Insights of 3D Digital Cities: The Past, Present and Futures

Mao-Lin Chiu
Department of Architecture, National Cheng Kung University, Tainan, Taiwan
e-mail: mc2p@mail.ncku.edu.tw
Chengzhi Peng
School of Architecture, University of Sheffield, Sheffield, UK
e-mail: C.Peng@sheffield.ac.uk

[editor]
The recent developments of Computer-Aided Design (CAD), Geographic Information System (GIS), and Web-based technologies seem to have motivated the creation of 3D digital cities (3D cities in short) around the globe. The stories of why and how people created 3D cities, and what are their uses at present or in the future are increasingly being sought after by people in academia as well as in industry. This introductory chapter provides an overall review of the development of 3D cities. Its aim is to introduce readers some representative examples of 3D cities created recently by people working in the field, and in so doing, we hope to set up a general stage for playing out each specific story to be told by the following chapters.
1. The Emergence of 3D Digital Cities

Urban planners and architectural designers are highly interested in the urban formation and its development, including the density, building height, open spaces, and skylines. Therefore, physical models are used as a representation and communication tool for the policy makers and citizens, Figure 1, Shanghai model. In the mid-1980s, computer models of real cities were created by experimental uses of a few digital technologies. The widely available applications of computer and communication technologies such as CAD, computer graphics (CG), virtual reality (VR), photogrammetry, satellite images, web-based technologies, geographic information system (GIS) and global positioning system (GPS) have opened up opportunities for large-scale urban landscape visualization and urban information integration, Figure 2 (Chiu and Lan, 2001; Sasada, 1999; Day and Radford, 1998; Ligget and Jepson, 1995).

Figure 1, Physical Model of Shanghai City
Figure 1: Various technologies foster the emergence of 3D digital cities (An-Ping
Currently, at least 60 digital cities are reported in the world, and it is found that these 3D cities were applied with various representations and technologies for different purposes (CASA 2004). Some well-known 3D cities such as Glasgow, Bath, Berlin, Helsinki, and Los Angeles have been reported in many publications, and have since become exemplary models for other similar developments. On seeing these 3D cities, we are first shown alternative ways of visualizing city form, and we could also experience unusual interactive functions such as way-findings, navigation and virtual visits (Morozumi et al, 2000). However, some important issues have been asked in the creation of 3D digital cities, such as: What are the values of city models? Who are the users? How to utilize digital city models? How to receive feedbacks from its applications? Apparently, a 3D digital city has dimensions other then the technical and practical that are social, cultural, political, ideological, and of course also theoretical (Couclelis, 2004).

While many digital cities are known to exist, the definitions and visions of digital cities varied from a real city to a virtual information city (Mitchell, 1994; Ishida, 2000). A 3D digital city can be defined in this chapter as “a comprehensive, web-based representation, or reproduction, of multiple aspects or functions of a real city, accessible to all kinds of users”. The following content will provide a survey of existing digital cities that provide the foundation for further discussions.

2. Surveying 3D Digital Cities: A methodology

Digital cities are generally composed of 1D data (such as text and symbols), 2D or 3D objects and scenes created through computer modeling. The characteristics of 3D digital cities are related to the goals of their creation, the approach and technologies applied to the uses, and the users. The purpose of this survey is to discover the needs of uses, the technical implementation and necessary supports.

In the late 20th century, the Centre for Advanced Spatial Analysis (CASA) at the University College London was commissioned by the Corporation of London to carry out a review of 3D models of world-wide cities. A preliminary review was conducted based on searches of literature, the World Wide Web, email

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1 The Centre for Advanced Spatial Analysis (CASA) is an initiative within the University College London to develop emerging computer technologies in several disciplines which deal with geography, space, location, and the built environment. CASA is run under the Directorship of Michael Batty, Professor of Spatial Analysis and Planning at the UCL.
questionnaires to experts and requests targeted to specific news groups and email lists. The CASA research team visited each city to conduct a series of interviews with private, non-profit making and public sector organizations involved in 3D modeling. The eight cities chosen were Tokyo, Berlin, Glasgow, Helsinki, New York City, Philadelphia, Washington DC and Jerusalem (The full list of the 60 plus cases can be found at http://www.casa.ucl.ac.uk/3dcities/table_all.htm). At CASA, the next stage of the research was to build a 3D model of London – the Virtual London project (see Chapter 4).

On the basis of accessibility, this study selects about 20 cities world-wide in digital form from literature survey and/or web site visits, including Adelaide, Bath, Beijing, Berlin, Glasgow, Graz, Helsinki, Jerusalem, Kaohsiung, Kumamoto, Kyoto, Liverpool, London, Los Angels, New York, Okayama, Philadelphia, Putrajaya, Sheffield, and Tainan, in the alphabetic order (Figure 3). Among them, researchers of 12 city projects were invited to provide in-depth reports in this book.

Similar to what CASA has reported, it was found that there are at least three distinct approaches to 3D city modeling, each from very different viewpoints based on different methods:

• traditional 3D computer aided architectural design
• the engineering approach based on photogrammetric analysis and surveying
• geographic information systems

It is safe to say that there is no widely accepted standard approach to the construction of 3D cities. As we shall see from the chapters to follow, each method applied to city modeling requires different inputs (such as modeling and data collection) and results in different outputs (such as representations and applications). Some cities may apply more than one method. In addition to the variety in modeling methods, city modeling involves complex data collection and preparation before the actual building of the city models, and these works are often labor-intensive and costly. Furthermore, a good city model system needs to consider how the city data may be continuously updated as well as how special functions for spatial analyses or services could be developed effectively. All these require considerable expertise and financial supports in addition to technical implementations.

3. Dimensions in Developing 3D Digital Cities: content, technology, and application

In his book “Invisible Cities,” the famous Italian author Italo Calvino depicts multiple representations and memories about the city of Venice (Calvino, 1974). The scenes depicted by Calvino are full of imagination and implications. Indeed, the content of a 3D digital city should include not only three-dimensional geometry, but also multiple development dimensions, i.e. content, technology, and application. In this section, we look briefly at four digital cities – Glasgow, Bath, Los Angeles, and Helsinki as a preliminary discussion, while more detailed presentations of 3D cities will be given by other authors from their individual perspectives.

◎ The Glasgow Model (More details are provided in Chapter 2)
Glasgow is one of the largest cities in UK. Since its inception in 1968, ABACUS (Architecture and Building Aids Computer Unit Strathclyde) at University of Strathclyde, UK, led by Thomas Maver and Alan Bridges, has established an international reputation for the use of computers in architectural research, teaching and practice. As a leading player in the field of city modeling, ABACUS has created the Glasgow Directory to meet the growing demands from urban planning and design for specialized computing skills and a wide range of application programs. The original 3D Glasgow computer model was constructed in the mid-1980, when it represented one of the largest computer models in the world (Figure 4). Since then, it has been the basis of many ABACUS projects, including the “Glasgow Directory”
and many recent projects on city visualizations. More recently, the Glasgow 2000 project, commissioned and funded by SCiRAN, tells the story of Glasgow's development from pre-historical times until the present (Maver, 2002). The web version of the Glasgow Directory becomes an online city information system (Figure 5). The CD-ROM version of the city guide, comprising 140,000 words of text, 230 images, 5 video clips and 35 sound clips, becomes a documentary city archive.

Figure 4: Glasgow Model (Courtesy of ABACUS)

Figure 5: A snapshot of the Glasgow Directory (Courtesy of ABACUS)
This project was later commissioned by the Merchant City Townscape Heritage Initiative and created a “virtual map” of the Merchant City area of Glasgow. A fully rendered 3D model of the Merchant City was created by combining a digital photographic survey with building plans and aerial photographs of the district (Figure 6). The project was finally presented as an Internet format and included a series of animation walk-throughs of the area with high resolution digital images. The Glasgow Directory is now an established 3D website, attracting around 10,000 online visits per year. The model represents approximately 10,000 properties in the city and is populated by contextual information on its culture and socio-economic topography (Maver, 2000).

![Figure 6: Simulation of A Historical Building (Courtesy of ABACUS)](image)

© Bath Model (More details are provided in Chapter 3)
In 1991, the Centre for Advanced Studies in Architecture (CASA) at the University of Bath received a grant from J Sainsbury PLC to construct a three-dimensional computer model of Bath. This project, directed by Alan Day, was supported by the Bath City Council, and since its completion the model has been used to test the visual impact of a number of proposed developments on the city sites. The 152 blocks that make up the Bath Model were initially constructed in AutoCAD and were made available in the DWG and DXF formats. The model was constructed to be the digital equivalent of a conventional 1:500 model and is intended to be used for massing studies at that scale. The model was constructed using stereo pairs of aerial photographs of the city provided by the UK Ordnance Survey in 1991. These were then digitized on a small format photogrammetric plotter. The model was not intended to be routinely updated to reflect changes in the city, but the model comprising over 150 urban blocks has been made available as a database of three dimensional information for those involved in designing new buildings in the city. Figure 7 illustrates the rendering of the Royal Crescent.
and the Circus and Queen's Square.

Figure 7: Simulation of Royal Crescent, the Circus and Queen's Square (Courtesy of Alan Day, CASA, U. Bath)

CASA was later commissioned to construct a fully interactive 3D model. Unavoidably, the creator of the Bath model like most other city modelers starts to commercializing digital models for maintaining the models and providing continuous services.

The Georgian City of Bath was modeled in greater detail in 3D during the period 1991-1995. Following the initial modeling, the resulting CAD files were optimized and converted to VR (http://fos.prd.uth.gr/VRML/casa/bath/bath.html). In 1997, Bath model was generated as a VRML model (approximately 1.8Mbyte, a high polygon count, fully optimized, layered, LODed model). The model is structured in 4 different levels of detail and covers an area of 2.5km x 3.0km. The landscape surrounding the city at an area of 10km x 10km is also modeled and texture mapped (Bourdakis and Day, 1997). Panoramas should run on all Java aware browsers and no plug-ins are needed. Alternatively, the QuickTime VR movie of the city of Bath can also be browsed.
The aim of the VRML Bath project is to provide a research tool to be used by the planning officers in the city of Bath to evaluate new proposals, to choose among a series of alternatives and to convey feedback to the designers enhancing the whole planning process. This is of a paramount importance in the fully listed Georgian Bath. The interface simply familiarizes the user with the controls and navigational aids supplied in this VRML model. The control panels include the functions of compass, fly/walk, day/night (a pseudo night simulation mode), summer/winter, and viewer position.

Unlike conventional CAD technologies, VRML has several differences and technical concerns such as Level of Details (LOD) and hierarchy of models. For example, the city model was analyzed in small manageable units (usually urban blocks) and uses textures instead of geometry when camera is close enough. Furthermore, group LOD checks are implemented in street level or urban block level to speed up navigation.

The whole project is split into a series of interlinked files and at its current form is approx 1.8MB compressed with only the main urban blocks surrounding the Bath Abbey linked in all four levels of detail - approximately twenty urban blocks. The focus is on detail and accuracy, so textures have been used in shop fronts, building windows and billboards whilst keeping a high level of detail in the polygon description of buildings. It was decided to restrict urban blocks that are currently complete, since the size of the model would exceed half a million triangles and would only run on high end SGIs. The lowest level of detail is available on all urban blocks in the city, that doesn't affect the overview of the city. Typically, a 400KB download will let users experience the whole city, examining certain urban blocks in the centre will trigger further downloads.

Los Angeles Model - The Urban Simulator

A more visual and elaborate example of simulation is the Urban Simulator, developed by Liggett and Jepson (1995) at the Department of Architecture, UCLA in the mid-1990s for the city of Los Angeles (LA). The Urban Simulator is a visualization system that provides high quality simulations of selected projects (Figure 8). This LA model continues to grow into the 21st century. Students are constantly adding new content (i.e., a city block, a new building, a subway station, etc.) to the model. When completed, the entire Virtual Los Angeles model will cover an area well in excess of 10,000 square miles and will elegantly scale from
satellite images to street level views accurate enough to allow the signs in the windows of the shops and the graffiti on the walls to be legible. The finished model is estimated to exceed 1 terabyte in size and will be maintained on a large multi-client server that will allow multiple simulation clients to fly, drive and/or walk through the Virtual LA model simultaneously.

Beyond architectural and urban planning applications, the possible uses of the model are endless. For example, the team has been in discussions with the City of Los Angeles about the feasibility of using the model in conjunction with Global Positional System (GPS) transponders to accurately locate and remotely manage Emergency Response Vehicles in real-time.

![Figure 8: Rendering of LA downtown (Courtesy of Bill Jepson, Director UCLA Urban Simulation Laboratory)](image)

© Virtual Helsinki

Helsinki is the capital city of Finland. Virtual Helsinki is part of the Infocities Project that was the joint Arena 2000 project of the City of Helsinki and Elisa Communications, with the aim to deploy and test new telecommunication network services for citizens. The objective of Virtual Helsinki is to discover the cultural heritages as well as public services in the central city area. For example, Virtual Helsinki Directory (http://www.virtualhelsinki.net/) lists the inner city buildings and services (Figure 9). Users can take a panorama tour in the central
Virtual Helsinki is a successful networked platform that gives online information about city services, and creates a flexible and reliable environment for e-transacting. Consequently, it increases the availability of municipal services through data networks, creates a free, open-to-all events calendar with information of all city events, and advance the availability and use of cultural services through data networks by utilizing the latest aids of multimedia technology. For example, the Virtual Museum based on the archives of the City Museum is one of its best applications. The Historical tour is a picture show of the township then and now. With the help of a 3D model, users can also make a fact-finding trip to the fast developing Viikki district.

Figure 9: Virtual Helsinki Website (http://www.virtualhelsinki.net/)

The above four examples provide some implications about their strategies of developing 3D cities. It is clear that the success of integrating technologies and their applications becomes the new directions for future development of digital cities.

4. Applications of 3D Digital Cities
The applications of 3D city models are spreading widely into many areas of city life such as city planning submission, urban design practices, online education of built heritage, marketing of new/renewed urban estates, and urban development management (Peng 2003). The potential end-users of these applications include city planning consultants, citizens or tourists, design professions, students, and city officers among others. More broadly speaking, users of a digital city system could include people who play the roles of content provider, online publisher, software developer, and online service provider. City navigation becomes one of the most popular applications. The Liverpool model, for example, provides a good example of delivering city information via mobile technologies (More details are provided in Chapter 6.)

If applying 3D cities to urban design, the concerns will be the support for the development process ranging from conceptual design, detailed modeling, domain-specific simulations, project internal review, to urban proposal presentation (Figure 10). In the Virtual Sheffield project, various functionalities are implemented at the Sheffield Urban Contextual Databank (SUCoD) system to address user’s needs (Figure 11, more details are provided in Chapter 7). Chan, Morozumi, Kaga and Sasada, Rafi, Lin, and Chiu also reported their researches adopted for urban design applications with different approaches (More details are provided from Chapters 9 to 14.)
One of the most important aspects to be conveyed by any city models is the key characteristics of the cities: cultural (e.g., Tainan, Kumamoto, Bath, Adelaide, Philadelphia), commercial enterprise (e.g., Los Angeles), political capital (London, Berlin, Beijing), or archaeological (e.g., Chang’An in China, Digital Hangyang in Seoul, Korea). Looking into the near future, these models are likely to be made available for wider and easier access through the ever-growing infrastructure of e-Commerce. Clues of the new developments can be seen in the case of Virtual LA; the city model is established as an “Urban Simulator.” Some city information service companies such as Planet 9 Studios, MultiGen-Paradigm or Google Earth are quickly becoming the key players in the making and distribution of 3D city models. For instance, Planet 9 Studios, one of the largest suppliers of accurate 3D city data, has produced more than 40 virtual cities. Virtual San Francisco, begun in 1991, was the predecessor of the growing collection of major metropolitan areas. Databases are available for many major metropolitan areas at a variety of resolutions, including highly texture-mapped, photo realistic versions.

In summary, these urban modeling projects and services aim to provide the following:

- Visualization - visualizing the past, the president, or the future of the city;
- Communication for participatory planning and design - provision of 3D or 4D communication tools for facilitating public participation;
- Documentation of the city history; and
- Management of city information involved in various periods of time and projects.

5. Physical and Virtual City

As voiced promptly by Mitchell, one of the most significant impacts of information technology seen in the 1990s is the Internet and the creation of information cities, digital cities, networked cities, or virtual cities (Mitchell 2003, 2000, 1995). Cityscapes already become an intimate part of our daily activities either physically or virtually. On one hand, there are more physical places or cities presented on the digital world without the physical form. On the other hand, there are more digital places or cities with distinct physical appearances but they do not actually exist in the real world. The virtual city examples such as Kyoto, San Francisco, Sydney, Tokyo, and Vancouver can be seen in the “Virtual city directory” (Figure 12). Although these virtual cities look similar to real cities, they are not identical. At least, in a virtual city people are not walking on the streets for shopping or catching a bus as in real life. However, the boundary between physical and virtual cities is becoming blurred. This trend of development may invite more debates about the content or even the definition of 3D digital cities.

![Figure 12: A Snapshot of Virtual Tokyo (Source: Planet 9 Studios)](image)

Nevertheless, Kalay and Marx (2003) indicates that cyberspace is quickly become an alternative “place” for everyday economic, cultural, and other human activities.
Therefore, digital cities ought to be designed according to the principles, theories, and experience that have been guiding physical place-making for thousands of year, rather than just identified as a city metaphor.

No doubt, time can be the fourth dimension of a digital city, and it is one of the factors that cities exist or disappear. For example, Chang’An was the ancient capital of China over one thousand years ago and it is invisible now. Reconstruction of historical Chang’ An for a cultural exploration purpose demonstrates another significant contribution from the making of digital cities. (More details are provided in Chapter 9)

6. Lessons Learned and Directions for Future Developments: A View from 3D Digital Cities

As much as we can tell at the beginning of the 21st century, there is a wide interest and acceptance of the usefulness of 3D city modeling; however, there is no one preferred strategy for model development and no one strategy emerged as being the most appropriate. Technically speaking, we see that 3D cities of the past and present are mostly coupled with CAD, photogrammetry, or derived from GIS. Digital cities are increasingly seen as a platform for building interactive digital repository of urban information, and future e-Services for urban planning, cultural navigation, or commercial advertisement.

Clearly, 3D (or, even 4D to include the dimension of time) cities have been built for a variety of reasons and expectations. Given that the developments of computer graphics and Web technologies are constantly on the move, the exploration and exploitation of multidimensional urban visualization or modeling are likely to continue. However, from the viewpoint of supporting architectural and urban design processes, we consider that the present approaches to creating and managing 3D digital cities are still short of better solutions to the following challenges:

1. Users (architects, urban designers etc.) can only retrieve pre-built urban model sets in fixed ways that have been pre-determined by the model makers; there is no way for the users to select or combine the models in ways suited to their own purposes.

2. The growth of 3D city models has to be wholesale, that is, piecemeal increments of parts of a city cannot be justified cost-effectively.
3. Users cannot directly combine their own design proposals with existing urban datasets to reveal the design consequences; IT specialists are often required to execute the integration of proposed urban interventions and existing city contexts.

A city in the real world is a highly complex living entity. To model an entire city in just a few data files is impractical if not impossible. It is inevitable that the modelers must divide a city into smaller parts and create the datasets accordingly in order that manageable file sizes can be achieved. The problem is that the urban data creators' schemes of spatial division can seldom match those of end-users. If there is no way for architects or urban designers to avoid the division imposed, the usability of the city models, no matter how sophisticated they may be, could be drastically reduced. For instance, if the focal point of interest of a design project happens to lie on or near to some line of segmentation, it will be not much of usefulness to the design team if the city model segments involved cannot be combined into a single one.

To preserve the usability and perhaps more importantly the reusability of 3D city models against unforeseen user purposes, how a model segment is created ought not to dictate how the individual segment may be retrieved and used. In other words, there must be a ‘gap’ or ‘separation’ created between model creation/management and model uses. There will be two benefits brought by the separation: (a) City models can be grown and maintained in ways that the data development teams deem desirable; (b) Users' accessing city models can be free from any particular scheme of spatial segmentation devised by the modeling team. To put it simply, if there is no such a separation established, 3D digital cities do not function fundamentally different from physical ones.

In retrospect, applying digital technologies to the visualization and simulation of the built environment at an urban scale was first seen nearly twenty years ago. However, as other researchers and educators have observed, digital systems and tools have not brought about significant benefits to urban design education and practice. This may be attributed to several practical difficulties: Firstly, it is often time consuming and resource intensive to establish a city-wide database covering a sufficiently large city area; secondly, we are short of well-researched methodologies for managing and maintaining a temporal organization of urban data that reflects how the city has evolved; and thirdly, there lacks the provision of innovative user-centered access facilities with which the planner, urban designers and architects can actively explore the 3D urban contexts and generate well-thought responsive design proposals.
The concerns with usability and reusability of 3D cities are particularly urgent when considering future applications of the city models and information in direct support for designing new buildings or urban spaces. The importance of investigating and understanding an urban context in which an architectural design is to be developed has been constantly valued and emphasized by city authorities, design practitioners and educators. At most schools of architecture, we see that studio design projects often start with some contextual investigations of the city sites on which the projects are based. The contextual study involves, typically, gathering information regarding the physical, historical and social dimensions of a site, and producing various kinds of records such as drawings or models of the site. Design students then develop their proposals in relation to these records. The results may turn out drastically in contrast with the existing conditions of the site, or they may appear much blended into the urban setting. Of course, one would argue that a design cannot be entirely ‘site-determined,’ yet a general consensus seems to suggest that the pedagogical goal is to foster the students' positive attitude or inspirations for engaging in ‘dialogues’ with the urban contexts in question. If anything to be avoided, ignorance or perhaps worse still indifference may come at the top of the list. But in what exact approaches to achieving the educational goal and how to develop students' necessary skills and knowledge to establish such design dialogues, different schools of thoughts have different opinions and have developed various methodologies.

We therefore argue that future projects of building 3D digital cities should provide not only an adequate urban data repository of a high quality but also flexible ways of interacting with the contextual information for any area of the city. After all, what constitutes a urban context that is relevant or irrelevant to the objectives of a design or research project is subject to the participants' interpretations and analyses. We often see that different individuals define and delineate differently what an urban and architectural context actually consists of (for instance, locations of focal points, paths, boundaries or viewpoints, to name a few). It is therefore, in our view, one of the critical requirements that future 3D digital cities should be capable of allowing interactive retrieval of 3D models and other related contextual resources according to user-specified locations and boundaries of relevance.

The conventional approaches to building virtual cities based on pre-determined static modeling will certainly fail on meeting this requirement. In many aspects, subdividing a city region into smaller areas is necessary both in terms of data generation and transmission, and large and sophisticated 3D models are difficult to maintain and
cause long downloading time over the Internet. However, if the separate models cannot be combined or re-assembled in ways as demanded by the users, the usefulness of these models can be drastically reduced. As mentioned earlier, there will be difficulties if the users' focal points of interest happen to lie on or somewhere near at the lines of subdivision where the separate models actually meet. The points raised here suggest what we really look for is a system's capability of generating the models and related information sets on the fly according to individual users' retrieval criteria.

6. Conclusions

There is a wide acceptance of the role of 3D city modelling; however, there is no one preferred strategy for model development and no one strategy emerged as being the most appropriate. It was largely agreed that those 3D models that were strongly coupled with CAD, photogrammetry, or derived from a GIS. Digital cities become a platform of digital repository of urban information, a digital service of urban planning, cultural navigation, or commercial advertisement.

To conclude the introductory chapter, we invite readers to visit the 3D digital city projects presented in the following chapters. Some of them have dedicated websites for online viewing. We believe that each of the projects provides an insightful story of the making of 3D cities, revealing various facets of virtual city experience. Although their focuses and application areas may be different, users or readers of these virtual cities are in a very good position to look out how the various features may be further combined to better reflect the complexity of real cities. The developments of 3D digital cities as shown in this volume are not just phenomena driven solely by what contemporary information technologies are capable of but also the creative and visionary responses to the many crises as well as opportunities presented by our cities.
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