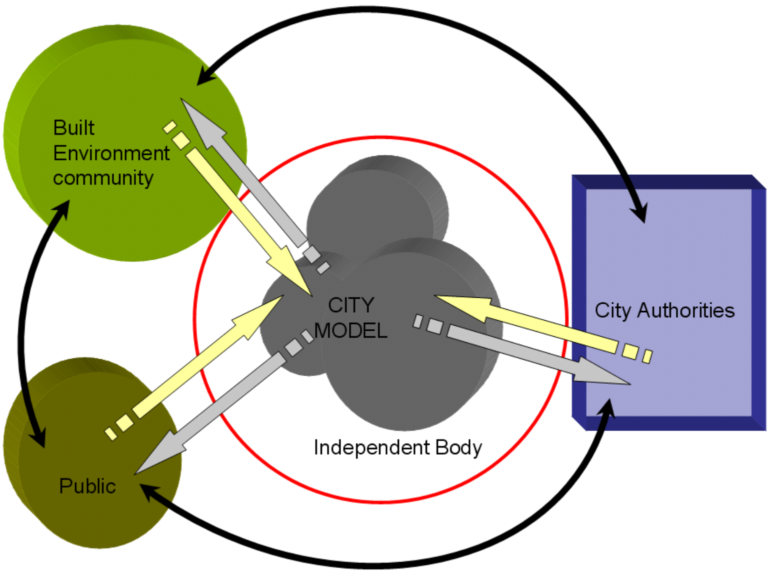

Fig. 1: The role of an independent body between multiple stakeholders in a participatory project.(Thompson et al, 2006).

The use of different visualisation tools in planning particiapation is greatly documented (e.g. Schroth O., Schmid W. A., 2006; Kyungjin A., 2005; Al-Kodmany , 1999; Bishop, 2005; Schroth et al, 2005; Lang E., 2005). In this paper embedding virtual reality techniques to the traditional planning process is determined.

2.2 Pilot Study Approach

A pilot study was undertaken to explore how Northumbria University could work with a local architect, client, and city planners to introduce interactive VR technologies into the existing planning process. The site of a proposed new development was located in an architecturally sensitive area, adjacent to an important listed iconic building in Newcastle upon Tyne and a streak of the medieval city wall. Furthermore, the site at the top of a steep bank above the river is visible from many key view points around the city. The architect and their client sought a more efficient and transparent planning process than the typical consultancy and approval procedure that a large development must typically carry out.

2.3. Existing Process

Currently, the designer is required to produce 'redline images' of the building proposal in its context for visualisation purposes. This involves outlining the proposed building profile over an existing photograph of the site from various angles as stipulated by the planning officials. This is done to give an impression of the scale and impact of the new development without being distracted by the visual seduction of ‘artist’s impressions’. In addition, multimedia (e.g. video, photomontages and fly-throughs) are becoming common for large developments that are used, to some extent, during the planning approval stage, as well as for marketing exercises. The accuracy of these images relies on the skill of the architect/ designer/ visualiser to properly judge the position and aspect of the design proposal.

2.4 Compatibility Issues

Having established the details of the project, it was determined that Northumbria University would import the 3D design data created by the architect into the existing 3D model data of Newcastle upon Tyne currently owned by the University. The successful transfer of data between two different organisations required careful management. Three compatibility categories were identified in this project:

1. **Software and data compatibility**: this was tested at an early stage, including verifying backwards compatibility between established software. In this case, the compatibility was verified and the new building development was exchanged in .3ds format, for use in Autodesk's AutoCAD, Revit, 3Ds Max and SketchUp. These are commonly used packages in practice today, all of which now boast improved compatibility and import/ export functions. However, the extent of compatibility between software and file types can be the deciding factor of how much re-work has to be done after the file import process.

2. **Modelling protocols:** these can vary across all practices, industries and indeed, countries. Although BS (British Standards) and ISO standards exist to alleviate these problems, these only really apply to 2d drawings as 3D modelling is more difficult to standardise due to its complexity.

3. **Geographic Position:** similarly, the correct location of building models can vary depending on the organisation for a number of reasons. It is often the case that architects will conduct a site survey that does not need to be properly geographically located on a national level, merely located in relation to adjacent buildings. The altitude and orientation of a site is a similar issue but are typically true in both cases, as these are normally required to properly indicate the topography of the building proposal, accurate roof heights, etc[12].

2.4 Legal Issues

Due to copyright and licensing restrictions, if an independent body is to host a city model, it will be a requirement from the data provider that city model data is not released to third-parties, or re-sold for commercial purposes. However, with the correct licensing arrangements in place, model data may be made available in “read-only” format which could be used for online public viewing purposes without the underlying actual data being extracted, modified and re-used.

In the UK many current city models are based on Ordnance Survey (OS) data. This means that the model must then conform to OS’ Intellectual Property rights that restricts the distribution and prevents the re-sale of its data. However some UK data suppliers are providing data using a combination of aerial photogrammetry and GPS surveys, and the use of such data is defined in the licensing agreements provided by the supplier, and not by OS. Such data providers will expect that clients, developers and architects will purchase 3D data for each new development project prior to inserting this into a larger urban model owned by a city authority, or an impartial body working with a city authority.

[12] Designs may be deliberately not geo-referenced as a virtual building model may be re-located at 0,0,0 as this is far easier for hardware (desktop PC) to compute. On the other hand, a building that is located at (424037, 563223, 0) must carry out more complex calculations in order to modify or navigate a 3D model

2.5 The Process

The raw data of the city model in this study exists in .dwg (AutoCAD) format. This is usually run and modified in 3dsMax (.max) for its 3D capabilities. The building proposal was created using Autodesk Revit 8, which is compatible with all of the above. Once the two models were merged together, some modifications had to be made to the city model. This included removing any existing buildings and landscape features from the immediate areas that were not to be part of the final design. Furthermore, the topography layer in the city model had to be modified to allow for the new building.

Having successfully imported the new development into the existing city model, interactive elements were added to the scene to make the completed product more presentable. This included some on-screen buttons for match-views, a fly-through button, user instructions (on-screen dialogue box) and company logos (acknowledging the architect, original data provider and Northumbria University (as model host)). Pre-agreed camera views were placed at prominent positions around the model to correspond to those city views usually analysed by the planning committee.

Having satisfied the architects that their building development model import was complete, the final model was presented to the client. Although the geometry of the model was fairly detailed, no materials or texture maps were applied to the building at this stage, as the aim of this task was to analyse the impact of the building within its context, rather than analyse the aesthetics. Introducing this element to the design process was extremely beneficial, as it soon became apparent that the design could be modified to add an extra floor onto the building before the final product was presented to the city planners.

The second presentation of the model involved the architect, the client and two members from Newcastle upon Tyne City planning department. In order to explore all options, the model was updated prior to this meeting in order to include the modified building. A second modified design proposal was also imported into the city model, whose visibility could be toggled on/ off that alternated between the 4 and 5 storey building proposals at the touch of a button. The comparison of the modified building with its shorter predecessor within its surroundings created dynamic discussions that engaged all of the parties.

Finally, a meeting was called by the architects to present the model to a member of English Heritage who assessed how architecturally sensitive the building was to its surrounding buildings. Again, this raised some informative points about the more detailed elements of the building and how they should reflect its surroundings, rather than focusing on the overall scale of the building. Although, this was not a formal assessment by English Heritage (this would be carried out at a later date), the meeting raised issues that would be mentioned during English Heritage's assessment of the building proposal and so could be rectified at these earlier stages.

2.6 Discussion

This pilot study identified some of the issues in adopting a VR city model, hosted by an independent body, into the traditional planning process. The study created an environment in which to assess and discuss an accurate building representation in its context. Although the city planners acknowledged the benefits the VR model offered they still required the traditional redline images of the building in order to remain fair and consistent to the current process. However, the pilot study succeeded in introducing and testing a new collaborative, accurate and immersive process that would save cost and time over the current methods using two-dimensional representations.

A massive advantage that this 3D approach presents to the planning process is its greater transparency. Providing that the source data is accurate and the hardware which is being used to communicate the model is set up correctly, the analysis of any design proposals can be carried out with reliable accuracy, which cannot be guaranteed using traditional 2d photomontages or 'artists impressions'.

The success of this pilot study strengthens the case of the hosting of a city model by an independent organisation - Northumbria University in this case. Newcastle upon Tyne City Council was assured that the model was not being manipulated to enhance the imported building model. Furthermore, the architects themselves could see their design proposal in a much wider context and this was valuable to the design process, even in the early stages.

This need and concern for accuracy and credibility of 3D model data, if to be used to inform urban planning decisions, led to a second case study in order to explore issues emerging in exporting accurate 3D city model data into free web-based services. Institutions and organisations may begin to consider their use in favour of a traditional server and services infrastructure (Stobl, 2006). The following case study evaluates the process of placing urban data onto Google Earth.

3 The Role of web-based GIS Applications

3.1 Introduction

Northumbria University has developed a photorealistic, interactive 3D computer model of the University's City Campus. The competed model enables users to navigate around the campus, explore future building developments of Northumbria University and has become a useful tool for presenting VR technology in the School of the Built Environment.

Following the tremendous growth of Google Earth and its user-centred approach to 3D building models, the decision was made to publish a modified version of the campus through this software. This was done for the following reasons:

- To explore the process of modelling in Google Earth.
- To explore the management issues of the platform, including legal and update issues.
- To showcase this emerging technology as a tool for the built environment.
- To explore the use of a network link as a way of communication.
- To promote Northumbria University and expand web search hits.
- 'Do it before someone else does'- The ability to upload a 3D model of an actual building presents risks to the owners of the building who may not wish to advocate a model of their own building.
- To take advantage of this free service that is already used by a vast market.

The 3D mapping programme that Google has begun describes a massive potential for visualisation in the built environment and city modelling.

3.2 Background to Google Earth

Google Earth (GE) is free software that enables users to navigate Earth through satellite imagery, terrain and a vast amount of geographical features and content shared by a 'Google Earth Community'. The imagery and data is supplied from a range of data providers around the world and varies in resolution depending on its source and contains a digital elevation model (DEM) to form a realistic model of the globe.

In 2006, Google acquired 'SketchUp', a 3D modelling program particularly suited to visualising the built environment, allowing users to model buildings and place them into the '3D Warehouse', an open database of 3D models.

Another feature of GE is the ability to share a live data feed via a 'Network Link', which is a URL that relates to a third party's server and allows information to be shared across the web using GE. An example of this is Berlin City Council's network link[13] that allows users to view more detailed 3D buildings of Berlin.

3.3 Exporting accurate 3D data into Google Earth

Although accurate campus data was available and the necessary permissions had been sought to distribute it on the web and much optimisation of the data was necessary to prepare the 3D models for web use and streaming over the internet. Although the existing models could have been uploaded directly into the 3D warehouse, this was not done for two reasons:

1. Large file sizes would have little or no chance of being included (approved) in the '3D building' layer of GE.
2. Some features of the buildings needed checking and removing from the models for security reasons.

In this way, simplified versions of the models would retain the function of the original, detailed campus model that was commissioned and paid for by Northumbria University.
This modification process involved:

- Compressing the texture maps (.jpgs) into more suitable sizes (typically 1/10th of their original size). This was significantly the most effective way of reducing the model sizes in this case.
- Removing unnecessary geometry.

3.4 Issues Emerging

One of the major problems of this process is the inaccuracy and inconsistencies in GE's terrain layer. The existing campus data is based on accurate measurement, wheras the accuracy of Google's terrain is varied and height data is based on the average over a large area. This can create a range of problems, especially for

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[13] Available at http://www.3d-stadtmodell-berlin.de/3d/en/seite0.jsp

large buildings, which means that parts of the building can either be underground or suspended above ground in certain places (see below).

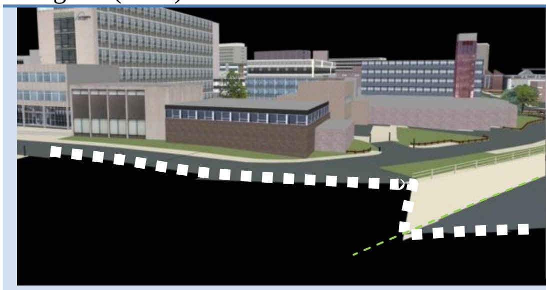
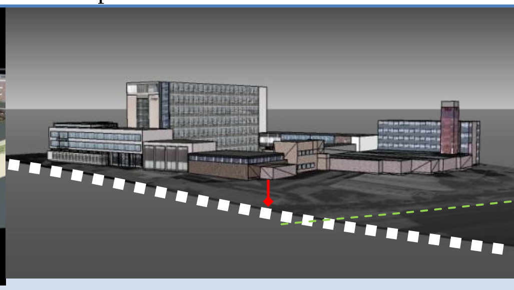
Original (.max) model	SketchUp/ GE model
	
The original building model lies true on its terrain, which steps down to the motorway.	The imported terrain causes the building model to float above the terrain. The motorway boundary is indicated in both images.

Fig 3: Issues in GE terrain data.

The terrain layer can be modified temporarily when uploaded into SketchUp, but any changes made would contravene the ‘3D warehouse’ criteria for modelling and so will be omitted from the 3D buildings layer. However, some exceptions have been made by Google, such as the town of Westport[14] in Co. Mayo, Ireland. Originally developed as a planning tool, a photo-realistic virtual model of the town has been added to the ‘3D buildings’ layer of GE.

3.5 Discussion

The discrepancies between the two levels of accuracies are not uncommon in city modelling. Some city models are based on two different datasets, such as OS building footprints and LIDAR terrain data. This can depend on the age of the data, technology used, and calibration of the equipment or even human error.

Given these issues, it is clear that GE has not yet developed sufficiently as tool for detailed architectural planning. The program, as well as SketchUp has seen huge success in architectural and landscape design. The problem herin lies in the attention to detail and what is now required is accurate terrain data and imagery. This also relies upon the constant improvement of data exchange over the internet, as the performance of the program very much relies upon the speed at which large quantities of data can be streamed and must therefore allow for users with slower internet connections.

A further development of note is the introduction of Microsoft Virtual Earth. This program is similar to GE in many ways but has taken a different approach to its data collection. Microsoft has planned an extensive mapping program over the next five years, which involves the scanning and modelling of 3000 major cities around the world. Much research and development has been carried out by Microsoft in the field of remote sensing and automatic modelling techniques. These highlight the different approaches between Microsoft and Google, with the latter offering a more user-centric approach to develop their content.

4 Conclusions

The two case studies in this paper have:

- Raised some of the issues in incorporating VR technologies into the traditional planning process.
- Explored the role of an independent body to host a city model
- Offered an overview of placing accurate urban landscape data onto web-based GIS applications, such as Google Earth, for different usage such as public participation.

Emerging technologies in the fields of visualisation and web-based GIS applications are beginning to converge due to their cross-compatibility and advances in web 2.0. Although there are few examples of where applications such as Google Earth have been used for urban planning activities, the two disciplines are becoming increasingly connected in terms of ICT.

In an attempt to create a 3D DTM map that covers the entire globe, Google has avoided becoming a tool for accurate visualisation during its early stages. This highlights a continued need for such technologies for applications within the Built Environment, as well as the careful management and hosting of its data. But with the ensuing rivalry between Google and Microsoft may drive both developers to compete for accurate

[14] Developed by AMT3D (www.amt3d.com)

(and realistic) model data at street and micro level. Much research is being carried out by the latter in remote sensing and automatic modelling techniques, although much manual input is still required. Furthermore, the update of this data is also a major concern as urban areas are continually changing and expanding.

There is a requirement for city data to be accurate and credible if to be used as a decision making tool for planning process. If data accuracy could be preserved on freely available web-based applications they afford a way for the communication of 3D models remotely. They offer advantages such as:

- Free access to software
- Ease-of-use, requiring little or no technical knowledge
- Widely available and run off a standard desktop PC.
- Original raw data cannot be manipulated.
- Access could be given to clients, planners, design teams and the public to view building developments in some context.

Although the issues mentioned above do lack the technical basis for accurate planning, their simple interface and usability of the software lends itself well to better planning participation. Designs can be shared more easily and to a far greater audience than using specialist software.

5 Areas for Future Research

- An extensive list of architecturally sensitive features relating to the category and location of a building would be a useful resource for any modeller. The question of 'what to model?' is left to the discretion of the modeller. Although CityGML[15] does outline certain features for their official levels-of-detail, a comprehensive list of features exists only as separate theoretical guidelines.
- The legal rights to virtual models remain unresolved in many situations. For example, when a model is built 'based on OS data', to what extent does this basis tie the modeller to the copyright restrictions of OS data, such as when only one (OS)dimension has been referred to base a model upon. Furthermore, there may be no evidence that this is neither enforceable nor even traceable.

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14 PAPER 3: AN OVERVIEW OF VIRTUAL CITY MODELLING: EMERGING ORGANISATIONAL ISSUES.

AN OVERVIEW OF VIRTUAL CITY MODELLING: EMERGING ORGANISATIONAL ISSUES

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Abstract: This paper presents a recent overview of the increasing use of Virtual Reality (VR) technologies for the simulation of urban environments. It builds on previous research conducted on the identification of three-dimensional (3D) city models and offers an analysis of the development, utilization and construction of VR city models. Issues pertaining to advantages, barriers and ownership are identified. The paper describes a case study of the development of a VR model for the city of Newcastle upon Tyne in the UK and outlines the role that academic institutions can play in both the creation and utilization of urban models. The study offers a new approach for the creation, management and update of urban models and reflects on issues which are emerging. Areas for future research are discussed.

Keywords: city models, Virtual Reality, management, diversity, ownership

1. INTRODUCTION

The production of virtual city models is an emerging concept that is being driven forward by the rapid evolution of computer technologies. The creation of such models is now being tackled by a range of city authorities, researchers and developers. The representation of an urban environment, from the aerial view maps of medieval times to the more accurate city plan projections of the Renaissance, to inexpensively produced, standardised, printed two-dimensional (2D) maps of 19th Century is not a new concept (Thompson E. et al. 2006). However, 3D virtual city models have emerged steadily over the last forty years following the development of suitable hardware platforms and accurate rapid-modelling methods. The introduction of Computer Aided Design (CAD) and three-dimensional computer modelling is now shaping the way in which we create and simulate our cities. Yet, like their real life equivalences, city models are never finished products (Thompson E. et al. 2006). With ever-changing and developing urban structures, legislations, trends and citizens' needs, city simulations have increasing need for a dynamic and flexible platform where such modifications are possible with ease. Whilst many case studies have been reported on the creation of virtual city models, the management and update of these models has been largely neglected, partly due to their experimental nature. This paper offers an overview of the role of virtual reality (VR) in urban modelling and considers organizational issues in the adoption of VR for the representation of cities. This study also describes the development a virtual city model of Newcastle upon Tyne in the UK.

2. THREE DIMENSIONAL CITY MODELS

As information that exists about a city is hard to comprehend in its totality, good representations allow rapid understanding of the relevant features of a data-set (Whyte 2002). VR urban models have been described as computerized graphical representations or visualisations of any city and its components (Thompson E. et al., 2006).

The importance of 3D reconstruction of buildings, cities and urban landscapes is becoming increasingly recognized and acknowledged (Horne 2004). The computer technology in urban planning is widely utilized in many overlapping research areas such as transportation modelling, agent-based modelling, GIS and public participation, planning and decision support, urban morphology, spatial analysis and virtual cities etc. Many cities around the world are employing real-time virtual reality technology to support the decision making process throughout the management, design and planning steps of urban environments. Much research has been conducted on 3D city models. The Corporation of London commissioned the Center for Advanced Spatial Analysis (CASA) to carry out a research of 3D models of cities and this study produced more than sixty 3D city models. According to their research these models ranged from CAD models to various 3D Geographical Information System (GIS) and Virtual Reality Mark Up Language (VRML) Web content and related simulations. Eight cities were selected for more detailed investigation. One of the most comprehensive reviews (Batty M. et al. 2000) was a result of the above research. Thirty-five cities with greater than one million population were listed. Table 1 shows an updated and enhanced list of city models. Urban Planners in Beirut report that a 3D computer model is now an essential tool when considering complex townscapes and planning issues (Horne 2005) and they recognize the need for a flexible tool to generate 3D massing diagrams, show the context for future developments, as well as the evolution of street landscaping and public spaces. Yet "it is still necessary to think about the amount of detail that is necessary for different applications, different phases and different target groups to be used in a 3D representation of the spatial plans" (Pleizier I. et al. 2004).

Currently there exist no widely accepted standardised conventions for encoding 3D virtual city models (Dollner J. et al. 2006). The process of generation and distribution of 3D virtual cities for government use is not obligatory and "characterised by a lively, inconclusive discussion of standards and emergence of new technologies" (Kohlhaas and Mitchell, 2007). The International Standards Organisation (ISO) and other organisations, such as the EU directive INSPIRE, have responded to this by publishing suggested standards and protocols for the formation of 3D data so that information can be shared across the internet on a global scale to access and view in a secure manner (Evans and Hudson-Smith 2005).

Table 1: Visualisation projects[16] of cities around the world

[16] 3D models, photogrammetric models, VR models. Information gathered from (Batty M. et al. 2000a), (Dikaiakou M. et al. 2003), (Dokonal W. et al. 2001), (El Araby M. et al. 2004), (Ftácnik M. 2004), (Hadjri K. 2004), (Horne M. 2004), (Ishida T.

North, South and Central America	
Mexico City, Mexico	Minneapolis, USA
Santiago, Chile	New Orleans
Calgary, Canada	New York, USA
Toronto, Canada	Oakland, USA
Vancouver, Canada	Orinda, USA
Arlington, USA	Orlando, USA
Atlanta, USA	Palo Alto, USA
Austin, USA	Pearl Harbour, USA
Baltimore, USA	Philadelphia, USA
Boston, USA	Phoenix, USA
Chicago, USA	Portland, USA
Cleveland, USA	Rosslyn, USA
Dallas, USA	Sacramento, USA
Denver, USA	Salt Lake City, USA
Detroit, USA	Santa Barbara, USA
Ford Island, USA	San Diego, USA
Friday Harbor, USA	San Jose, USA
Ft Benning, USA	San Francisco, USA
Houston, USA	Seattle, USA
Jacksonville, USA	Tampa, USA
Lake Tahoe	Telluride, USA
Las Vegas, USA	Tysons Corner, USA
Los Angeles, USA	Washington DC, USA
Europe	
Hard, Austria	Amsterdam, Netherlands
Salzburg, Austria	Warsaw, Poland
Vienna, Austria	Lisbon, Portugal
Nicosia, Cyprus	Berne, Switzerland
Helsinki, Finland	Zurich, Switzerland
Paris, France	Bratislava, Slovakia
Florence, Italy	Izmir, Turkey
Parma, Italy	Bath, UK
Berlin, Germany	Bristol, UK
Bonn, Germany	Glasgow, UK
Bremen, Germany	Harrow, UK
Coburg, Germany	Hounslow, UK
Frankfurt, Germany	Leeds, UK
Giessen, Germany	Liverpool, UK
Hamburg, Germany	London, UK
Heidelberg, Germany	Newcastle, UK
Hoechst, Germany	Nottingham, UK
Karlsruhe, Germany	Sheffield, UK
Munich, Germany	Slough, UK
Reutlingen, Germany	Southend-on-Sea, UK
Stuttgart, Germany	Swindon, UK
Saint Petersburg	Workington, UK
York, UK	
Asia Middle East and Africa	
Delhi, India	Tokyo, Japan
Hong Kong	Yokohama, Japan
Singapore	Beirut, Lebanon
Kobe, Japan	Al Ain City, UA Emirates
Kyoto, Japan	Dubai, U A Emirates

2002), (Peng C. et al. 2002), (Piersch S. 2001), (Thompson E. et al. 2006), (Zipf A. et al. 2003), Z-mapping, 3D Web Technologies, Planet 9 Studio and Cyber City web sites.

3. EVOLUTION OF THE VISUALISATION OF CITIES

Although many cities around the world are using three-dimensional computer modelling, physical scale 3D urban models are still being used in many cases. However modifying a physical model is expensive and difficult; this method of representation is not a flexible tool to demonstrate the effects of new developments in the urban fabric. Furthermore the way to experience the city in these models is usually restricted to a "bird's eye view" which makes the assessment of implications of new developments at a human scale almost impossible (Thompson E. et al. 2006). These physical models require 2D plans, perspective drawings, photomontages etc to give an understanding of the complex urban structure. Despite these difficulties, wooden models are still being used and have a role to play in "considering changes at an urban scale" (Day 1994).

"Computers [2D and 3D computer aided drafting] have been used in architecture and urban planning research" (Mitchell 1996) and practice for more than four decades. Although the computer as a tool is a great help for creating accurate drawings for the proposed scheme, it is sometimes not easy to put these schemes into the urban context without the factual representation of the surrounding. Urban planning is a complex process, bringing together aspects of social, economic, physical and spatial significance (Bourdakis 1997). During this complex process of planning applications, approvals, community involvement etc, having a flexible tool to interact with different parties/stakeholders and especially with the model is very important (Figure 1).

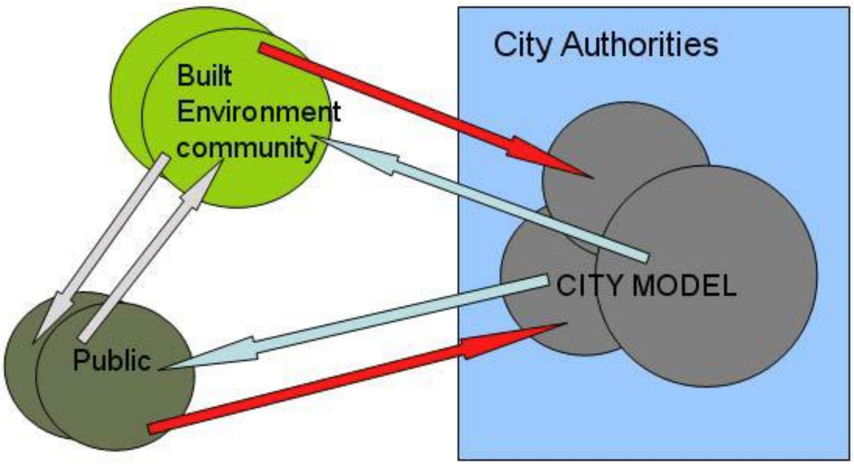

Figure 1: The current complex relationship between the parties/stakeholders for a proposed development.

This interaction, accuracy and "quality of visualization" (Pleizier I. et al. 2004) leads to better insights and better understanding of the spatial plans and more satisfying results for all parties involved.

The computer simulation of cities has emerged from several traditions (Day A. et al. 1998):

- City databases
- City maps
- City models
- City visualisations
- Representation of City behaviour

Data exchanges and analysing and observing the city model is vital for urban planning. This can be done with today's technology, which can offer a high level of visualization - an immersive and interactive virtual environment where interested parties can navigate through the city model using different hardware platforms ranging from PC screens to semi-immersive large screens to fully immersive cave automatic virtual environments (CAVE) etc.

3.1 Purposes of VR City Models

VR city models are been used to facilitate the dialogue with the local authority and the other stakeholders involved for a specific scheme and allow general debate on the city's future developments (Thompson E. et al., 2006). Additionally the visual and technical data they represent is easy to understand. "VR urban models can be used at two levels of complexity / engagement; low level, as a presentation and evaluation tool as well as a planning support - analytical tool, more advanced, real-time editing tool to be used by specially trained professionals" (Bourdakis 1997) who emphasises that "Urban models should be used to organise such information [city related information-from visitor specific aids to engineering focused information] and work as 3D fully interactive maps/indices of our cities/lives".

The 3D city model can be created for a very wide range of purposes. These have been classified into twelve different categories of use (Batty M et al. 2000):

- "Emergency Services
- Urban Planning
- Telecommunications
- Architecture
- Facilities and utilities management
- Marketing and economic development
- Property analysis
- Tourism and entertainment
- E-commerce
- Environment
- Education and learning
- City portals"

These categories have been enhanced and grouped into four categories (Shiode 2001) as:

- "planning and design,
- infrastructure and facility services,
- commercial sector and marketing,
- promotion and learning of information on cities"

3.2 Creation of VR City Models

Cities are complex physical and social entities. "The nature of urban environment comprises a number of elements from landscape modelling to transportation networks to various socio-economic exchanges. Every city possesses a unique structure with its own momentum" (Shiode 2001). This unique structure needs to be transferred into the digital environment realistically. In order to use VR city models in a continual process of consultation, decision making and revisions they should be based on accurate, detailed and spatially unambiguous data. The "basic steps in creating three-dimensional visualisation of landscape [and in general any digital model] are to acquire raw geographical data, process them into an appropriate form, then use them as inputs to software which will construct the three-dimensional geometry" (Discoe 2005). Consequently it can be said that data sources and choice of software and hardware plays a major part in constructing a VR city model.

Following is a summary of the digitizing / visualisation process:

- Data sources
  - Data capturing steps: aerial photography, 2D data, street level photography and laser scanning, auxiliary data, texture mapping, data processing etc.
- Software
- Accuracy level
  - Levels of abstraction / levels of detail
- City Objects
  - Terrain and sky,
  - Buildings,
  - Landmarks,
  - Vegetation and landscape modelling,
  - Street furniture, streetscape modelling
  - Populating the model with pedestrian and vehicle networks
- Monitoring, review and updating (Thompson E. et al., 2006)

Table 2 illustrates stakeholders' interests in city models.

Table 2: Stakeholders' Interests in Urban Models

CITY AUTHORITIES	
Planning and Design Related Activities	Urban planning scenarios Planning and decision support Spatial analysis What if scenarios GIS applications Development control Planning permission applications Contextual modelling Traffic simulations Transportation modelling Public participation Environmental impact assessments Visual impact analysis Climate, air quality, fire propagate, public safety studies
Infrastructure and Facility Services	Emergency planning Facilities and utilities management Property management
Commercial Sector and Marketing	Marketing and advertising E-commerce
Promotion of Cities	Tourism and entertainment City portals
BUILT ENVIRONMENT SECTOR	
Base data resource	Architectural, Planning Landscape architecture and planning Construction Surveying Real Estate etc. companies
Maintenance and development plans	Gas, Electricity Phone, internet, broadband, TV
Marketing and advertising	
ACADEMIA	
Teaching and learning	Use and creation of city models City models for students projects Context analysis, mass analysis
Research, Consultancy Archiving	

3.3 Advantages of, and Barriers to VR City Models

The theory and practice of applying virtual reality technologies for public participation in urban design have recently been reviewed (Changfen F et al. 2005) and advantages of, and barriers to, have been addressed. The diverse needs of various stakeholders in the city have to be taken into consideration when generating 3D city models and urban simulations, if VR is to be adopted and used appropriately by all interested parties.

Issues that have been identified from previous research have related to the areas of ownership of such virtual cities and the need for an accurate 3D urban model to be managed by an impartial body (Pritchard 2005).

Understanding the versatile physical and socio-economical structure of a city is not always easy from a blueprint. VR urban models improve the understanding for this complex data both for lay person, and also the expert. Although the VR city models can cover large areas, parts of them can be transferred to PC or a laptop and can be used on different platforms such as networks, intranets etc which enable quick and accurate updated information sharing. Also VR Urban models with different levels of immersiveness provide freedom of movement to its user. This freedom enables users to see and experience the model from their own viewpoint with no external participation. For different purposes (educational, municipal, commercial etc) various qualitative data can be attached to the VR models, which enables users to have instant access to diverse data. However as with most new technological developments VR urban models are facing with some technological, administrative and perception related difficulties as well. Table 3 summarize the advantages and barriers of using VR models.

Table 3: Advantages and Barriers of using VR models

Advantages of Adopting VR Urban Models	**Barriers to Adopting VR Urban Models**
Enhanced communication and easy to explore urban context Freedom of movement (movement between different scales and levels of details) Different levels of immersiveness Ability to attach qualitative data to the models Portability Formally and informally sharing data with diverse stakeholders Ability to involve diverse disciplines together under one roof	Technical issues (software, hardware compatibility, recurrent updating etc.) Organisational issues (management of shared resources, data copyright and ownership issues etc.) Ownership of the models Privacy and security Seduction of visual images

3.4 Ownership of VR City Models

Ownership of city models is a very complex and strategic issue involving diverse stakeholders. Authors of this paper are interested in this subject and believe that ownership issues are influencing utilisation of city models in great deal. “Academic projects have shown the potential of VR models at the urban scale and provide good case study examples, but few models built in academia are being used to their full potential in the planning process [by the relevant municipalities]. Municipal authorities are [also] beginning to use virtual reality in-house, or are working in collaboration with suppliers to develop and maintain city models” (Whyte 2002). Bringing together these individual models might answer some of the issues regarding design, production and management of the models; however this would require considerable time, effort and money from the different stakeholders. Ownership issues of some virtual city projects are outlined in the following section. This was a preliminary and limited exploration which established a foundation for a further study. It is believed that ownership of VR Urban models, and their management, are key issues for future developments and should be taken into consideration at the very early stages of model implementation.

Los Angeles

Starting from 1980s "The Urban Simulation Team's primary focus is to build a virtual model of the entire Los Angeles basin which can then be used to interactively fly, drive or walk-through the city. The model is constructed by combining aerial photographs with street level imagery and three-dimensional geometry to create a realistic visual simulation of the dense Los Angeles urban environment, detailed enough for the graffiti on the walls and signs in the windows to be legible" (UST no date). According to William (Bill) Jepson[17] (2006) "The UCLA Urban Simulation Lab and Bill Jepson own the complete Virtual L.A. model(s). They share non-exclusive ownership with their clients for the areas that they commission. However, that does not include any pre-existing Intellectual Property (IP) such as Urban Simulation Lab's extensive landscape, foliage and texture databases".

Helsinki

"The Helsinki City Simulator, which was presented for the first time to the public in January 2000 at the Helsinki City Planning 2000 exhibition, contains a virtual model of the Helsinki City centre and a powerful multi channel display system for real time simulation on large screen. The purpose of the simulator project was to build a realistic vision of the future city centre as it is planned today. For architects and planners a virtual model is a platform to test and improve their design. For city residents and politicians the simulator is an easy and very illustrative way to walk and fly in the future city. It provides a good basis for exchanging opinions on future design" (Suomisto 2001). Jarmo Suomisto[18] (2006) also explains their stand regarding the ownership of VR models by explaining that Helsinki virtual models are made by Helsinki City Survey Division and owned by them, they also have the rights to sell them. City Planning Department also buys the basic 3D-models and then add materials such as textures, lighting, new plans etc. Although individual modellers have no right to the model, the city planning department can use these models in their own work and give them to their planning consultants.

London

"Virtual London is a project funded by the Greater London Authority and CASA, University College of London, has been working on this project for many years. The model is being produced using GIS, CAD, and a variety of new photorealistic imaging techniques and photogrammetric methods of data capture. "The core model is aimed to be distributed via the Internet utilising techniques to optimise large urban data sets for broadband distribution" (CASA, no date). According to Michael Batty[19] the ownership of Virtual London is a very complicated issue. There are several vendors who have contributed money and data or donated software to this big project, including CASA, Greater London Authority, Ordnance Survey, Infoterra, ESRI, London Connects etc. Therefore the ownership becomes very problematic and became an issue recently when Google Earth wanted to buy this model [and we believe that still there isn't a clear answer for this problem] (Batty 2006).

Beirut

The 3D model of Beirut, recently updated because of the requirement for a visualisation of Martyrs' Square, is owned by the private sector real estate company Solidere[20] which was

[17] Director of Urban Simulation Team at UCLA.
[18] Architect, Head of IT in the Helsinki City Planning Department
[19] Director of CASA
[20] Solidere (Société Libanaise pour le Développement et la Reconstruction du Centre-Ville de Beyrouth), is a Lebanese joint-stock company. For more info please visit http://www.solidere.com/solidere.html

created by Lebanese government decree in 1994 to reconstruct entire Beirut city centre, an area of 1.9 million square metres (Horne 2004). This company's role is very diverse and Solidere act as a land developer, real estate developer, property owner, property and services manager and operator. . They began developing a three-dimensional computer model in 1995 to be used as an interactive urban design tool which could be used to consider building footprint and massing options, as well as maintaining a record of floor space and proposed land use by parcel, block and sector (Gavin 1996).

4. NEWCASTLE UPON TYNE VISUALISATION PROJECT: A PILOT WORK

This project started as an experiment to extend a previously developed virtual model of Northumbria University's campus into a wider area of the city of Newcastle upon Tyne in the UK. This experiment set out to show the close relationship between the city and the campus, as well as approaches to the campus and major landmarks of the city.

4.1 Newcastle upon Tyne

Newcastle upon Tyne is a city in the North East of England with a population of 269,500 according to the 2001 census. The city is located on the northern bank of the River Tyne at latitude of 54.97°N and a longitude of 1.62°W. The Tyne gorge separates Newcastle from Gateshead, (an administratively separate borough) on the south bank. Newcastle City Council is the governing body for the metropolitan borough of Newcastle upon Tyne.

Newcastle upon Tyne has had varied identities, from Roman frontier to Norman stronghold to Great Medieval town to home of railways to industrial powerhouse to a Georgian planned town[21], which has created a rich and interesting urban texture and culture. In the nineteenth century, shipbuilding and heavy engineering were central to the city's prosperity but since the decline of such industries Newcastle has faced many challenges. Today the City Council has embarked on a major urban regeneration programme and a development framework is in place to advance the future development of Newcastle. Office, residential and retail sectors are now key industries, and major regeneration schemes are beginning to transform large parts of the city centre and contribute to its economic prosperity.

4.2 Urban and Architectural Landmarks

Newcastle upon Tyne has several urban and architectural landmarks including The Tyne Bridge, The Millennium Bridge, The Swing Bridge, The High Level Bridge, The Redheugh Bridge, Central Station, The Castle, River Tyne, Northumberland Road, Eldon Gardens, Grainger Town and Grainger Street, Jesmond Dene etc. All of these landmarks are the legacy of Newcastle's rich history. Therefore, from a modelling point of view, such landmarks should be included as a part of a VR urban model.

4.3 Wooden City Model

[21] Please visit for more info: http://www.newcastle.gov.uk/hods.nsf/a/histncl

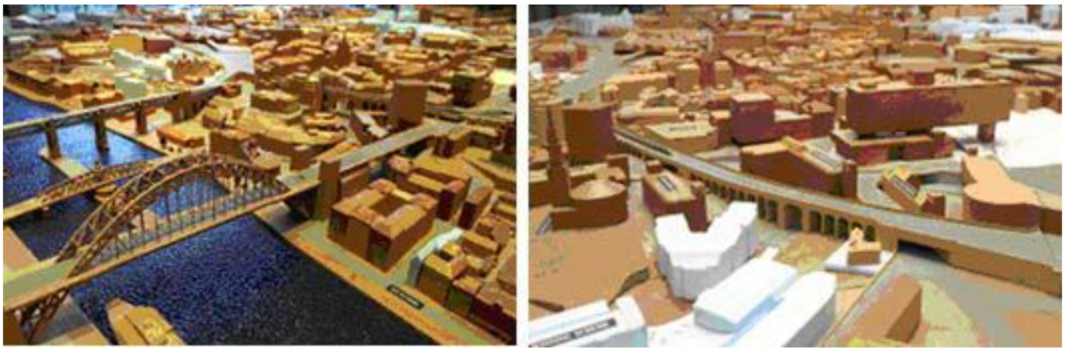

Figure 4: Newcastle Wooden Model.

The wooden, physical scale model of Newcastle has a long history. At the time of writing this model is located in the Member's Lounge in the Newcastle Civic Centre. It is of 1:500 scale and is used as a working model as well as a demonstration model. The first wooden model was created in late 1960s and since then the model has gone through several alterations and additions. At one time there were three model makers working on it. For any major development, the model makers would create updates in blue foam (to aid easy amendments etc.) and, after discussions with the architects and planners, these blue foam models were used as the basis for permanent additions to the model.

More recently, architects who propose new developments generally will have their own model makers and will create a physical scale model (often in cardboard) in the same scale of the city model to show their scheme in context. After a consultation process these models may be left attached to the city model as an update (Figure 4).

4.4 Building a Virtual Newcastle Model

The initial intention of creating the city campus model was to develop and show the close physical links between the city and the campus in a virtual model. The VR model of the Northumbria University City Campus has created great interest both from the faculty and the students and is been used for variety of purposes for teaching and learning and research in the School of the Built Environment.

Figure 5: Newcastle VR Model.

After the completion of this pilot project; the project team[22] saw the opportunities of extending this model into a wider city model (Figure 5). 3D data was gathered from ZMapping[23] and the initial campus model data were stitched to these raw data. The method of getting the campus model into the ZMapping data was a process of isolating

[22] Project team includes the academics from the School of the Built Environment and modellers from Insite Environments.
[23] For more info Please see http://www.zmapping.com/urban3dmodelling.htm

the elements that already been created and merging them into the city model. After the alignment of the Zmapping unit scale to the campus scale, the relevant buildings were removed and faces were isolated and detached from the main model.

Keyboard presses were then created to toggle on and off the Northumbria City Campus in the City Model to show the city model in different levels of detail.

Formal and informal meetings with various stakeholders (architects, planners, landscape architects, etc, and academics from various universities) are resulting in interest in having a virtual city model. This has led the project team to evaluate the opportunities and issues emerging, and discussions are ongoing with the City Council to exploring options for the development of a sustainable framework for the development of Virtual Newcastle.

4.5 Virtual Newcastle and Google Earth

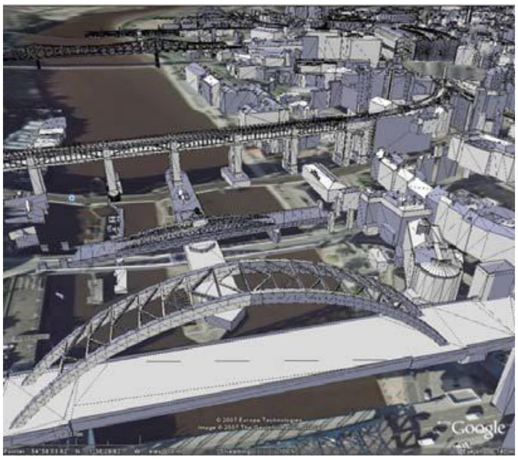

Figure 6. Newcastle VR Model placed in Google Earth

The recent introduction of Google Earth does not herald any particular advances in technology, but reflects the shift in IT towards open access to (GIS) data that can now be distributed over the web. The success of Google Earth also owes much to its interface and navigational features. 3D data can be exported into Google Earth with minimal effort, but detailed city models must be adapted and optimized to run smoothly, even using a keyhole mark-up language (KML) viewer. This highlights a current issue with the compatibility of large, detailed virtual cityscapes and the applicability of the program as a tool for detailed analysis for the built environment. More recently, the launch of Microsoft's Virtual Earth demonstrate a different approach to rapid modelling, for more realistic city models. Both of these commercial (non-specialist) approaches to GIS have focused on the user-friendliness and interactivity of geographical data. Although these virtual worlds have generated a huge amount of interest, they highlight the continued need for accurate GIS data and building geometry. As both of these software giants are still in the fairly early stages of expansion into GIS, it is clear that they are in danger of becoming tools for tourism and marketing that distract the user from exploration and other functions. This can be seen in Virtual Earth where floating billboards have appeared over major cities.

Future Work

Future research will involve the further investigation of a sustainable organizational framework for the management of virtual city models. It will include the investigation and establishment of virtual city model protocols, currently emerging in the areas of

- Main model management
- Design development model management
- Planning submission management

- Scale and data co-ordinates management

The interest from diverse stakeholders regarding the creation and functionality of the VR model of Newcastle is increasing. It is believed that this will lead a more useful and flexible representation where various stakeholders can access and utilize the model according to their needs. The organisation, remote sharing and control of model data are also emerging as areas of key importance.

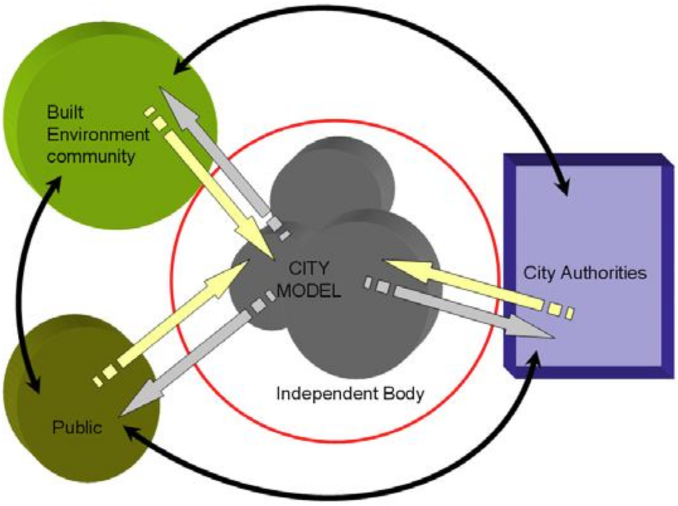

Figure 7. An alternative relationship between interested parties (Thompson E. et al., 2006)

Figure 7 shows an alternative process and relationship that has been proposed to enhance the understanding and the communication between the different stakeholders in the city. With this approach, Whyte's (2002) observations on lack of utilization of models that had been created by academia, in the planning process, can be rectified if academia undertakes a coordinating role and acts as an impartial, independent body working in collaboration with all the stakeholders to maintain the city model.

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